

ABB ABILITY™ SMART SUBSTATION CONTROL AND PROTECTION FOR ELECTRICAL SYSTEMS

# SSC600

## Technical Manual







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This product complies with following directive and regulations.

Directives of the European parliament and of the council:

- Electromagnetic compatibility (EMC) Directive 2014/30/EU
- Low-voltage Directive 2014/35/EU
- RoHS Directive 2011/65/EU

UK legislations:

- Electromagnetic Compatibility Regulations 2016
- Electrical Equipment (Safety) Regulations 2016
- The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2012

These conformities are the result of tests conducted by the third-party testing in accordance with the product standard EN / BS EN 60255-26 for the EMC directive / regulation, and with the product standards EN / BS EN 60255-1 and EN / BS EN 60255-27 for the low voltage directive / safety regulation.

The product is designed in accordance with the international standards of the IEC 60255 series.

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# 1 Introduction

ABB Ability™ Smart Substation Control and Protection for electrical systems SSC600 is a Smart Substation device designed for protection, control, measurement and supervision of utility substations and industrial switchgear and equipment. The design of the device has been guided by the IEC 61850 standard for communication and interoperability of substation automation devices. It is fully integrable with Relion series IEDs for creating a complete solution. Optional functionality is available at the time of order for both software and hardware, for example, special application packages and additional communication modules.



Figure 1: SSC600

## 1.1 Device physical connections

### 1.1.1 Communication connections

SSC600 has multiple ethernet ports for communication purposes that are more described below.



Never touch the end face of an optical fiber connector.



Always install dust caps on unplugged fiber connectors.



If contaminated, clean optical connectors only with fiber-optic cleaning products.

### 1.1.1.1 Ethernet RJ-45 local and engineering connections

The IED is provided with an RJ-45 connector as a 'Local port'. The connector is intended for local operator actions. WHMI can be accessed from this port in local mode from control point of view, so control operations are possible in the Single Line Diagram of WHMI. The interface on the PC side has to be configured in a way that it obtains the IP address automatically. There is a DHCP server inside IED for the local interface.

The events and setting values and all input data such as memorized values and disturbance records can be read via the local communication port.

Only one of the possible clients can be used for parametrization at a time.

- PCM600
- WHMI

The default IP address of the IED through this port is 192.168.0.254.

The local port supports TCP/IP protocol. A standard Ethernet CAT 5 crossover cable is used with the local port. Local port is used for engineering and it can be used only for point-to-point configuration access with PCM600 or WHMI. Local port should not be connected to any Ethernet network.

### 1.1.1.2 Ethernet RJ-45 remote connection

Ethernet RJ-45 remote connection The IED is provided with an RJ-45 connector as an 'Remote port'. The connector is intended for configuration and setting purposes. WHMI can be accessed from this port in local mode from control point of view, so control operations are possible in the Single Line Diagram of WHMI. The interface on the PC side has to be configured in a way that it obtains the IP address automatically. There is a DHCP server inside IED for the remote interface.

The events and setting values and all input data such as memorized values and disturbance records can be read via the remote port.

Only one of the possible clients can be used for parametrization at a time.

- PCM600
- WHMI

The default IP address of the IED through this port is 192.168.1.254.

The remote port supports TCP/IP protocol. A standard Ethernet CAT 5 crossover cable is used with the remote port.

### 1.1.1.3 Ethernet RJ-45 service connection

Ethernet RJ-45 service connection The IED is provided with an RJ-45 connector as an 'Service port'. The connector is intended for remote service and maintenance purposes. WHMI can be accessed from this port in local mode from control point of view, so control operations are possible in the Single Line Diagram of WHMI. The IP address of the port is configurable.

The events and setting values and all input data such as memorized values and disturbance records can be read via the service port.

Only one of the possible clients can be used for parametrization at a time.

- PCM600

- WHMI

The default IP address of the IED through this port is 192.168.3.10.

The service port supports TCP/IP protocol. A standard Ethernet CAT 5 crossover cable is used with the service port.

#### 1.1.1.4 Ethernet rear connections

The Ethernet station bus communication module is provided with either galvanic RJ-45 connection or optical multimode LC type connection, depending on the product variant and the selected communication interface option. A shielded twisted-pair cable CAT 5e is used with the RJ-45 connector and an optical multimode cable ( $\leq 2$  km) with the LC type connector.

The IED's default IP address through rear Ethernet port is 192.168.2.10 with the TCP/IP protocol. The data transfer rate is 1 Gbit full duplex.

All physical ports dedicated for station bus communication can be opened and closed in device configuration.

For a detailed description of physical ports on device's communication cards, see [Chapter 13.1 Dimensions](#) in this manual.

## 1.2 Communication

The IED supports the IEC 61850 standard and its specified GOOSE, MMS and SAV/SMV communication profiles. Operational information and controls are available through these protocols.

The IEC 61850 communication implementation supports all monitoring and control functions. Additionally, parameter settings, disturbance recordings and fault records can be accessed using the IEC 61850 protocol. Disturbance recordings are available to any Ethernet-based application in the IEC 60255-24 standard COMTRADE file format. The IED can receive binary signals from other devices (so-called horizontal communication) using the IEC 61850-8-1 GOOSE profile, where the highest performance class with a total transmission time of 3 ms is supported. Furthermore, the IED supports receiving of analog values using GOOSE messaging.

The IED meets the GOOSE performance requirements for class P1 (10 ms) tripping applications in distribution substations, as defined by the IEC 61850 standard.

The IED can support five simultaneous clients for IEC 61850 MMS reporting. The IED supports receiving sampled analogue measurements according to IEC 61850-9-2LE from up to 30 Merging Units or other IEDs.

Maximum amount of events, which SSC600 can report, depends on other communication load, especially amount of received SMV streams. When SSC600 is receiving full 30 SMV streams @60Hz it can continuously report over 100 events/sec. If events are reported in bursts, SSC600 can report up to 25000 events in 15 sec bursts. If the limits are exceeded, SSC600 will record a separate *Status overflow* event.

## 1.2.1 Ethernet redundancy

IEC 61850 specifies a network redundancy scheme that improves the system availability for substation communication. It is based on parallel redundancy protocol PRP-1 defined in the IEC 62439-3:2012 standard. The protocol relies on the duplication of all transmitted information via two Ethernet ports for one logical network connection. Therefore, it is able to overcome the failure of a link or switch with a zero-switchover time, thus fulfilling the stringent real-time requirements for the substation automation horizontal communication and time synchronization.

PRP specifies that each device is connected in parallel to two local area networks. Thus, each device incorporates a switch element that forwards frames from port to port.



IEC 62439-3:2012 cancels and replaces the first edition published in 2010. These standard versions are also referred to as IEC 62439-3 Edition 1 and IEC 62439-3 Edition 2. The IED supports IEC 62439-3:2012 and it is not compatible with IEC 62439-3:2010.

### PRP

Each PRP node, called a doubly attached node with PRP (DAN), is attached to two independent LANs operated in parallel. These parallel networks in PRP are called LAN A and LAN B. The networks are completely separated to ensure failure independence, and they can have different topologies. Both networks operate in parallel, thus providing zero-time recovery and continuous checking of redundancy to avoid communication failures. Non-PRP nodes, called single attached nodes (SANs), are either attached to one network only (and can therefore communicate only with DANs and SANs attached to the same network), or are attached through a redundancy box, a device that behaves like a DAN.

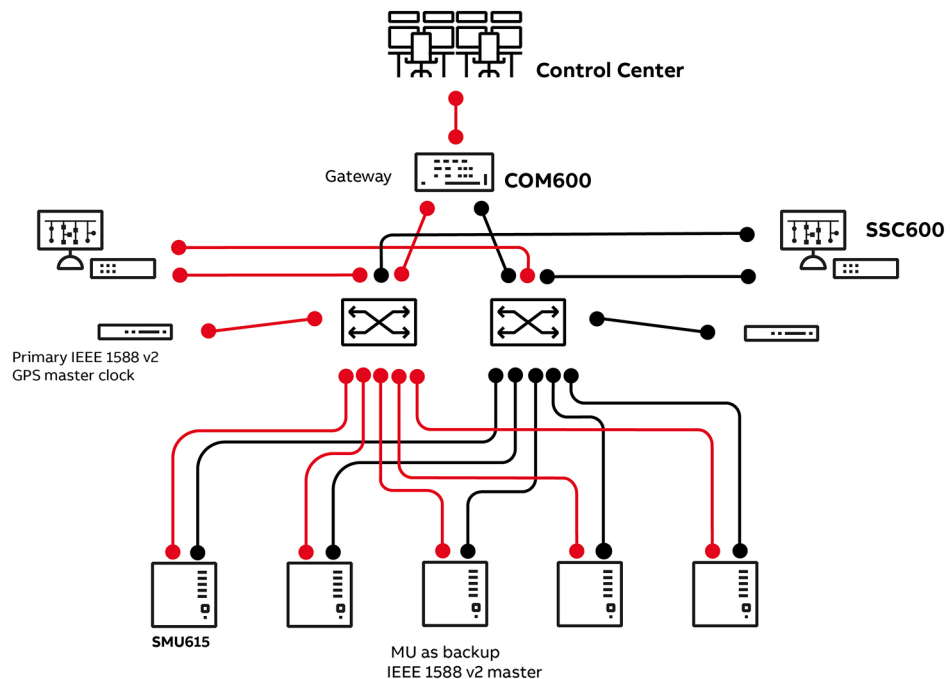


Figure 2: PRP solution

In case a laptop or a PC workstation is connected as a non-PRP node to one of the PRP networks, LAN A or LAN B, it is recommended to use a redundancy box device or an Ethernet switch with similar functionality between the PRP network and SAN to remove additional PRP information from the Ethernet frames. In some cases, default PC workstation adapters are not able to handle the maximum-length Ethernet frames with the PRP trailer.

There are different alternative ways to connect a laptop or a workstation as SAN to a PRP network.

- Via an external redundancy box (RedBox) or a switch capable of connecting to PRP and normal networks
- By connecting the node directly to LAN A or LAN B as SAN

## 1.2.2 Process bus

Process bus IEC 61850-9-2 defines the transmission of Sampled Measured Values within the substation automation system. UCA users' group created a guideline IEC 61850-9-2 LE that defines an application profile of IEC 61850-9-2 to facilitate implementation and enable interoperability. Process bus is used for distributing process data from the primary circuit to all process bus compatible IEDs in the local network in a real-time manner. The data can then be processed by any IED to perform different protection, automation and control functions.

Transmitting measurement samples over process bus brings also higher error detection because the signal transmission is automatically supervised. Additional contribution to the higher availability is the possibility to use redundant Ethernet network for transmitting SMV signals.

The SSC600 supports receiving of sampled values of analog currents and voltages. The measured values need to be transferred as sampled values using the IEC 61850-9-2 LE protocol.

The SSC600 IEDs with process bus based applications use IEEE 1588 v2 Precision Time Protocol (PTP) according to IEEE C37.238-2011 Power Profile for high accuracy time synchronization. With IEEE 1588 v2, the cabling infrastructure requirement is reduced by allowing time synchronization information to be transported over the same Ethernet network as the data communications.



When using PTP in redundant mode, synchronization master is primarily searched from LAN A. Synchronization master from LAN B is used only, if no master in LAN A is detected.

## 1.3 PCM600 tool

Protection and Control IED Manager PCM600 offers all the necessary functionality to work throughout all stages of the IED life cycle.

- Planning
- Engineering
- Commissioning
- Operation and disturbance handling
- Functional analysis

The whole substation can be controlled and different tasks and functions can be performed with the individual tool components. PCM600 can operate with many different topologies, depending on the customer needs.



For more information, refer to PCM600 documentation.

### 1.3.1 Connectivity packages

A connectivity package is a software component that consists of executable code and data which enables system tools to communicate with an IED. Connectivity packages are used to create configuration structures in PCM600. The latest PCM600 and connectivity packages are backward compatible with older IED versions.

A connectivity package includes all of the data which is used to describe the IED. For example, it contains a list of the existing parameters, data format used, units, setting range, access rights and visibility of the parameter. In addition, it contains code which allows software packages that consume the connectivity package to properly communicate with the IED. It also allows for localization of text even when its read from the IED in a standard format such as COMTRADE.

Update Manager is a tool that helps in defining the right connectivity package versions for different system products and tools. Update Manager is included with products that use connectivity packages.

### 1.3.2 PCM600 and IED connectivity package version

- Protection and Control IED Manager PCM600 2.9 or later
- SSC600 Connectivity Package Ver.1.0 or later



Download connectivity packages from the ABB Web site [www.abb.com/mediumvoltage](http://www.abb.com/mediumvoltage) or directly with the Update Manager in PCM600.

## 1.4 Web HMI

The WHMI is the only user access service in the protection device. To provide encryption and secure identification in the communication to the WHMI, the device supports HTTPS protocol. In this case, plain HTTP connection request is automatically changed to HTTPS. The WHMI requires a modern web browser, with support for HTML5 and ECMAScript 6. Note that Internet Explorer is not supported. Secure communication is required, with TLS v1.2 or v1.3. The WHMI is verified with latest versions of Microsoft Edge, Firefox and Google Chrome."

WHMI offers several functions:

- Programmable virtual LEDs and event lists
- System supervision
- Parameter settings
- Measurement display



- Disturbance records
- Fault records
- Phasor diagram
- Single line diagram
- Switch control operations
- Report summary
- Configuration back up and restore for merging units

The WHMI can be accessed locally and remotely.

- Locally by connecting the laptop to the IED via the local communication port
- Remotely over LAN/ WAN

### 1.4.1 Authorization

Four users have been predefined for the WHMI, each with different rights and default passwords.

The default passwords in the IED delivered from the factory can be changed using an user account with User Management right (refer to table Default roles-to-rights in the Cyber Security Deployment Guideline).

**Table 1: Predefined users**

| Username      | User rights  |
|---------------|--|
| VIEWER        | Read only access   |
| OPERATOR      | <ul style="list-style-type: none"> <li>• Changing setting groups</li> <li>• Controlling</li> <li>• Clearing indications</li> </ul>   |
| ENGINEER      | <ul style="list-style-type: none"> <li>• Changing settings</li> <li>• Changing system settings such as IP address</li> <li>• Setting the IED to test mode</li> <li>• Selecting language</li> </ul> |
| ADMINISTRATOR | <ul style="list-style-type: none"> <li>• All listed above</li> <li>• Changing password</li> <li>• Factory default activation</li> </ul>  |



For user authorization for PCM600, see PCM600 documentation.



Controlling operations with Web HMI are only allowed with local mode for user with Control Operation Right (refer to table Default roles-to-rights in the Cyber Security Deployment Guideline).

#### 1.4.1.1 Audit trail

The IED offers a large set of event-logging functions. Critical system and IED security-related events are logged to a separate nonvolatile audit trail for the administrator.

Audit trail is a chronological record of system activities that allows the reconstruction and examination of the sequence of system and security-related events and changes in the IED. Both audit trail events and process related events can be examined and analyzed in a consistent method with the help of Event List in WHMI and Event Viewer in PCM600.

The IED stores 2048 audit trail events to the nonvolatile audit trail. Additionally, 8192 process events are stored in a nonvolatile event list. Both the audit trail and event list work according to the FIFO principle. Nonvolatile memory is based on a memory type which does not need battery backup nor regular component change to maintain the memory storage.

Audit trail events related to user authorization (login, logout, violation remote and violation local) are defined according to the selected set of requirements from IEEE 1686. The logging is based on predefined user names or user categories. The user audit trail events are accessible with IEC 61850-8-1, PCM600 and WHMI.

PCM600 Event Viewer can be used to view the audit trail events and process related events. Audit trail events are visible through dedicated Security events view. Since only the administrator has the right to read audit trail, authorization must be used in PCM600. The audit trail cannot be reset, but PCM600 Event Viewer can filter data. Audit trail events can be configured to be visible also in WHMI Event list together with process related events.



To expose the audit trail events through Event list, define the *Authority logging* level parameter via **Configuration > Authorization > Security**. This exposes audit trail events to all users.

**Table 2: Comparison of authority logging levels**

| Audit trail event         | Authority logging level |                           |                  |                                |                    |     |
|---------------------------|-------------------------|---------------------------|------------------|--------------------------------|--------------------|-----|
|                           | None                    | Configura-<br>tion change | Setting<br>group | Setting<br>group, con-<br>trol | Settings ed-<br>it | All |
| Configuration change      |                         | •                         | •                | •                              | •                  | •   |
| Firmware change           |                         | •                         | •                | •                              | •                  | •   |
| Firmware change fail      |                         | •                         | •                | •                              | •                  | •   |
| Setting group re-<br>mote |                         |                           | •                | •                              | •                  | •   |
| Setting group local       |                         |                           | •                | •                              | •                  | •   |
| Control remote            |                         |                           |                  | •                              | •                  | •   |
| Control local             |                         |                           |                  | •                              | •                  | •   |
| Test on                   |                         |                           |                  | •                              | •                  | •   |
| Test off                  |                         |                           |                  | •                              | •                  | •   |
| Reset trips               |                         |                           |                  | •                              | •                  | •   |
| Setting commit            |                         |                           |                  |                                | •                  | •   |
| Time change               |                         |                           |                  |                                |                    | •   |
| View audit log            |                         |                           |                  |                                |                    | •   |
| Login                     |                         |                           |                  |                                |                    | •   |
| Logout                    |                         |                           |                  |                                |                    | •   |

*Table continues on the next page*

| Audit trail event | Authority logging level |  |  |  |  |   |
|-------------------|-------------------------|--|--|--|--|---|
| Password change   |                         |  |  |  |  | • |
| Firmware reset    |                         |  |  |  |  | • |
| Violation local   |                         |  |  |  |  | • |
| Violation remote  |                         |  |  |  |  | • |

### 1.4.2 Using the Web HMI

As secure communication is enabled by default, the WHMI must be accessed from a Web browser using the HTTPS protocol. Log in with the proper user rights to use the WHMI.



To establish a remote WHMI connection to the IED, contact the network administrator to check the company rules for IP and remote connections.













Disable the Web browser proxy settings or make an exception to the proxy rules to allow the IED's WHMI connection, for example, by including the IED's IP address in **Internet Options > Connections > LAN Settings > Advanced > Exceptions**.

### 1.4.3 Command buttons

Command buttons can be used to edit parameters and control information via the WHMI.

| Name | Description                                       |
|------|---|
|      | Show context sensitive help messages              |
|      | Error icon  |
|      | Alarm icon  |
|      | Enable parameter editing                          |
|      | Disable parameter editing                         |
|      | Write parameters to the IED                       |
|      | Refresh parameter values                          |
|      | Print out parameters                              |
|      | Commit changes to IED's non-volatile flash memory |
|      | Reject changes                                    |

*Table continues on the next page*

| Name   | Description  |
|--|--|
|  Clear events     | Clear events   |
|  Manual trigger   | Trigger the disturbance recorder manually                    |
|  Save             | Save values to TXT or CSV file format                        |
| Freeze   | Freeze the values so that updates are not displayed          |
| ▶ Continue   | Receive continuous updates to the monitoring view            |
|  Delete           | Delete the selection   |
|  Delete all       | Delete all selections  |
|                   | Download files   |
|  View all         | View all records   |
|  Select all       | Select all   |
|  Clear all       | Clear all selections   |
|  Enable Control | Enable controlling Circuit Breakers and Disconnectors in SLD |

## 1.5 Product documentation

### 1.5.1 Product documentation set

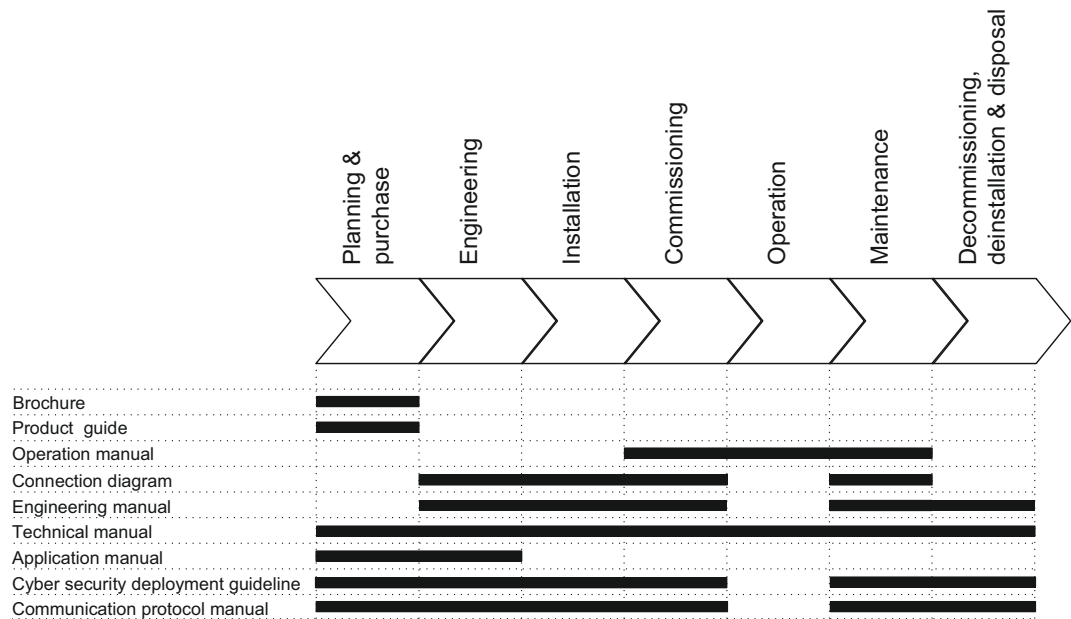


Figure 3: The intended use of documents during the product life cycle



Product series- and product-specific manuals can be downloaded from the ABB Web site.

### 1.5.2 This manual

The installation manual contains instructions on how to install the IED. The manual provides procedures for mechanical and electrical installation. The chapters are organized in chronological order in which the IED should be installed.

### 1.5.3 Intended audience

This manual addresses the personnel responsible for installing the product hardware.

The installation personnel must have basic knowledge of handling electronic equipment.

#### 1.5.3.1 Document conventions

A particular convention may not be used in this manual.

- Abbreviations and acronyms are spelled out in the glossary. The glossary also contains definitions of important terms.
- Menu paths are presented in bold.

Select **Main menu > Settings**.

- Parameter names are shown in italics

The function can be enabled and disabled with the *Operation* setting.

- Parameter values are indicated with quotation marks.

The corresponding parameter values are "On" and "Off".

- Input/output messages and monitored data names are shown in Courier font.

When the function starts, the *START* output is set to TRUE.

- This document assumes that the parameter setting visibility is "Advanced".

### 1.5.3.2

#### Symbols



The warning icon indicates the presence of a hazard which could result in electrical shock or other personal injury.



The caution icon indicates important information or warning related to the concept discussed in the text. It might indicate the presence of a hazard which could result in corruption of software or damage to equipment or property.



The information icon alerts the reader of important facts and conditions.



The tip icon indicates advice on, for example, how to design your project or how to use a certain function.

Although the warning hazards are related to personal injury, it is necessary to understand that under certain operational conditions, operation of damaged equipment may result in degraded process performance leading to personal injury or death. Therefore, comply fully with all warning and caution notices.

### 1.5.3.3

#### Functions, codes and symbols

All available functions included in the IED are listed in the tables below. Available functions depend on the chosen product options.

**Table 3: Protection functions**

| Function  | IEC 61850 | IEC 60617 | ANSI  | Logical device | Logical nodes |
|---|-----------|-----------|-------|----------------|---------------|
| Three-phase non-directional overcurrent protection, low stage           | PHLPTOC   | 3I>       | 51P-1 | LD0            | PHLPTOC       |
| Three-phase non-directional overcurrent protection, high stage          | PHHPTOC   | 3I>>      | 51P-2 | LD0            | PHHPTOC       |
| Three-phase non-directional overcurrent protection, instantaneous stage | PHIPTOC   | 3I>>>     | 50P   | LD0            | PHIPTOC       |

*Table continues on the next page*

| Function  | IEC 61850 | IEC 60617                        | ANSI            | Logical device | Logical nodes   |
|---|-----------|----------------------------------|-----------------|----------------|---|
| Three-phase directional over-current protection, low stage                              | DPHLPDOC  | 3I> ->                           | 67P/51P-1       | LD0            | DPHLPTOC DPHLRDIR   |
| Three-phase directional over-current protection, high stage                             | DPHHPDOC  | 3I>> ->                          | 67P/51P-2       | LD0            | DPHHPTOC DPHHRDIR   |
| Non-directional earth-fault protection, low stage                                       | EFLPTOC   | I <sub>o</sub> >                 | 51G/51N-1       | LD0            | EFLPTOC   |
| Non-directional earth-fault protection, high stage                                      | EFHPTOC   | I <sub>o</sub> >>                | 51G/51N-2       | LD0            | EFHPTOC   |
| Non-directional earth-fault protection, instantaneous stage                             | EFIPTOC   | I <sub>o</sub> >>>               | 50G/50N         | LD0            | EFIPTOC   |
| Directional earth-fault protection, low stage   | DEFLPDEF  | I <sub>o</sub> > ->              | 67G/N-1 51G/N-1 | LD0            | DEFLPTOC DEF LRDIR  |
| Directional earth-fault protection, high stage  | DEFHPDEF  | I <sub>o</sub> >> ->             | 67G/N-1 51G/N-2 | LD0            | DEFHPTOC DEF HRDIR  |
| Admittance-based earth-fault protection   | EFPADM    | Y <sub>o</sub> > ->              | 21YN            | LD0            | EFPADM  |
| Wattmetric-based earth-fault protection   | WPWDE     | P <sub>o</sub> > ->              | 32N             | LD0            | WRDIR WPSDE WMMXU   |
| Transient/intermittent earth-fault protection   | INTRPTEF  | I <sub>o</sub> > -> IEF          | 67NTEF/NIEF     | LD0            | INTRPTEF  |
| Non-directional (cross-country) earth-fault protection, using calculated I <sub>o</sub> | EFHPTOC   | I <sub>o</sub> >>                | 51G/51N-2       | LD0            | EFHPTOC   |
| Negative-sequence overcurrent protection  | NSPTOC    | I <sub>2</sub> >                 | 46M             | LD0            | NSPTOC  |
| Phase discontinuity protection  | PDNSPTOC  | I <sub>2</sub> /I <sub>1</sub> > | 46PD            | LD0            | PDNSPTOC  |
| Residual overvoltage protection   | ROVPTOV   | U <sub>o</sub> >                 | 59G/59N         | LD0            | ROVPTOV   |
| Three-phase undervoltage protection   | PHPTUV    | 3U<                              | 27              | LD0            | PHPTUV  |
| Three-phase overvoltage protection  | PHPTOV    | 3U>                              | 59              | LD0            | PHPTOV  |
| Positive-sequence undervoltage protection   | PSPTUV    | U <sub>1</sub> <                 | 27PS            | LD0            | PSPTUV  |
| Negative-sequence overvoltage protection  | NSPTOV    | U <sub>2</sub> >                 | 59NS            | LD0            | NSPTOV  |
| Frequency protection  | FRPFRQ    | f>/f<,df/dt                      | 81              | LD0            | FRPTRC FRPTOF FRPTUF FRPFRC   |
| Distance protection   | DSTPDIS   | Z<                               | 21P, 21N        | LD0            | GFCPDIS<br>GFCRDIR<br>DST1PDIS<br>DST2PDIS<br>DST3PDIS<br>DST4PDIS<br>DST5PDIS<br>DSTRDIR<br>GFC1RFRC<br>GFC2RFRC<br>GFC3RFRC |
| Three-phase thermal protection for feeders, cables and distribution transformers        | T1PTTR    | 3I <sub>th</sub> >F              | 49F             | LD0            | T1PTTR  |
| Three-phase thermal overload protection, two time constants                             | T2PTTR    | 3I <sub>th</sub> >T/G/C          | 49T/G/C         | LD0            | T2PTTR  |
| Negative-sequence overcurrent protection for machines                                   | MNSPTOC   | I <sub>2</sub> >M                | 46M             | LD0            | MNSPTOC   |
| Loss of load supervision  | LOFLPTUC  | 3I<                              | 37              | LD0            | LOFLPTUC  |

Table continues on the next page

| Function  | IEC 61850 | IEC 60617   | ANSI            | Logical device | Logical nodes  |
|---|-----------|-------------|-----------------|----------------|--|
| Motor load jam protection   | JAMPTOC   | Ist>        | 50TDJAM         | LD0            | JAMPTOC  |
| Motor start-up supervision  | STTPMSU   | Is2t n<     | 49,66,48,50TDLR | LD0            | STTPMSS STTPMRI  |
| Phase reversal protection   | PREVPTOC  | I2>>        | 46R             | LD0            | PREVPTOC   |
| Thermal overload protection for motors  | MPTR      | 3Ith>M      | 49M             | LD0            | MPTR   |
| Stabilized and instantaneous differential protection for two-winding transformers | TR2PTDF   | 3dl>T       | 87T             | LD0            | TR2PTRC<br>TR2LPDIF<br>TR2H2PHAR<br>TR2H5PHAR<br>TR2HPDIF                  |
| Numerically stabilized low-impedance restricted earth-fault protection            | LREFPNDP  | dIoLo>      | 87NLI           | LD0            | LREFPDIF LREFPHAR  |
| Circuit breaker failure protection  | CCBRBRF   | 3I>/Io>BF   | 50BF            | LD0            | CCBRBRF  |
| Three-phase inrush detector   | INRPHAR   | 3I2f>       | 68HB            | LD0            | INRPHAR  |
| Switch onto fault   | CBPSOF    | SOTF        | SOTF            | LD0            | CBPSOF   |
| Master trip   | TRPPTRC   | Master Trip | 94/86           | LD0            | TRPPTRC  |
| Arc protection  | ARCSARC   | ARC         | AFD             | LD0            | ARCSARC ARC1PIOC<br>ARC2PIOC ARCPTRC                                       |
| Multipurpose protection   | MAPGAPC   | MAP         | MAP             | LD0            | MAPGAPC  |
| Load-shedding and restoration   | LSHDPFRQ  | UFLS/R      | 81LSH           | LD0            | LSHDPTRC LSHDPDIF<br>LSHDPTUF LSHDPFRC                                     |
| Fault locator   | SCEFRFLO  | FLOC        | FLOC            | LD0            | SCEFRFLO SCEFZLIN<br>SCEF2ZLIN SCEF3ZLIN<br>FLORFRC                        |
| Reverse power/directional overpower protection                                    | DOPDPDR   | P>/Q>       | 32R/32O         | LD0            | DPPDOP DOPMMXU   |
| Three-phase underimpedance protection   | UZPDIS    | Z>G         | 21G             | LD0            | UZPDIS UZMMXU  |
| Multifrequency admittance-based earth-fault protection                            | MFADPSDE  | Io> ->Y     | 67NYH           | LD0            | MFADPSDE MFADRDIR  |
| Busbar differential protection  | BBPBDF    | 3Id/I       | 87BL            | LD0            | BBPTRC<br>ZNAPDIF<br>ZNPBDIF<br>ZNCZPDIF<br>SFAPDIF<br>SFBPDIF<br>BBCCSPVC |
| Busbar zone selection   | ZNRSRC    | ZNRSRC      | ZNRSRC          | LD0            | ZNRSRC   |
| Load blinder  | LBRDOB    | LB          | 21LB            | LD0            | LBRDOB<br>LBMMXU   |
| Three-phase overload protection for shunt capacitor banks                         | COLPTOC   | 3I> 3I<     | 51,37,86C       | LD0            | COL1PTOC<br>COLPTUC<br>COL2PTOC  |
| Current unbalance protection for shunt capacitor banks                            | CUBPTOC   | dI>C        | 60N             | LD0            | CUB1PTOC<br>CUB2PTOC   |
| Three-phase current unbalance protection for shunt capacitor banks                | HCUBPTOC  | 3dI>C       | 60P             | LD0            | HCUB1PTOC<br>HCUB2PTOC   |
| Shunt capacitor bank switching resonance protection, current based                | SRCPTOC   | TD>         | 55ITHD          | LD0            | SRC1PTOC   |

Table continues on the next page



| Function         | IEC 61850 | IEC 60617 | ANSI    | Logical device | Logical nodes |
|------------------|-----------|-----------|---------|----------------|---------------|
|                  |           |           |         |                | SRC2PTOC      |
| Anomaly detector | ANOGAPC   | ANOGAPC   | ANOGAPC | LDO            | ANOGAPC       |

**Table 4: Interconnection functions**

| Function   | IEC 61850 | IEC 60617 | ANSI   | Logical device | Logical nodes              |
|--|-----------|-----------|--------|----------------|----------------------------|
| Directional reactive power undervoltage protection | DQPTUV    | Q> ->,3U< | 32Q,27 | LDO            | DQPTUV<br>DQPDOP<br>DQMMXU |
| Low-voltage ride-through protection                | LVRTPTUV  | U<RT      | 27RT   | LDO            | LVRTPTUV                   |

**Table 5: Power quality functions**

| Function                          | IEC 61850 | IEC 60617 | ANSI  | Logical device  | Logical nodes   |
|-----------------------------------|-----------|-----------|-------|---|---|
| Current total demand distortion   | CMHAI     | PQM3I     | PQM3I | CMHAI   | CMHAI   |
| Voltage total harmonic distortion | VMHAI     | PQM3U     | PQM3V | VMHAI   | VMHAI,VMHAI   |
| Voltage variation                 | PHQVVR    | PQMU      | PQMV  | PHQVVR<br>PH2QVVR<br>PH3QVVR<br>QVVRQRC<br>QVV2RQRC<br>QVV3RQRC | PHQVVR<br>PH2QVVR<br>PH3QVVR<br>QVVMSTA<br>QVV2MSTA<br>QVV3MSTA |
| Voltage unbalance                 | VSQVUB    | PQUUB     | PQVUB | -   | -   |

**Table 6: Control functions**

| Function                                   | IEC 61850 | IEC 60617   | ANSI        | Logical device | Logical nodes              |
|--|-----------|-------------|-------------|----------------|----------------------------|
| Circuit-breaker control                    | CBXCBR    | I <-> O CB  | I <-> O CB  | CTRL           | CBCSWI<br>CBCILO<br>CBXCBR |
| Disconnecter control                       | DCXSWI    | I <-> O DCC | I <-> O DCC | CTRL           | DCCSWI<br>DCCILO<br>DCXSWI |
| Earthing switch control                    | ESXSWI    | I <-> O ESC | I <-> O ESC | CTRL           | ESCSWI<br>ESCILO<br>ESXSWI |
| Disconnecter position indication           | DCSXSWI   | I <-> O DC  | I <-> O DC  | CTRL           | DCSXSWI                    |
| Earthing switch indication                 | ESSXSWI   | I <-> O ES  | I <-> O ES  | CTRL           | ESSXSWI                    |
| Emergency start-up                         | ESMGAPC   | ESTART      | ESTART      | LDO            | ESMGAPC                    |
| Autoreclosing                              | DARREC    | O -> I      | 79          | LDO            | DARREC                     |
| Tap changer position indication            | TPOSYLTC  | TPOSM       | 84M         | LDO            | TPOSYLTC                   |
| Tap changer control with voltage regulator | OLATCC    | COLTC       | 90V         | LDO            | OLATCC                     |
| Synchronism and energizing check           | SECRSYN   | SYNC        | 25          | LDO            | SECRSYN                    |

**Table 7: Condition monitoring and supervision functions**

| Function                                 | IEC 61850 | IEC 60617 | ANSI    | Logical device | Logical nodes  |
|--|-----------|-----------|---------|----------------|--|
| Circuit-breaker condition monitoring     | SSCBR     | CBCM      | CBCM    | LDO            | SSCBR1<br>SPH1SCBR<br>SPH2SCBR<br>SPH3SCBR<br>SSOPM<br>SSIMG |
| Runtime counter for machines and devices | MDSOPT    | OPTS      | OPTM    | LDO            | MDSOPT   |
| Fuse failure supervision                 | SEQSPVC   | FUSEF     | VCM, 60 | LDO            | SEQSPVC  |

**Table 8: Measurement functions**

| Function                                 | IEC 61850  | IEC 60617  | ANSI       | Logical device | Logical nodes                                       |
|--|------------|------------|------------|----------------|---|
| Disturbance recorder                     | RDRE       | DR         | DFR        | LDO            | DR_LLNO<br>DR_LPHD<br>RDRE<br>RBDR                  |
| Fault record                             | FLTRFRC    | FAULTREC   | FAULTREC   | LDO            | FLTRFRC   |
| Three-phase current measurement          | CMMXU      | 3I         | 3I         | LDO            | CMMXU<br>CAVMMXU<br>CMAMMXU<br>CMIMMXU              |
| Sequence current measurement             | CSMSQI     | I1, I2, I0 | I1, I2, I0 | LDO            | CSMSQI  |
| Residual current measurement             | RESCMMXU   | Io         | In         | LDO            | RESCMMXU<br>RCAVMMXU<br>RCMAMMXU<br>RCMIMMXU        |
| Three-phase voltage measurement          | VMMXU      | 3U         | 3V         | LDO            | VMMXU<br>VAVMMXU                                    |
| Residual voltage measurement             | RESVMMXU   | Uo         | Vn         | LDO            | RESVMMXU<br>RVAVMMXU<br>RVMAMMXU<br>RVMIMMXU        |
| Sequence voltage measurement             | VSMSQI     | U1, U2, U0 | V1, V2, V0 | LDO            | VSMSQI  |
| Three-phase power and energy measurement | PEMMXU     | P, E       | P, E       | LDO            | PEMMXU<br>PEMMTR<br>PEAVMMXU<br>PEAMMXU<br>PEMIMMXU |
| Frequency measurement                    | FMMXU      | f          | f          | LDO            | FMMXU   |
| IEC 61850-9-2 LE sampled value receiving | SMVRECEIVE | SMVRECEIVE | SMVRECEIVE |                | SVIL1TCTR<br>SVIL2TCTR<br>SVIL3TCTR<br>SVRESTCTR    |

| Function | IEC 61850 | IEC 60617 | ANSI | Logical device | Logical nodes                                    |
|----------|-----------|-----------|------|----------------|--|
|          |           |           |      |                | SVUL1TVTR<br>SVUL2TVTR<br>SVUL3TVTR<br>SVRESTVTR |

**Table 9: Other functions**

| Function                                | IEC 61850 | IEC 60617 | ANSI  | Logical device | Logical nodes                                |
|---|-----------|-----------|-------|----------------|--|
| Minimum pulse timer                     | TPGAPC    | TP        | TP    |                | TPGAPC                                       |
| Minimum pulse timer (second resolution) | TPSGAPC   | TPS       | TPS   |                | TPSGAPC                                      |
| Minimum pulse timer minute resolution)  | TPMGAPC   | TPM       | TPM   |                | TPMGAPC                                      |
| Pulse timer                             | PTGAPC    | PT        | PT    |                | PTGAPC                                       |
| Time delay off                          | TOFGAPC   | TOF       | TOF   |                | TOFGAPC                                      |
| Time delay on                           | TONGAPC   | TON       | TON   |                | TONGAPC                                      |
| Set-reset                               | SRGAPC    | SR        | SR    |                | SRGAPC                                       |
| Move                                    | MVGAPC    | MV        | MV    |                | MVGAPC                                       |
| Generic control point                   | SPCGAPC   | SPC       | SPC   |                | SPCGAPC                                      |
| Analog value scaling                    | SCA4GAPC  | SCA4      | SCA4  |                | SCA4GAPC                                     |
| Integer value move                      | MVI4GAPC  | MVI4      | MVI4  |                | MVI4GAPC                                     |
| Voltage switch                          | VMSWI     | VSWI      | VSWI  |                | VMSWI  |
| Current switch                          | CMSWI     | CMSWI     | CMSWI |                | CMSWI  |
| Current sum                             | CMSUM     | CSUM      | CSUM  |                | SIL1TCTR<br>SIL2TCTR<br>SIL3TCTR<br>SRESTCTR |

## 1.5.4 Document revision history

| Document revision/date | Product series version | History         |
|------------------------|------------------------|-----------------|
| A/2019-05-13           | 1.0                    | First release   |
| B/2020-02-23           | 1.0 FP1                | Content updated |
| C/2020-09-11           | 1.0 FP2                | Content updated |
| D/2021-11-26           | 1.0 FP3                | Content updated |
| E/2021-12-29           | 1.0 FP3                | Content updated |
| F/2022-02-14           | 1.0 FP3                | Content updated |
| G/2022-12-05           | 1.0 FP4                | Content updated |



Download the latest documents from the ABB Web site <http://www.abb.com/mediumvoltage>.

## 1.5.5 Related documentation

Product series- and product-specific manuals can be downloaded from the ABB Web site [www.abb.com/mediumvoltage](http://www.abb.com/mediumvoltage).

## 2 Basic functions

### 2.1 General parameters

#### 2.1.1 Authorization settings

Table 10: Authorization settings

| Parameter            | Values (Range)  | Unit | Step | Default | Description             |
|----------------------|---|------|------|---------|-------------------------|
| Authority logging    | 1=None<br>2=Configuration change<br>3=Setting group<br>4=Setting group, control<br>5=Settings edit<br>6=All |      |      | 1=None  | Authority logging level |
| Remote override      | 0=False <sup>1</sup><br>1=True <sup>2</sup>   |      |      | 1=True  | Disable authority       |
| Remote viewer        |   |      |      | 0       | Set password            |
| Remote operator      |   |      |      | 0       | Set password            |
| Remote engineer      |   |      |      | 0       | Set password            |
| Remote administrator |   |      |      | 0       | Set password            |
| Local override       | 0=False <sup>3</sup><br>1=True <sup>4</sup>   |      |      | 1=True  | Disable authority       |

*Table continues on the next page*

<sup>1</sup> Authorization override is disabled, communication tools ask password to enter the IED.

<sup>2</sup> Authorization override is enabled, communication tools do not need password to enter the IED, except for WHMI which always requires it.

<sup>3</sup> Authorization override is disabled, WHMI password must be entered.

| Parameter           | Values (Range) | Unit | Step | Default | Description  |
|---------------------|----------------|------|------|---------|--------------|
| Local viewer        |                |      |      | 0       | Set password |
| Local operator      |                |      |      | 0       | Set password |
| Local engineer      |                |      |      | 0       | Set password |
| Local administrator |                |      |      | 0       | Set password |

## 2.1.2 Ethernet port settings

**Table 11: Ethernet local port settings**

| Parameter   | Values (Range) | Unit | Step | Default          | Description                       |
|-------------|----------------|------|------|------------------|-----------------------------------|
| IP address  |                |      |      | 192.168.0.254    | IP address for local port (fixed) |
| Mac address |                |      |      | XX-XX-XX-XXXX-XX | Mac address for local port        |

**Table 12: Ethernet rear port settings**

| Parameter       | Values (Range) | Unit | Step | Default          | Description                      |
|-----------------|----------------|------|------|------------------|----------------------------------|
| IP address      |                |      |      | 192.168.2.10     | IP address for rear port(s)      |
| Subnet mask     |                |      |      | 255.255.255.0    | Subnet mask for rear port(s)     |
| Default gateway |                |      |      | 192.168.2.1      | Default gateway for rear port(s) |
| Mac address     |                |      |      | XX-XX-XX-XXXX-XX | Mac address for rear port(s)     |

<sup>4</sup> Authorization override is enabled, WHMI password is not asked.

**Table 13: Ethernet remote port settings**

| Parameter   | Values (Range) | Unit | Step | Default           | Description                        |
|-------------|----------------|------|------|-------------------|------------------------------------|
| Enable      |                |      |      | False             |                                    |
| IP address  |                |      |      | 192.168.1.254     | IP address for remote port (fixed) |
| Mac address |                |      |      | XX-XX-XX-XX-XX-XX | Mac address for remote port        |

**Table 14: Ethernet service port settings**

| Parameter   | Values (Range) | Unit | Step | Default           | Description                     |
|-------------|----------------|------|------|-------------------|---------------------------------|
| Enable      |                |      |      | False             |                                 |
| IP address  |                |      |      | 192.168.3.10      | IP address for service port(s)  |
| Subnet mask |                |      |      | 255.255.255.0     | Subnet mask for service port(s) |
| Mac address |                |      |      | XX-XX-XX-XX-XX-XX | Mac address for service port(s) |

### 2.1.3 General system settings

**Table 15: General system settings**

| Parameter                    | Values (Range)  | Unit | Step | Default        | Description                         |
|------------------------------|---|------|------|----------------|-------------------------------------|
| Rated frequency <sup>5</sup> | 1=50Hz<br>2=60Hz  |      |      | 1=50Hz         | Rated frequency of the network      |
| Phase rotation <sup>5</sup>  | 1=ABC<br>2=ACB  |      |      | 1=ABC          | Phase rotation order                |
| Blocking mode                | 1=Freeze timer<br>2=Block all<br>3=Block OPERATE output |      |      | 1=Freeze timer | Behaviour for function BLOCK inputs |

*Table continues on the next page*

<sup>5</sup> After changing this parameter the device needs to be restarted.

| Parameter                           | Values (Range) | Unit | Step | Default             | Description                                 |
|-------------------------------------|----------------|------|------|---------------------|---|
| Unit name <sup>6</sup>              |                |      |      | SSC600 <sup>7</sup> | Bay name in system                          |
| IDMT Sat pointr                     | 10...50        | I/ > | 1    | 50                  | Overcurrent IDMT saturation point           |
| SV angle correction <sup>8, 9</sup> | -5.0...5.0     | deg  | 0.1  | -0.6                | SV angle correction of merging unit         |
| SV delay <sup>9, 10</sup>           | 10...5000      | %    | 1    | 100                 | SV Delay based on nominal network frequency |

## 2.1.4 HMI settings

Table 16: HMI settings

| Parameter            | Values (Range)                         | Unit | Step | Default    | Description                       |
|----------------------|--|------|------|------------|-----------------------------------|
| FB naming convention | 1=IEC61850<br>2=IEC60617<br>3=IEC-ANSI |      |      | 1=IEC61850 | FB naming convention used in IED  |
| Web HMI timeout      | 1...60                                 | min  | 1    | 3          | Web HMI login timeout             |
| SLD symbol format    | 1=IEC<br>2=ANSI                        |      |      | 1=IEC      | Single Line Diagram symbol format |

<sup>6</sup> Used in the IED main menu header and as part of the disturbance recording identification

<sup>7</sup> Depending on the product variant

<sup>8</sup> Default value of 0.6 deg is the suitable value when using ABB 615 series IEDs or Merging Units.

<sup>9</sup> After changing this parameter the device needs to be restarted.

<sup>10</sup> SV delay percentage determines the delay that protection application waits to receive the SMV samples, and the value is dependent on nominal network frequency. Suitable value for 615 series IEDs and Merging Units is the default value of 100%, which in 50Hz is 1313us and in 60Hz systems it is 1094us. Because SV delay impacts directly the protection speed, big values are meant for non-time critical applications, like alarming.

## 2.1.5 IEC 61850-8-1 MMS settings

Table 17: IEC 61850-8-1 MMS settings

| Parameter | Values (Range)  | Unit | Step | Default   | Description             |
|-----------|---|------|------|-----------|-------------------------|
| Unit mode | 1=Primary <sup>11</sup><br>0=Nominal <sup>12</sup><br>2=Primary-Nominal <sup>13</sup> |      |      | 0=Nominal | IEC 61850-8-1 unit mode |

## 2.1.6 IEC 60870-5-104 protocol I5CLPRT

### 2.1.6.1 Function block



Figure 4: Function block

### 2.1.6.2 Functionality

The function block represents one IEC 60870-5-104 TCP/IP server protocol instance in the protection relay.

An IEC 60870-5-104 server protocol instance is activated if the function block instance is added to the application configuration. The setting *Operation* should be "On".

The *STATUS* output of the function block is active if IEC 60870-5-104 client activity is noticed on the communication interface within 15 seconds.

The function block input *IT\_FRZ* relates to the IEC 610870-5-104 integration totals counter objects defined in the protection relay. The *IT\_FRZ* input can be configured for external counter freezing.

By default no IEC 60870-5-104 data objects are mapped to the protocol instance. Protocol data can be added and modified using Communication Management in PCM600.

For more information on the IEC 60870-5-104 server protocol, see the IEC 60870-5-104 communication protocol manual.

<sup>11</sup> MMS client expects primary values from event reporting and data attribute reads

<sup>12</sup> MMS client expects nominal values from event reporting and data attribute reads; this is the default for PCM600

<sup>13</sup> For PCM600 use only, When *Unit mode* is set to "Primary", the PCM600 client can force its session to "Nominal" by selecting "Primary-Nominal" and thus parameterizing in native form. The selection is not stored and is therefore effective only for one session. This value has no effect if selected via the WHMI.



## 2.2 Self-supervision

The extensive self-supervision system continuously monitors the software and the electronics. It handles run-time fault situation and informs the user about a fault via the WHMI and through the communication channels.

There are two types of fault indications.

- Internal faults
- Warnings

### 2.2.1 Internal faults

An indication about the fault is shown in the event list of the WHMI. The text Internal Fault with an additional text message, a code, date and time, is shown to indicate the fault type.

Different actions are taken depending on the severity of the fault. The IED tries to eliminate the fault by restarting. After the fault is found to be permanent, the IED stays in the internal fault mode. Protection application is not running and function outputs are disabled for the internal fault. The IED continues to perform internal tests during the fault situation and recovers if possible. During device reboot the protection application is not available. Protection will be fully operational depending on the configuration size. Rebooting to full operation might take up to 4 minutes. With SSC600 SW the reboot to full operation depends on the chosen hardware and hypervisor.

The internal fault code indicates the type of internal IED fault. When a fault appears, the code must be recorded so that it can be reported to ABB customer service.

| Fault indication                  | Fault code | Additional information                                     |
|-----------------------------------|------------|--|
| Internal Fault System error       | 2          | An internal system error has occurred.                     |
| Internal Fault File system error  | 7          | A file system error has occurred.                          |
| Internal Fault Test               | 8          | Internal fault test activated manually by the user.        |
| Internal Fault SW watchdog error  | 10         | Watchdog reset has occurred too many times within an hour. |
| Internal Fault License check fail | 117        | The devices is equipped with invalid license.              |

### 2.2.2 Warnings

Warnings are shown in the event list of the WHMI. The text Warning additionally provided with the name of the warning, a numeric code as well as the date and time is shown on the WHMI. The warning indication message can be manually cleared.



If a warning appears, record the name and code so that it can be provided to ABB customer service.

**Table 18: Warning indications and codes**

| Warning indication                           | Warning code | Additional information                                      |
|--|--------------|---|
| Warning IEC61850 error                       | 20           | Error when building the IEC 61850 data model.               |
| Warning Dataset error                        | 24           | Error in the Data set(s).                                   |
| Warning<br>Report cont. error                | 25           | Error in the Report control block(s).                       |
| Warning<br>GOOSE contr. error                | 26           | Error in the GOOSE control block(s).                        |
| Warning<br>SCL config error                  | 27           | Error in the SCL configuration file or the file is missing. |
| Warning Logic error                          | 28           | Too many connections in the configuration.                  |
| Warning<br>SMT logic error                   | 29           | Error in the SMT connections.                               |
| Warning<br>GOOSE input error                 | 30           | Error in the GOOSE connections.                             |
| ACT error                                    | 31           | Error in the ACT connections.                               |
| Warning<br>GOOSE Rx. error                   | 32           | Error in the GOOSE message receiving.                       |
| Warning AFL error                            | 33           | Analog channel configuration error.                         |
| Warning<br>SMV config error                  | 34           | Error in the SMV configuration.                             |
| Warning<br>Real-time task's latency exceeded | 117          | Real-time task execution is delayed.                        |
| Warning<br>Redundant PSU fail                | 118          | One of the power supply is faulty, maintenance recommended. |

## 2.3 LED indication control

### 2.3.1 Function block

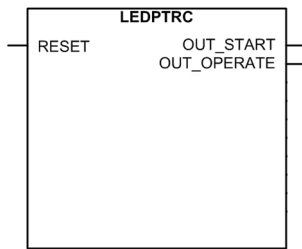


Figure 5: Function block

### 2.3.2 Functionality



LED indication control should never be used for tripping purposes. There is a separate trip logic function TRPPTRC available in the relay configuration.

LED indication control is preconfigured in a such way that all the protection function general start and operate signals are combined with this function (available as output signals `OUT_START` and `OUT_OPERATE` ). These signals are always internally connected to Start and Trip LEDs.

## 2.4 Programmable virtual LEDs

### 2.4.1 Function block

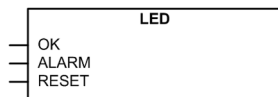


Figure 6: Function block

### 2.4.2 Functionality

The programmable LEDs on the toolbar

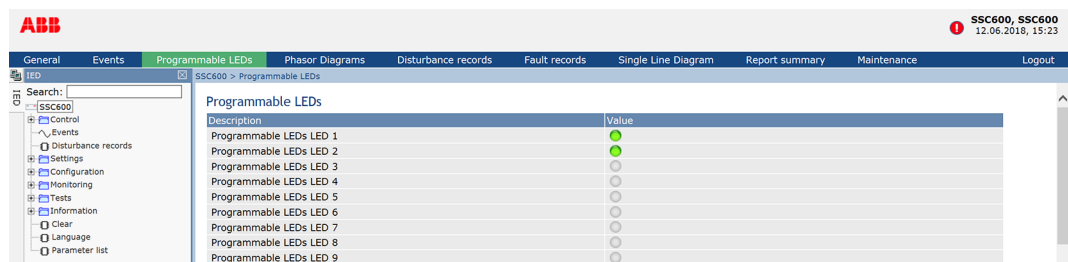


Figure 7: The programmable LEDs on the WHMI toolbar

All the programmable LEDs in the WHMI have two colors, green and red. For each LED, the different colors are individually controllable.

Each LED has two control inputs, ALARM and OK. The color setting is common for all the LEDs. It is controlled with the *Alarm colour* setting, the default value being "Red". The OK input corresponds to the color that is available, with the default value being "Green".

Changing the Alarm colour setting to "Green" changes the color behavior of the OK inputs to red.

The ALARM input has a higher priority than the OK input.



ALARM signal of all programmable LEDs is connected to a physical Alarm LED in SSC600 front panel. The physical Alarm LED is lit if any of the programmable LEDs is in alarm state. Alarm LED is cleared when all programmable LEDs alarm state is cleared.

Each LED is seen in the Application Configuration tool as an individual function block. Each LED has user-editable description text for event description. The state ("None", "OK", "Alarm") of each LED can also be read under a common monitored data view for programmable LEDs.

The LED status also provides a means for resetting the individual LED via communication. The LED can also be reset from configuration with the RESET input.

The resetting and clearing function for all LEDs is under the Clear menu.

The menu structure for the programmable LEDs is presented in [Chapter 10.5 Measurement modes](#). The common color selection setting Alarm colour for all ALARM inputs is in the General menu, while the LED-specific settings are under the LED-specific menu nodes.

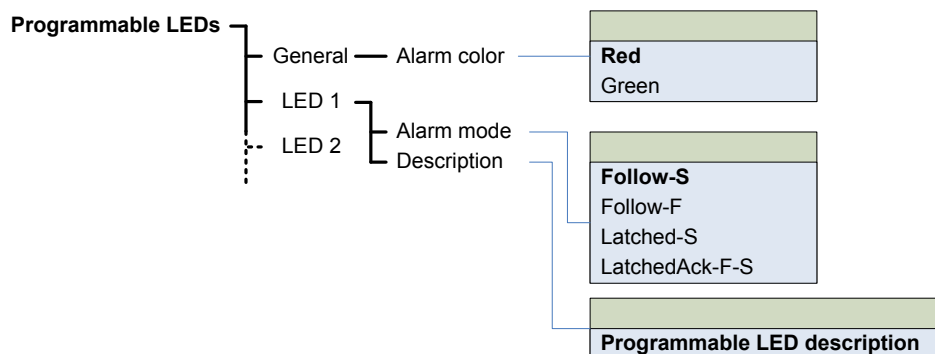


Figure 8: Menu structure

### Alarm mode alternatives

The ALARM input behavior can be selected with the alarm mode settings from the alternatives "Follow-S", "Follow-F", "Latched-S" and "LatchedAck-F-S". The OK input behavior is always according to "Follow-S". The ALARM input latched modes can be cleared with the reset input in the application logic.

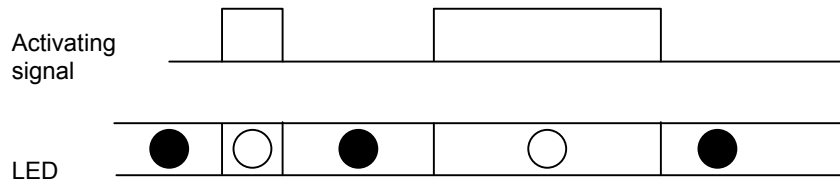
● = No indication    ○ = Steady light    ⊕ = Flash

Figure 9: Symbols used in the sequence diagrams

**"Follow-S": Follow Signal, ON**

In this mode ALARM follows the input signal value, Non-latched

**Operating sequence "Follow-S"**



**"Follow-F": Follow Signal, Flashing**

Similar to "Follow-S", but instead the LED is flashing when the input is active, Nonlatched.

**"Latched-S": Latched, ON**

This mode is a latched function. At the activation of the input signal, the alarm shows a steady light. After acknowledgement by the local operator pressing any key on the keypad, the alarm disappears.

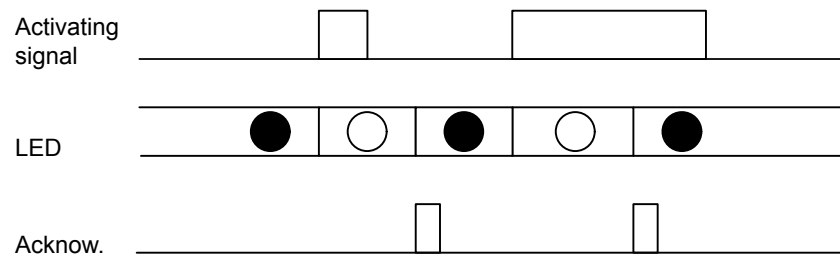


Figure 10: Operating sequence "Latched-S"

**"LatchedAck-F-S": Latched, Flashing-ON**

This mode is a latched function. At the activation of the input signal, the alarm starts flashing. After acknowledgement, the alarm disappears if the signal is not present and gives a steady light if the signal is present

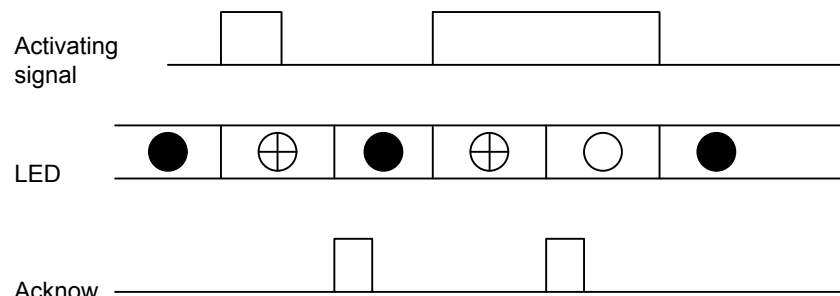


Figure 11: Operating sequence "LatchedAck-F-S"

## 2.4.3 Signals

### 2.4.3.1 LED Input signals

Only LED 1 data is shown in table and other LEDs 2...99 are similar.

**Table 19: Input signals**

| Name  | Type    | Default | Description           |
|-------|---------|---------|-----------------------|
| OK    | BOOLEAN | 0=False | Ok input for LED 1    |
| ALARM | BOOLEAN | 0=False | Alarm input for LED 1 |
| RESET | BOOLEAN | 0=False | Reset input for LED 1 |

## 2.4.4 Settings

### 2.4.4.1 LED settings

Only LED 1 data is shown in table and other LEDs 2...100 are similar.

**Table 20: LED settings**

| Parameter    | Values (Range)   | Unit | Step | Default                 | Description                           |
|--------------|--|------|------|-------------------------|---------------------------------------|
| Alarm colour | 1=Green<br>2=Red   |      |      | 2=Red                   | Colour for the alarm state of the LED |
| Alarm mode   | 0=Follow-S<br>1=Follow-F<br>2=Latched-S<br>3=LatchedAck- F-S |      |      | 0=Follow-S              | Alarm mode for programmable LED 1     |
| Description  |  |      |      | Programmable LEDs LED 1 | Programmable LED description          |

## 2.4.5 Monitored data

### 2.4.5.1 LED Monitored data

Only LED 1 data is shown in table and other LEDs 2...100 are similar.

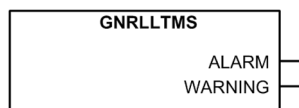
**Table 21: Monitored data**

| Name               | Type | Values (Range)            | Unit | Description                  |
|--------------------|------|---------------------------|------|------------------------------|
| Programmable LED 1 | Enum | 0=None<br>1=Ok<br>3=Alarm |      | Status of programmable LED 1 |

## 2.5 Time synchronization

### 2.5.1 Time master supervision GNRLTMS

#### 2.5.1.1 Function block

*Figure 12: Function block*

#### 2.5.1.2 Functionality

The IED has an internal real-time clock which can be either free-running or synchronized from an external source. The real-time clock is used for time stamping events, recorded data and disturbance recordings.

The setting Synch source determines the method to synchronize the real-time clock. The IED supports IEEE 1588 v2 to update the real-time clock, that is operational regardless of the Synch source setting. IEEE 1588 v2 with GPS grandmaster clock provides the best accuracy  $\pm 1 \mu\text{s}$ . If Synch source is set to “None” and DST in Use is set to “FALSE”, it is also possible to set the manually with settings Date and Time.

The IEEE 1588 time synchronization complies with the IEEE C37.238-2011 Power Profile, interoperable with IEEE 1588 v2. According to the power profile, the frame format used is IEEE 802.3 Ethernet frames with 88F7 Ethertype as communication service and the delay mechanism is P2P. For better switch compatibility it is possible to select if the PTP messages sent by SSC600 include the VLAN Priority tag or not. Selection is done with *PTP Profile* setting where “P2P Default 1588-2008” removes VLAN tags and “Power profile C37.238-2011” includes VLAN priority tag.

### 2.5.1.3 Setting daylight saving time

The protection relay can be set to determine the correct date for the DST shift every year. The local time is used to set the DST.

1. Set the *DST on day (weekday)* and *DST off day (weekday)* parameters to define on which week day the time shift occurs.
2. Set the *DST on date (day)*, *DST on date (month)* and *DST off date (month)* parameters to define on which month and week the time shift occurs. The *DST on/off date* must precede the selected DST on/off day. If the selected *DST on/off day* does not match the set *DST on/off date* the time shift will occur on the next matching weekday.

| Day of the DST shift                  | DST on/off date (day) |
|---------------------------------------|-----------------------|
| First Sunday of the month             | 1                     |
| Second Sunday of the month            | 8                     |
| Third Sunday of the month             | 15                    |
| Fourth Sunday of the month            | 22                    |
| Last Sunday, if the month has 30 days | 24                    |
| Last Sunday, if the month has 31 days | 25                    |

For example, if DST on time shift occurs on the last Sunday in March, at 03:00 local time and DST off time shift occurs on the last Sunday in October, at 04:00 local time, the settings are the following:

| Setting                | Value   |
|------------------------|---------|
| DST on time (hours)    | 3 h     |
| DST on time (minutes)  | 0 min   |
| DST on date (day)      | 25      |
| DST on date (month)    | March   |
| DST on day (weekday)   | Sunday  |
| DST off time (hours)   | 4 h     |
| DST off time (minutes) | 0 min   |
| DST off date (day)     | 25      |
| DST off date (month)   | October |
| DST off day (weekday)  | Sunday  |



Set the *DST on day (weekday)* and *DST off day (weekday)* to "reserved" to determine the exact date and time for the DST shift. Repeat the setting yearly, as the time for the DST shift is not on the same date every year.





To disable the DST, set the *DST in use* parameter to "False".

## 2.5.1.4 Signals

### GNRLLTMS output signals

Table 22: GNRLLTMS output signals

| Name    | Type    | Description                  |
|---------|---------|------------------------------|
| ALARM   | BOOLEAN | Time synchronization alarm   |
| WARNING | BOOLEAN | Time synchronization warning |

## 2.5.1.5 Settings

### Time format

Table 23: Time format

| Parameter   | Values (Range)   | Unit | Step | Default            | Description |
|-------------|--|------|------|--------------------|-------------|
| Time format | 1=24H:MM:SS:<br>MS<br>2=12H:MM:SS:<br>MS   |      |      | 1=24H:MM:SS:<br>MS | Time format |
| Date format | 1=DD.MM.YYY<br>Y<br>2=DD/MM/<br>YYYY<br>3=DD-MM-<br>YYYY<br>4=MM.DD.YYY<br>Y<br>5=MM/DD/<br>YYYY<br>6=YYYY-MM-<br>DD<br>7=YYYY-DD-<br>MM<br>8=YYYY/DD/<br>MM |      |      | 1=DD.MM.YYY<br>Y   | Date format |

### Time settings

**Table 24: Time settings**

| Parameter     | Values (Range)   | Unit | Step | Default                       | Description  |
|---------------|--|------|------|-------------------------------|--|
| Synch source  | 0=None<br>1=SNTP<br>3=IEEE 1588 <sup>1</sup>             |      |      | 3=IEEE 1588                   | Time synchronization source  |
| PTP domain ID | 0...127  |      | 1    | 0                             | The domain is identified by an integer, the domain number, in the range of 0...127 |
| PTP profile   | 1=P2P Default 1588-2008<br>2= Power profile C37.238-2011 |      |      | 2= Power profile C37.238-2011 | IEEE 1588 profile selection  |

**Table 25: Time settings**

| Parameter         | Values (Range) | Unit | Step | Default       | Description                          |
|-------------------|----------------|------|------|---------------|--------------------------------------|
| IP SNTP primary   |                |      |      | 10.58.125.165 | IP address for SNTP primary server   |
| IP SNTP secondary |                |      |      | 192.168.2.165 | IP address for SNTP secondary server |

**Table 26: Time settings**

| Parameter         | Values (Range) | Unit | Step | Default | Description                  |
|-------------------|----------------|------|------|---------|------------------------------|
| Date              |                |      |      | 0       | Date                         |
| Time              |                |      |      | 0       | Time                         |
| Local time offset | -840...840     | min  | 1    | 0       | Local time offset in minutes |

**Table 27: Time settings**

| Parameter             | Values (Range)  | Unit | Step | Default | Description                           |
|-----------------------|---|------|------|---------|---------------------------------------|
| DST in use            | 0=False<br>1=True   |      |      | 1=True  | DST in use setting                    |
| DST on time (hours)   | 0...23  | h    |      | 2       | Daylight saving time on, time (hh)    |
| DST on time (minutes) | 0...59  | min  |      | 0       | Daylight saving time on, time (mm)    |
| DST on date (day)     | 1...31  |      |      | 1       | Daylight saving time on, date (dd:mm) |
| DST on date (month)   | 1=January<br>2=February<br>3=March<br>4=April<br>5=May<br>6=June<br>7=July<br>8=August<br>9=September<br>10=October |      |      | 5=May   | Daylight saving time on, date (dd:mm) |

*Table continues on the next page*

<sup>1</sup> IEEE 1588 is required when the application is using sampled values measurements.

| Parameter              | Values (Range)  | Unit | Step | Default     | Description                            |
|------------------------|---|------|------|-------------|--|
|                        | 11=November<br>12=December  |      |      |             |  |
| DST on day (week-day)  | 0=reserved<br>1=Monday<br>2=Tuesday<br>3=Wednesday<br>4=Thursday<br>5=Friday<br>6=Saturday<br>7=Sunday  |      |      | 0=reserved  | Daylight saving time on, day of week   |
| DST off time (hours)   | 0...23  | h    |      | 2           | Daylight saving time off, time (hh)    |
| DST off time (minutes) | 0...59  | min  |      | 0           | Daylight saving time off, time (mm)    |
| DST off date (day)     | 1...31  |      |      | 25          | Daylight saving time off, date (dd:mm) |
| DST off date (month)   | 1=January<br>2=February<br>3=March<br>4=April<br>5=May<br>6=June<br>7=July<br>8=August<br>9=September<br>10=October<br>11=November<br>12=December |      |      | 9=September | Daylight saving time off, date (dd:mm) |
| DST off day (week-day) | 0=reserved<br>1=Monday<br>2=Tuesday<br>3=Wednesday<br>4=Thursday<br>5=Friday<br>6=Saturday<br>7=Sunday  |      |      | 0=reserved  | Daylight saving time off, day of week  |
| DST offset             | -720...720  | min  | 1    | 60          | Daylight saving time offset            |

## 2.5.2 Technical revision history

Table 28: GNRLTMS Technical revision history

| Technical revision | Change              |
|--------------------|---------------------|
| B                  | Modified for SSC600 |
| C                  | Content updated     |

## 2.6 Parameter setting groups

### 2.6.1 Function block

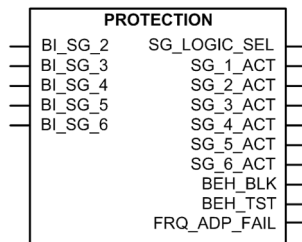


Figure 13: Function block

### 2.6.2 Functionality

The IED supports six setting groups. Each setting group contains parameters categorized as group settings inside application functions. The customer can change the active setting group at run time.

The active setting group can be changed by a parameter or via binary inputs depending on the mode selected with the **Configuration > Setting Group > SG operation mode** setting.

The default value of all inputs is FALSE, which makes it possible to use only the required number of inputs and leave the rest disconnected. The setting group selection is not dependent on the SG\_x\_ACT outputs.

Table 29: Optional operation modes for setting group selection

| SG operation mode  | Description   |
|--------------------|---|
| Operator (Default) | Setting group can be changed with the setting <b>Settings &gt; Setting group &gt; Active group</b> .<br>Value of the SG_LOGIC_SEL output is FALSE.  |
| Logic mode 1       | Setting group can be changed with binary inputs (BI_SG_2 . . . BI_SG_6). The highest TRUE binary input defines the active setting group.<br>Value of the SG_LOGIC_SEL output is TRUE.                 |
| Logic mode 2       | Setting group can be changed with binary inputs where BI_SG_4 is used for selecting setting groups 1-3 or 4-6.<br>When binary input BI_SG_4 is FALSE, setting groups 1-3 are selected with binary in- |

| SG operation mode | Description  |
|-------------------|--|
|                   | <p>puts BI_SG_2 and BI_SG_3. When binary input BI_SG_4 is TRUE, setting groups 4-6 are selected with binary inputs BI_SG_5 and BI_SG_6.</p> <p>Value of the SG_LOGIC_SEL output is TRUE.</p> |

For example, six setting groups can be controlled with three binary inputs. The *SG operation mode* is set to “Logic mode 2” and inputs BI\_SG\_2 and BI\_SG\_5 are connected together the same way as inputs BI\_SG\_3 and BI\_SG\_6.

**Table 30: SG operation mode = “Logic mode 1”**

| Input   |         |         |         |         | Active group |
|---------|---------|---------|---------|---------|--------------|
| BI_SG_2 | BI_SG_3 | BI_SG_4 | BI_SG_5 | BI_SG_6 |              |
| FALSE   | FALSE   | FALSE   | FALSE   | FALSE   | 1            |
| TRUE    | FALSE   | FALSE   | FALSE   | FALSE   | 2            |
| any     | TRUE    | FALSE   | FALSE   | FALSE   | 3            |
| any     | any     | TRUE    | FALSE   | FALSE   | 4            |
| any     | any     | any     | TRUE    | FALSE   | 5            |
| any     | any     | any     | any     | TRUE    | 6            |

**Table 31: SG operation mode = “Logic mode 2”**

| Input   |         |         |         |         | Active group |
|---------|---------|---------|---------|---------|--------------|
| BI_SG_2 | BI_SG_3 | BI_SG_4 | BI_SG_5 | BI_SG_6 |              |
| FALSE   | FALSE   | FALSE   | any     | any     | 1            |
| TRUE    | FALSE   | FALSE   | any     | any     | 2            |
| any     | TRUE    | FALSE   | any     | any     | 3            |
| any     | any     | TRUE    | FALSE   | FALSE   | 4            |
| any     | any     | TRUE    | TRUE    | FALSE   | 5            |
| any     | any     | TRUE    | any     | TRUE    | 6            |

The setting group 1 can be copied to any other or all groups from HMI (Copy group 1).

## 2.7 Test mode

### 2.7.1 Function blocks

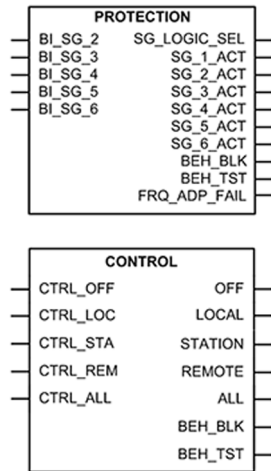


Figure 14: Function blocks

### 2.7.2 Functionality

The mode of all the logical nodes in the relay's IEC 61850 data model can be set with *Test mode*. *Test mode* is selected through one common parameter via the HMI path **Tests > IED test**. By default, *Test mode* can only be set locally through WHMI. *Test mode* is also available via IEC 61850 communication (LD0.LLN0.Mod).

Table 32: Test mode

| Test mode            | Description  | Protection BEH_BLK |
|----------------------|--|--------------------|
| Normal mode          | Normal operation   | FALSE              |
| IED blocked          | Protection working as in "Normal mode" but ACT configuration can be used to block physical outputs to process. Control function commands blocked.  | TRUE               |
| IED test             | Protection working as in "Normal mode" but protection functions are working in parallel with test parameters.  | FALSE              |
| IED test and blocked | Protection working as in "Normal mode" but protection functions are working in parallel with test parameters. ACT configuration can be used to block physical outputs to process. Control function commands blocked. | TRUE               |



Behaviour data objects in all logical nodes follow LD0.LLN0.Mod value. If "Normal mode" is selected, behaviour data objects follow mode (.Mod) data object of the corresponding logical device.



Vertical and horizontal communication is not blocked by the "IED blocked" or "IED test and blocked" modes.

## 2.7.3 Application configuration and Test mode

The physical outputs from control commands to process are blocked with *IED blocked* and *IED test and blocked* modes. If physical outputs need to be blocked from the protection, the application configuration must be used to block these signals. Blocking scheme needs to use `BEH_BLK` output of PROTECTION function block.

## 2.7.4 Control mode

The mode of all logical nodes located under CTRL logical device can be set with *Control mode*. The *Control mode* parameter is available via the WHMI or PCM600 path **Configuration > Control > General**. By default, *Control mode* can only be set locally through WHMI. *Control mode* inherits its value from *Test mode* but *Control mode* "On", "Blocked" and "Off" can also be set independently. *Control mode* is also available via IEC 61850 communication (CTRL.LLN0.Mod).

**Table 33: Control mode**

| Control mode | Description                       | Control BEH_BLK |
|--------------|-----------------------------------|-----------------|
| On           | Normal operation                  | FALSE           |
| Blocked      | Control function commands blocked | TRUE            |
| Off          | Control functions disabled        | FALSE           |



Behaviour data objects under CTRL logical device follow CTRL.LLN0.Mod value. If "On" is selected, behaviour data objects follow the mode of the corresponding logical device.

## 2.7.5 Application configuration and Control mode

The physical outputs from commands to process are blocked with *Blocked mode*. If physical outputs need to be blocked totally, meaning also commands from the binary inputs, the application configuration must be used to block these signals. Blocking scheme uses `BEH_BLK` output of CONTROL function block.

## 2.7.6 Authorization

By default, *Test mode* and *Control mode* can only be changed from WHMI. It is possible to write test mode by remote client, if it is needed in configuration. This is done via WHMI only by setting the *Remote test mode* parameter via **Tests > IED test > Test mode**. Remote operation is possible only when control position of the relay is in remote position. Local and remote control can be selected via Control function block in application configuration.

When using the Signal Monitoring tool to force on-line values, the following conditions need to be met.

- *Remote force* is set to "All levels"
- *Test mode* is enabled
- Control position of the relay is in remote position

**Table 34: Remote test mode**

| Remote test mode | 61850-8-1-MMS                           | WHMI/PCM600 |
|------------------|---|-------------|
| Off              | No access                               | No access   |
| Maintenance      | Command originator category maintenance | No access   |
| All levels       | All originator categories               | Yes         |

## 2.7.7 LED indications

The Start LED flashes when the relay is in "IED blocked" or "IED test and blocked" mode. The Ready LED flashes to indicate that the "IED test and blocked" mode or "IED test" mode is activated.

## 2.7.8 Signals

### 2.7.8.1 PROTECTION output signals

**Table 35: PROTECTION output signals**

| Name    | Type    | Default | Description                     |
|---------|---------|---------|---------------------------------|
| BEH_BLK | BOOLEAN | 0       | Logical device LDO block status |
| BEH_TST | BOOLEAN | 0       | Logical device LDO test status  |

### 2.7.8.2 CONTROL output signals

**Table 36: CONTROL output signals**

| Name    | Type    | Default | Description                      |
|---------|---------|---------|----------------------------------|
| BEH_BLK | BOOLEAN | 0       | Logical device CTRL block status |
| BEH_TST | BOOLEAN | 0       | Logical device CTRL test status  |

## 2.7.9 Technical revision history

**Table 37: Test mode Technical revision history**

| Technical revision | Change              |
|--------------------|---------------------|
| B                  | Modified for SSC600 |



## 2.8 Simulation mode

### 2.8.1 Function blocks

The following function blocks support simulation data:

- SMVRECEIVE
- GOOSERCV\_BIN
- GOOSERCV\_DP
- GOOSERCV\_MV
- GOOSERCV\_INT8
- GOOSERCV\_INTL
- GOOSERCV\_CMV
- GOOSERCV\_ENUM
- GOOSERCV\_INT32

### 2.8.2 Functionality

SSC600 supports receiving simulated IEC 61850-9-2 Sampled Values and GOOSE data according to IEC 61850 Edition 2.1. Sending simulated SV or GOOSE is not supported. Simulation mode is not supported with IEC 61850 Ed. 1. Any SV or GOOSE input can receive simulated data.

Simulated messages can be sent in the network with testing tools simultaneously to normal communication sent by merging units. Simulated messages are marked by setting the simulated flag in the messages Ethernet frame and simulation parameter in the message SV and GOOSE header.

To allow the SSC600 to receive simulated data it must be set to allow simulation mode. This is done via WHMI by setting the *Allow simulation* parameter via **Tests > IED test > Allow simulation**. This is a general device setting that enables receiving of simulated data for all SV and GOOSE inputs.

When SSC600 is set to allow simulation mode it continues to receive all data normally. If it receives an SV or GOOSE message stream with simulated data, it switches to receive that stream as simulated instead of the normal. All other inputs continue to receive the normal streams. Once switched it continues to receive only the simulated stream until *Allow simulation* is disabled. When *Allow simulation* is disabled all inputs are switched to normal streams. All configuration and sequence checks are performed with the simulated streams as with the normal streams.



When receiving simulated data, it is processed as normal data. The SIMULATED outputs of the corresponding function blocks indicate if the outputs are using simulated data.

## 2.9 Fault recorder FLTRFRC

## 2.9.1 Function block



Figure 15: Function block

## 2.9.2 Functionality

The IED has the capacity to store the records of 128 latest fault events. Fault records include fundamental or RMS current values. The records enable the user to analyze recent power system events. Each fault record (FLTRFRC) is marked with an up-counting fault number and a time stamp that is taken from the beginning of the fault.

The fault recording period begins from the start event of any protection function and ends if any protection function trips or the start is restored before the operate event. If a start is restored without an operate event, the start duration shows the protection function that has started first.

Start duration that has the value of 100% indicates that a protection function has operated during the fault and if none of the protection functions has been operated, Start duration shows always values less than 100%.

The Fault recorded data Protection and Start duration is from the same protection function. The Fault recorded data operate time shows the time of the actual fault period. This value is the time difference between the activation of the internal start and operate signals. The actual operate time also includes the starting time and the delay of the output relay. The Fault recorded data *Breaker clear time* is the time difference between internal operate signal and activation of `CB_CLR'D` input.



If some functions in relay application are sensitive to start frequently it might be advisable to set the setting parameter *Trig mode* to “From operate”. Then only faults that cause an operate event trigger a new fault recording.

The fault-related current, voltage, frequency, angle values and the active setting group number are taken from the moment of the operate event, or from the beginning of the fault if only a start event occurs during the fault. The maximum current value collects the maximum fault currents during the fault. In case frequency cannot be measured, nominal frequency is used for frequency and zero for Frequency gradient and validity is set accordingly.

Measuring mode for phase current and residual current values can be selected with the *Measurement mode* setting parameter.

## 2.9.3 Settings

### 2.9.3.1 FLTRFRC Non group settings

**Table 38: FLTRFRC Non group settings (Basic)**

| Parameter | Values (Range)   | Unit | Step | Default           | Description        |
|-----------|--|------|------|-------------------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on              | Operation Off / On |
| Trig mode | 0=From all faults<br>1=From operate<br>2=From only start |      |      | 0=From all faults | Triggering mode    |

**Table 39: FLTRFRC Non group settings (Advanced)**

| Parameter          | Values (Range)                   | Unit | Step | Default | Description   |
|--------------------|----------------------------------|------|------|---------|---|
| A measurement mode | 1=RMS<br>2=DFT<br>3=Peak-to-Peak |      |      | 2=DFT   | Selects used measurement mode phase currents and residual current |

## 2.9.4 Monitored data

### 2.9.4.1 FLTRFRC Monitored data

**Table 40: FLTRFRC Monitored data**

| Name          | Type      | Values (Range)   | Unit | Description             |
|---------------|-----------|--|------|-------------------------|
| Fault number  | INT32     | 0...999999   |      | Fault record number     |
| Time and date | Timestamp |  |      | Fault record time stamp |
| Protection    | String    | Unknown<br>PHLPTOC<br>PHHPTOC<br>EFLPTOC<br>EFHPTOC<br>EFIPTOC |      | Protection function     |

*Table continues on the next page*

| Name | Type | Values (Range) | Unit | Description |
|------|------|----------------|------|-------------|
|      |      | NSPTOC         |      |             |
|      |      | INTRPTEF       |      |             |
|      |      | STTPMSU        |      |             |
|      |      | JAMPTOC        |      |             |
|      |      | PDNSPTOC       |      |             |
|      |      | T1PTTR         |      |             |
|      |      | T2PTTR         |      |             |
|      |      | MPTTR          |      |             |
|      |      | DEFLPDEF       |      |             |
|      |      | DEFHPDEF       |      |             |
|      |      | EFPADM         |      |             |
|      |      | FRPFRQ         |      |             |
|      |      | LSHDPFRQ       |      |             |
|      |      | DPHLPDOC       |      |             |
|      |      | DPHHPDOC       |      |             |
|      |      | MAPGAPC        |      |             |
|      |      | MNSPTOC        |      |             |
|      |      | LOFLPTUC       |      |             |
|      |      | TR2PTDF        |      |             |
|      |      | LREFPNDF       |      |             |
|      |      | ROVPTOV        |      |             |
|      |      | PHPTOV         |      |             |
|      |      | PHPTUV         |      |             |
|      |      | NSPTOV         |      |             |
|      |      | PSPTUV         |      |             |
|      |      | ARCSARC        |      |             |
|      |      | PREVPTOC       |      |             |
|      |      | RESCPSCH       |      |             |
|      |      | WPWDE          |      |             |
|      |      | DQPTUV         |      |             |
|      |      | DOPPDPR        |      |             |
|      |      | UZPDIS         |      |             |
|      |      | MFADPSDE       |      |             |
|      |      | LVRTPTUV       |      |             |
|      |      | DSTPDIS        |      |             |
|      |      | BBPBDF         |      |             |

*Table continues on the next page*

| Name                 | Type    | Values (Range)      | Unit | Description   |
|----------------------|---------|---------------------|------|---|
| Protection instance  | INT32   | 1...100             |      | Instance number of the protection function            |
| Start duration       | FLOAT32 | 0.00...100.00       | %    | Maximum start duration of all stages during the fault |
| Operate time         | FLOAT32 | 0.000...9999999.999 | s    | Operate time  |
| Active group         | INT32   | 1...6               |      | Active setting group                                  |
| Max diff current IL1 | FLOAT32 | 0.000...80.000      | pu   | Maximum phase A differential current                  |
| Max diff current IL2 | FLOAT32 | 0.000...80.000      | pu   | Maximum phase B differential current                  |
| Max diff current IL3 | FLOAT32 | 0.000...80.000      | pu   | Maximum phase C differential current                  |
| Diff current IL1     | FLOAT32 | 0.000...80.000      | pu   | Differential current phase A                          |
| Diff current IL2     | FLOAT32 | 0.000...80.000      | pu   | Differential current phase B                          |
| Diff current IL3     | FLOAT32 | 0.000...80.000      | pu   | Differential current phase C                          |
| Max bias current IL1 | FLOAT32 | 0.000...50.000      | pu   | Maximum phase A bias current                          |
| Max bias current IL2 | FLOAT32 | 0.000...50.000      | pu   | Maximum phase B bias current                          |
| Max bias current IL3 | FLOAT32 | 0.000...50.000      | pu   | Maximum phase C bias current                          |
| Bias current IL1     | FLOAT32 | 0.000...50.000      | pu   | Bias current phase A                                  |
| Bias current IL2     | FLOAT32 | 0.000...50.000      | pu   | Bias current phase B                                  |
| Bias current IL3     | FLOAT32 | 0.000...50.000      | pu   | Bias current phase C                                  |
| Diff current Io      | FLOAT32 | 0.000...80.000      | pu   | Differential current residual                         |
| Bias current Io      | FLOAT32 | 0.000...50.000      | pu   | Bias current residual                                 |
| Max current IL1      | FLOAT32 | 0.000...50.000      | xIn  | Maximum phase A current                               |

*Table continues on the next page*

| Name               | Type    | Values (Range)   | Unit | Description  |
|--------------------|---------|------------------|------|--|
| Max current IL2    | FLOAT32 | 0.000...50.000   | xIn  | Maximum phase B current                            |
| Max current IL3    | FLOAT32 | 0.000...50.000   | xIn  | Maximum phase C current                            |
| Max current Io     | FLOAT32 | 0.000...50.000   | xIn  | Maximum residual current                           |
| Current IL1        | FLOAT32 | 0.000...50.000   | xIn  | Phase A current                                    |
| Current IL2        | FLOAT32 | 0.000...50.000   | xIn  | Phase B current                                    |
| Current IL3        | FLOAT32 | 0.000...50.000   | xIn  | Phase C current                                    |
| Current Io         | FLOAT32 | 0.000...50.000   | xIn  | Residual current                                   |
| Current Io-Calc    | FLOAT32 | 0.000...50.000   | xIn  | Calculated residual current                        |
| Current Ps-Seq     | FLOAT32 | 0.000...50.000   | xIn  | Positive sequence current                          |
| Current Ng-Seq     | FLOAT32 | 0.000...50.000   | xIn  | Negative sequence current                          |
| Voltage U12        | FLOAT32 | 0.000...4.000    | xUn  | Phase A to phase B voltage                         |
| Voltage U23        | FLOAT32 | 0.000...4.000    | xUn  | Phase B to phase C voltage                         |
| Voltage U31        | FLOAT32 | 0.000...4.000    | xUn  | Phase C to phase A voltage                         |
| Voltage Uo         | FLOAT32 | 0.000...4.000    | xUn  | Residual voltage                                   |
| Voltage Zro-Seq    | FLOAT32 | 0.000...4.000    | xUn  | Zero sequence voltage                              |
| Voltage Ps-Seq     | FLOAT32 | 0.000...4.000    | xUn  | Positive sequence voltage                          |
| Voltage Ng-Seq     | FLOAT32 | 0.000...4.000    | xUn  | Negative sequence voltage                          |
| Frequency          | FLOAT32 | 30.00...80.00    | Hz   | Frequency  |
| Frequency gradient | FLOAT32 | -10.00...10.00   | Hz/s | Frequency gradient                                 |
| Angle Uo - Io      | FLOAT32 | -180.00...180.00 | deg  | Angle residual voltage - residual current          |
| Angle U23 - IL1    | FLOAT32 | -180.00...180.00 | deg  | Angle phase B to phase C voltage - phase A current |
| Angle U31 - IL2    | FLOAT32 | -180.00...180.00 | deg  | Angle phase C to phase A voltage - phase B current |
| Angle U12 - IL3    | FLOAT32 | -180.00...180.00 | deg  | Angle phase A to phase B voltage - phase C current |

## 2.9.5 Technical revision history

Table 41: FLTRFRC Technical revision history

| Technical revision | Change              |
|--------------------|---------------------|
| B                  | Modified for SSC600 |

## 2.10 Non-volatile memory

In addition to the setting values, some data can be stored in the non-volatile memory.

- Up to 8192 events are stored. The stored events are visible in WHMI and Event viewer tool in PCM600.
- Recorded data
  - Fault records (up to 128)
  - Maximum demands
- Circuit breaker condition monitoring
- Latched alarm and trip LEDs' statuses
- Trip circuit lockout
- Counter values

## 2.11 SMV function blocks

SMV function blocks are used in the process bus applications with the receiving of the sampled values of currents and voltages.

### 2.11.1 IEC 61850-9-2 LE sampled values receiving SMVRECEIVE

#### 2.11.1.1 Function block

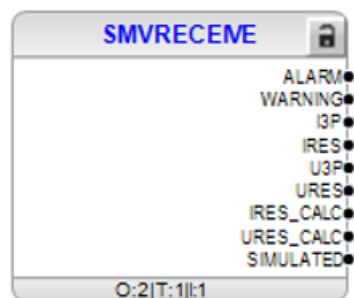


Figure 16: Function block

### 2.11.1.2 Functionality

The SMVRECEIVE function block is used for activating the SMV receiving functionality.

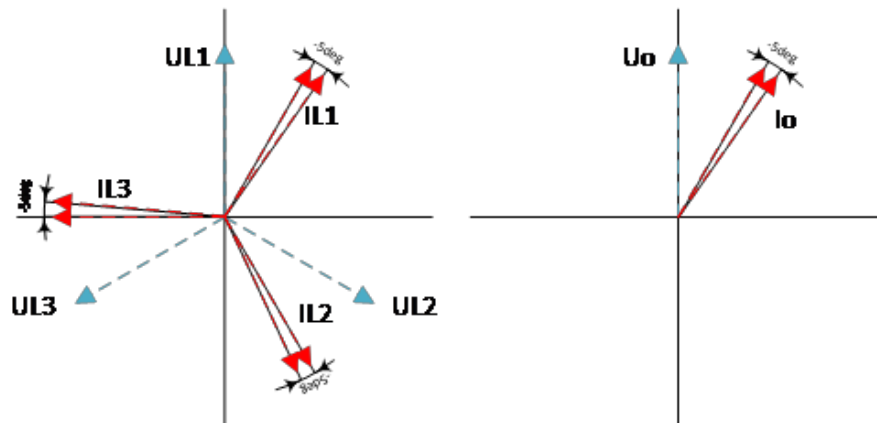
WARNING output is set TRUE if two frames in a sequence are lost. ALARM output is set true if three or more frames in a sequence is lost. Frames are marked as lost if they arrive later than defined with *SV Delay* parameter regardless of SmpCnt sequence. Also missing accurate time synchronization invalidates measurements. After time synchronization is recovered valid operation recovers in succeeding task cycle.

The received signal scaling from primary to secondary values are defined with the Primary current, Primary voltage, Primary residual current and Primary residual voltage settings.

*SV angle correction* setting is used to compensate angle difference between received voltages and currents. The parameter turns the phase angle of the currents based on the settings value.



Only phasors are turned, sample values are not affected at all. This means that sample based functions (like BBPBDF) are not affected by the *SV angle correction* setting.



The SIMULATED output indicates if the data is received with Simulation-bit set in the transmitted SMV message.

### 2.11.1.3 Signals

Table 42: SMVRECEIVE Output signals

| Name    | Type    | Description          |
|---------|---------|----------------------|
| ALARM   | BOOLEAN | SMV Receive Alarm    |
| WARNING | BOOLEAN | SMV Receive Warning  |
| I3P     | Group   | Three-phase currents |
| IRES    | Group   | Residual current     |
| U3P     | Group   | Three-phase voltages |

Table continues on the next page



| Name      | Type    | Description                  |
|-----------|---------|------------------------------|
| URES      | Group   | Residual voltage             |
| IRES_CALC | Group   | Residual current, calculated |
| URES_CALC | Group   | Residual voltage, calculated |
| SIMULATED | BOOLEAN | Receiving simulated data     |

### 2.11.1.4 Settings

#### SMVRECEIVE Settings

Table 43: SMVRECEIVE Settings

| Parameter                | Values (Range)   | Unit | Step  | Default | Description                                |
|--------------------------|------------------|------|-------|---------|--|
| SmvId                    | 0...35           |      |       | 0       | SmvID of the received IEC 61850-9-2 stream |
| Primary current          | 1.0...6000.0     | A    | 0.1   | 100.0   | Nominal primary current                    |
| Primary voltage          | 0.100...440.000  | kV   | 0.001 | 20.000  | Nominal primary voltage                    |
| Primary residual current | 1.0...6000.0     | A    | 0.1   | 100.0   | Nominal primary residual current           |
| Primary residual voltage | 0.100...440.000  | kV   | 0.001 | 11.547  | Nominal primary residual voltage           |
| SV angle correction      | -5.0 ... 5.0 deg | deg  |       | -0.6    | SV angle correction for merging unit       |

### 2.11.1.5 Monitored data

#### SMVRECEIVE Monitored data

Table 44: SMVRECEIVE Monitored data

| Parameter | Values (Range) | Unit | Step | Default | Description |
|-----------|----------------|------|------|---------|-------------|
| ALARM     |                |      |      | False   |             |
| WARNING   |                |      |      | False   |             |
| CONFIGERR |                |      |      | False   |             |
| SIMULATED |                |      |      | False   |             |

### 2.11.1.6 Technical revision history

Table 45: SMVRECEIVE Technical revision history

| Technical revision | Change              |
|--------------------|---------------------|
| B                  | Modified for SSC600 |

### 2.11.2 Technical revision history

Table 46: SMV Technical revision history

| Technical revision | Change              |
|--------------------|---------------------|
| B                  | Modified for SSC600 |

## 2.12 GOOSE function blocks

GOOSE function blocks are used for connecting incoming GOOSE data to application. They support BOOLEAN, Dbpos, Enum, FLOAT32, INT8 and INT32 data types.

#### Common signals

The `VALID` output indicates the validity of received GOOSE data, which means in case of valid, that the GOOSE communication is working and received data quality bits (if configured) indicate good process data. Invalid status is caused either by bad data quality bits or GOOSE communication failure. See IEC 61850 engineering guide for details.

The `OUT` output passes the received GOOSE value for the application. Default value (0) is used if `VALID` output indicates invalid status. The `IN` input is defined in the GOOSE configuration and can always be seen in SMT sheet.

The `SIMULATED` output indicates if the data is received with Simulation-bit set in the transmitted GOOSE message.

#### Settings

The GOOSE function blocks do not have any parameters available in WHMI or PCM600.

### 2.12.1 GOOSERCV\_BIN function block

### 2.12.1.1 Function block

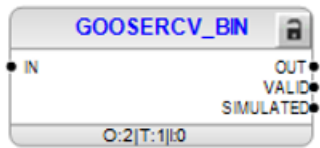


Figure 17: Function block

### 2.12.1.2 Functionality

The GOOSERCV\_BIN function is used to connect the GOOSE binary inputs to the application.

### 2.12.1.3 Signals

#### GOOSERCV\_BIN Input signals

Table 47: GOOSERCV\_BIN Input signals

| Name | Type    | Default | Description  |
|------|---------|---------|--------------|
| IN   | BOOLEAN | 0       | Input signal |

#### GOOSERCV\_BIN Output signals

Table 48: GOOSERCV\_BIN Output signals

| Name      | Type    | Description              |
|-----------|---------|--------------------------|
| OUT       | BOOLEAN | Output signal            |
| VALID     | BOOLEAN | Output signal            |
| SIMULATED | BOOLEAN | Receiving simulated data |

## 2.12.2 GOOSERCV\_DP function block

### 2.12.2.1 Function block

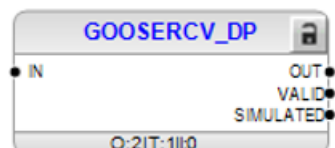


Figure 18: Function block

### 2.12.2.2 Functionality

The GOOSERCV\_DP function is used to connect the GOOSE double binary inputs to the application.

### 2.12.2.3 Signals

#### GOOSERCV\_DP Input signals

Table 49: GOOSERCV\_DP Input signals

| Name | Type  | Default | Description  |
|------|-------|---------|--------------|
| IN   | Dbpos | 00      | Input signal |

#### GOOSERCV\_DP Output signals

Table 50: GOOSERCV\_DP Output signals

| Name      | Type    | Description              |
|-----------|---------|--------------------------|
| OUT       | Dbpos   | Output signal            |
| VALID     | BOOLEAN | Output signal            |
| SIMULATED | BOOLEAN | Receiving simulated data |

## 2.12.3 GOOSERCV\_MV function block

### 2.12.3.1 Function block



Figure 19: Function block

### 2.12.3.2 Functionality

The GOOSERCV\_MV function is used to connect the GOOSE measured value inputs to the application.

### 2.12.3.3 Signals

**GOOSERCV\_MV Input signals****Table 51: GOOSERCV\_MV Input signals**

| Name | Type    | Default | Description  |
|------|---------|---------|--------------|
| IN   | FLOAT32 | 0       | Input signal |

**GOOSERCV\_MV Output signals****Table 52: GOOSERCV\_MV Output signals**

| Name      | Type    | Description              |
|-----------|---------|--------------------------|
| OUT       | FLOAT32 | Output signal            |
| VALID     | BOOLEAN | Output signal            |
| SIMULATED | BOOLEAN | Receiving simulated data |

**2.12.4 GOOSERCV\_INT8 function block****2.12.4.1 Function block***Figure 20: Function block***2.12.4.2 Functionality**

The GOOSERCV\_INT8 function is used to connect the GOOSE 8 bit integer inputs to the application.

**2.12.4.3 Signals****GOOSERCV\_INT8 Input signals****Table 53: GOOSERCV\_INT8 Input signals**

| Name | Type | Default | Description  |
|------|------|---------|--------------|
| IN   | INT8 | 0       | Input signal |

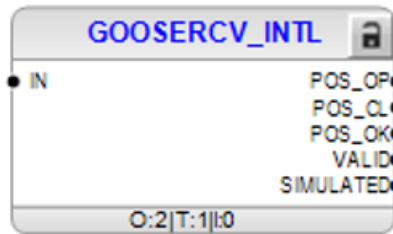
**GOOSERCV\_INT8 Output signals**

**Table 54: GOOSERCV\_INT8 Output signals**

| Name      | Type    | Description              |
|-----------|---------|--------------------------|
| OUT       | INT8    | Output signal            |
| VALID     | BOOLEAN | Output signal            |
| SIMULATED | BOOLEAN | Receiving simulated data |

**2.12.5 GOOSERCV\_INTL function block**

**2.12.5.1 Function block**



*Figure 21: Function block*

**2.12.5.2 Functionality**

The received GOOSE interlocking information function GOOSERCV\_INTL is used to connect the GOOSE double binary input to the application and extracting single binary position signals from the double binary position signal.

The **OP** output signal indicates that the position is open. Default value (0) is used if **VALID** output indicates invalid status.

The **CL** output signal indicates that the position is closed. Default value (0) is used if **VALID** output indicates invalid status.

The **OK** output signal indicates that the position is neither in faulty or intermediate state. The default value (0) is used if **VALID** output indicates invalid status.

**2.12.5.3 Signals**

**GOOSERCV\_INTL Input signals**

**Table 55: GOOSERCV\_INTL Input signals**

| Name | Type  | Default | Description  |
|------|-------|---------|--------------|
| IN   | Dbpos | 00      | Input signal |

## GOOSERCV\_INTL Output signals

Table 56: GOOSERCV\_INTL Output signals

| Name      | Type    | Description                   |
|-----------|---------|-------------------------------|
| POS_OP    | BOOLEAN | Position open output signal   |
| POS_CL    | BOOLEAN | Position closed output signal |
| POS_OK    | BOOLEAN | Position OK output signal     |
| VALID     | BOOLEAN | Output signal                 |
| SIMULATED | BOOLEAN | Receiving simulated data      |

## 2.12.6 GOOSERCV\_CMV function block

### 2.12.6.1 Function block

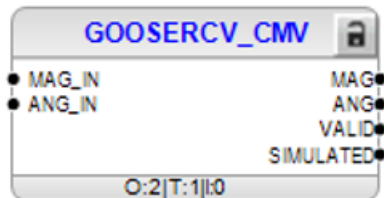


Figure 22: Function block

### 2.12.6.2 Functionality

The received GOOSE measured value (phasor) information function GOOSERCV\_CMV is used to connect GOOSE measured value inputs to the application. The `MAG_IN` (amplitude) and `ANG_IN` (angle) inputs are defined in the GOOSE configuration (PCM600).

The `MAG` output passes the received GOOSE amplitude and `ANG` the received angle value for the application.

### 2.12.6.3 Signals

#### GOOSERCV\_CMV Input signals

Table 57: GOOSERCV\_CMV Input signals

| Name   | Type    | Default | Description              |
|--------|---------|---------|--------------------------|
| MAG_IN | FLOAT32 | 0       | Input signal (amplitude) |
| ANG_IN | FLOAT32 | 0       | Input signal (angle)     |

**GOOSERCV\_CMV Output signals**

| Name      | Type    | Description               |
|-----------|---------|---------------------------|
| MAG       | FLOAT32 | Output signal (amplitude) |
| ANG       | FLOAT32 | Output signal (angle)     |
| VALID     | BOOLEAN | Output signal             |
| SIMULATED | BOOLEAN | Receiving simulated data  |

**2.12.7 GOOSERCV\_ENUM function block**

**2.12.7.1 Function block**

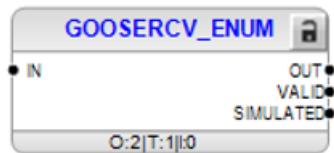


Figure 23: Function block

**2.12.7.2 Functionality**

The GOOSERCV\_ENUM function block is used to connect GOOSE enumerator inputs to the application.

**2.12.7.3 Signals**

**GOOSERCV\_ENUM Input signals**

Table 58: GOOSERCV\_ENUM Input signals

| Name | Type | Default | Description  |
|------|------|---------|--------------|
| IN   | Enum | 0       | Input signal |

**GOOSERCV\_ENUM Output signals**

Table 59: GOOSERCV\_ENUM Output signals

| Name      | Type    | Description              |
|-----------|---------|--------------------------|
| OUT       | Enum    | Output signal            |
| VALID     | BOOLEAN | Output signal            |
| SIMULATED | BOOLEAN | Receiving simulated data |



## 2.12.8 GOOSERCV\_INT32 function block

### 2.12.8.1 Function block

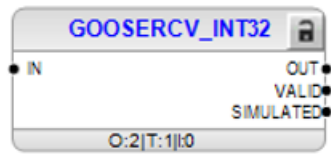


Figure 24: Function block

### 2.12.8.2 Functionality

The GOOSERCV\_INT32 function block is used to connect GOOSE 32 bit integer inputs to the application.

### 2.12.8.3 Signals

#### GOOSERCV\_INT32 Input signals

Table 60: GOOSERCV\_INT32 Input signals

| Name | Type  | Default | Description  |
|------|-------|---------|--------------|
| IN   | INT32 | 0       | Input signal |

#### GOOSERCV\_INT32 Output signals

Table 61: GOOSERCV\_INT32 Output signals

| Name      | Type    | Description              |
|-----------|---------|--------------------------|
| OUT       | INT32   | Output signal            |
| VALID     | BOOLEAN | Output signal            |
| SIMULATED | BOOLEAN | Receiving simulated data |

## 2.13 Type conversion function blocks

### 2.13.1 QTY\_GOOD function block

**2.13.1.1 Function block**

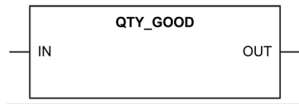


Figure 25: Function block

**2.13.1.2 Functionality**

The QTY\_GOOD function block evaluates the quality bits of the input signal and passes it as a Boolean signal for the application.

The IN input can be connected to any logic application signal (logic function output, binary input, application function output or received GOOSE signal). Due to application logic quality bit propagation, each (simple and even combined) signal has quality which can be evaluated.

The OUT output indicates quality good of the input signal. Input signals that have no quality bits set or only test bit is set, will indicate quality good status.

**2.13.1.3 Signals**

**QTY\_GOOD Input signals**

Table 62: QTY\_GOOD Input signals

| Name | Type | Default | Description  |
|------|------|---------|--------------|
| IN   | Any  | 0       | Input signal |

**QTY\_GOOD Output signals**

Table 63: QTY\_GOOD Output signals

| Name | Type    | Description   |
|------|---------|---------------|
| OUT  | BOOLEAN | Output signal |

**2.13.2 QTY\_BAD function block**

**2.13.2.1 Function block**

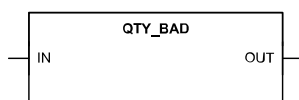


Figure 26: Function block

### 2.13.2.2 Functionality

The QTY\_BAD function block evaluates the quality bits of the input signal and passes it as a Boolean signal for the application.

The IN input can be connected to any logic application signal (logic function output, binary input, application function output or received GOOSE signal). Due to application logic quality bit propagation, each (simple and even combined) signal has quality which can be evaluated.

The OUT output indicates quality bad of the input signal. Input signals that have any other than test bit set, will indicate quality bad status.

### 2.13.2.3 Signals

#### QTY\_BAD Input signals

Table 64: QTY\_BAD Input signals

| Name | Type | Default | Description  |
|------|------|---------|--------------|
| IN   | Any  | 0       | Input signal |

#### QTY\_BAD Output signals

Table 65: QTY\_BAD Output signals

| Name | Type    | Description   |
|------|---------|---------------|
| OUT  | BOOLEAN | Output signal |

## 2.13.3 QTY\_GOOSE\_COMM function block

### 2.13.3.1 Function block

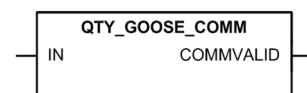


Figure 27: Function block

### 2.13.3.2 Functionality

The QTY\_GOOSE\_COMM function block evaluates the peer device communication status from the quality bits of the input signal and passes it as a Boolean signal to the application.

The IN input can be connected to any GOOSE application logic output signal, for example, GOOSERCV\_BIN.

The OUT output indicates the communication status of the GOOSE function block. When the output is in the true (1) state, the GOOSE communication is active. The value false (0) indicates communication timeout.

### 2.13.3.3 Signals

#### QTY\_GOOSE\_COMM Input signals

Table 66: QTY\_GOOSE\_COMM Input signals

| Name | Type | Default | Description  |
|------|------|---------|--------------|
| IN   | Any  | 0       | Input signal |

#### QTY\_GOOSE\_COMM Output signals

Table 67: QTY\_GOOSE\_COMM Output signals

| Name | Type    | Description   |
|------|---------|---------------|
| OUT  | BOOLEAN | Output signal |

### 2.13.4 T\_HEALTH function block

#### 2.13.4.1 Function block

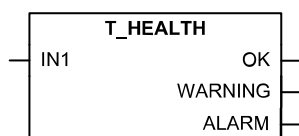


Figure 28: Function block

#### 2.13.4.2 Functionality

The T\_HEALTH function evaluates enumerated data of “Health” data attribute. This function block can only be used with GOOSE.

The IN input can be connected to GOOSERCV\_ENUM function block, which is receiving the LD0.LLN0.Health.stVal data attribute sent by another device.

The outputs OK, WARNING and ALARM are extracted from the enumerated input value. Only one of the outputs can be active at a time. In case the GOOSERCV\_ENUM function block does not receive the value from the sending device or it is invalid, the default value (0) is used and the ALARM is activated in the T\_HEALTH function block.

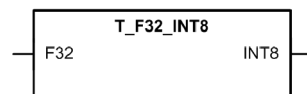
#### 2.13.4.3 Signals

**T\_HEALTH Input signals****Table 68: T\_HEALTH Input signals**

| Name | Type | Default | Description  |
|------|------|---------|--------------|
| IN   | Any  | 0       | Input signal |

**T\_HEALTH Output signals****Table 69: T\_HEALTH Output signals**

| Name    | Type    | Description   |
|---------|---------|---------------|
| OK      | BOOLEAN | Output signal |
| WARNING | BOOLEAN | Output signal |
| ALARM   | BOOLEAN | Output signal |

**2.13.5 T\_F32\_INT8 function block****2.13.5.1 Function block***Figure 29: Function block***2.13.5.2 Functionality**

The T\_F32\_INT8 function is used to convert 32-bit floating type values to 8-bit integer type. The rounding operation is included. Output value saturates if the input value is below the minimum or above the maximum value.

**2.13.5.3 Signals****T\_F32\_INT8 Input signals****Table 70: T\_HEALTH Input signals**

| Name | Type    | Default | Description  |
|------|---------|---------|--------------|
| F32  | FLOAT32 | 0.0     | Input signal |

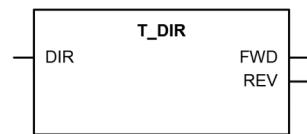
**T\_F32\_INT8 Output signal**

**Table 71: T\_F32\_INT8 Output signal**

| Name | Type | Description   |
|------|------|---------------|
| INT8 | INT8 | Output signal |

**2.13.6 T\_DIR function block**

**2.13.6.1 Function block**



*Figure 30: Function block*

**2.13.6.2 Functionality**

The T\_DIR function evaluates enumerated data of the FAULT\_DIR data attribute of the directional functions. T\_DIR can only be used with GOOSE. The DIR input can be connected to the GOOSERCV\_ENUM function block, which is receiving the LD0.<function>.Str.dirGeneral or LD0.<function>.Dir.dirGeneral data attribute sent by another IED.

In case the GOOSERCV\_ENUM function block does not receive the value from the sending IED or it is invalid , the default value (0) is used in function outputs.

The outputs FWD and REV are extracted from the enumerated input value.

**2.13.6.3 Signals**

**T\_DIR Input signals**

**Table 72: T\_DIR Input signals**

| Name | Type | Default | Description  |
|------|------|---------|--------------|
| DIR  | Enum | 0       | Input signal |

**T\_DIR Output signals**

**Table 73: T\_DIR Output signals**

| Name | Type    | Default | Description        |
|------|---------|---------|--------------------|
| FWD  | BOOLEAN | 0       | Direction forward  |
| REV  | BOOLEAN | 0       | Direction backward |

## 2.13.7 T\_TCMD function block

### 2.13.7.1 Function block



Figure 31: Function block

### 2.13.7.2 Functionality

The enumerator to boolean conversion function T\_TCMD is used to convert enumerated input signals to boolean output signals.

Table 74: Conversion from enumerated to Boolean

| IN | RAISE | LOWER |
|----|-------|-------|
| 0  | FALSE | FALSE |
| 1  | FALSE | TRUE  |
| 2  | TRUE  | FALSE |
| x  | FALSE | FALSE |

### 2.13.7.3 Signals

#### T\_TCMD input signals

Table 75: T\_TCMD input signals

| Name | Type | Default | Description  |
|------|------|---------|--------------|
| IN   | Enum | 0       | Input signal |

#### T\_TCMD output signals

Table 76: T\_TCMD output signals

| Name  | Type    | Description   |
|-------|---------|---------------|
| RAISE | BOOLEAN | Raise command |
| LOWER | BOOLEAN | Lower command |

## 2.13.8 T\_TCMD\_BIN function block

### 2.13.8.1 Function block

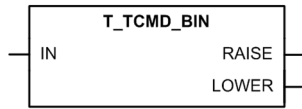


Figure 32: Function block

### 2.13.8.2 Functionality

The 32-bit integer to binary command conversion function T\_TCMD\_BIN is used to convert 32 bit integer input signal to boolean output signals.

Table 77: Conversion from integer to Boolean

| IN | RAISE | LOWER |
|----|-------|-------|
| 0  | FALSE | FALSE |
| 1  | FALSE | TRUE  |
| 2  | TRUE  | FALSE |
| x  | FALSE | FALSE |

### 2.13.8.3 Signals

#### T\_TCMD\_BIN input signals

Table 78: T\_TCMD\_BIN input signals

| Name | Type  | Default | Description  |
|------|-------|---------|--------------|
| IN   | INT32 | 0       | Input signal |

#### T\_TCMD\_BIN output signals

Table 79: T\_TCMD\_BIN output signals

| Name  | Type    | Description   |
|-------|---------|---------------|
| RAISE | BOOLEAN | Raise command |
| LOWER | BOOLEAN | Lower command |

### 2.13.9 T\_BIN\_TCMD function block



### 2.13.9.1 Function block

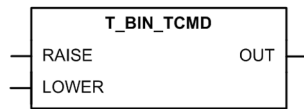


Figure 33: Function block

### 2.13.9.2 Functionality

The binary command to 32-bit integer conversion function T\_BIN\_TCMD is used to convert boolean input signals to 32 bit integer output signals.

Table 80: Conversion from Boolean to integer

| RAISE | LOWER | OUT |
|-------|-------|-----|
| FALSE | FALSE | 0   |
| FALSE | TRUE  | 1   |
| TRUE  | FALSE | 2   |

### 2.13.9.3 Signals

#### T\_TCMD\_BIN input signals

Table 81: T\_TCMD\_BIN input signals

| Name  | Type    | Default | Description   |
|-------|---------|---------|---------------|
| RAISE | BOOLEAN | 0       | Raise command |
| LOWER | BOOLEAN | 0       | Lower command |

#### T\_TCMD\_BIN output signals

Table 82: T\_TCMD\_BIN output signals

| Name | Type  | Description   |
|------|-------|---------------|
| OUT  | INT32 | Output signal |

## 2.14 Configurable logic blocks

### 2.14.1 Standard configurable logic blocks

#### 2.14.1.1 OR function block

**Function block**

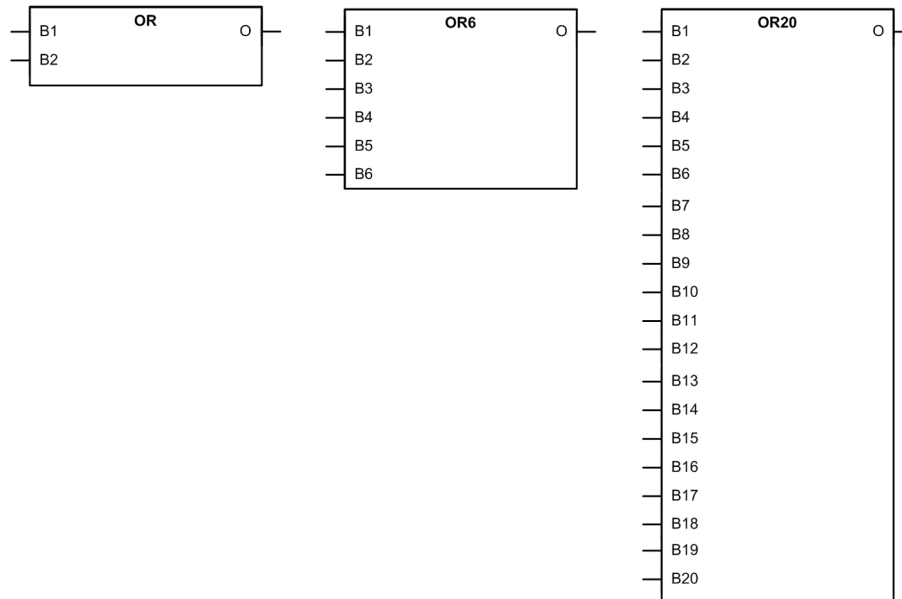


Figure 34: Function blocks

**Functionality**

OR, OR6 and OR20 are used to form general combinatory expressions with Boolean variables

The  $\circ$  output is activated when at least one input has the value TRUE. The default value of all inputs is FALSE, which makes it possible to use only the required number of inputs and leave the rest disconnected.

OR has two inputs, OR6 six and OR20 twenty inputs.

**Signals**

*Input signals*

**Table 83: OR Input signals**

| Name | Type    | Default | Description    |
|------|---------|---------|----------------|
| B1   | BOOLEAN | 0       | Input signal 1 |
| B2   | BOOLEAN | 0       | Input signal 2 |

**Table 84: OR6 Input signals**

| Name | Type    | Default | Description    |
|------|---------|---------|----------------|
| B1   | BOOLEAN | 0       | Input signal 1 |
| B2   | BOOLEAN | 0       | Input signal 2 |
| B3   | BOOLEAN | 0       | Input signal 3 |
| B4   | BOOLEAN | 0       | Input signal 4 |

*Table continues on the next page*

| Name | Type    | Default | Description    |
|------|---------|---------|----------------|
| B5   | BOOLEAN | 0       | Input signal 5 |
| B6   | BOOLEAN | 0       | Input signal 6 |

**Table 85: Input signals**

| Name | Type    | Default | Description     |
|------|---------|---------|-----------------|
| B1   | BOOLEAN | 0       | Input signal 1  |
| B2   | BOOLEAN | 0       | Input signal 2  |
| B3   | BOOLEAN | 0       | Input signal 3  |
| B4   | BOOLEAN | 0       | Input signal 4  |
| B5   | BOOLEAN | 0       | Input signal 5  |
| B6   | BOOLEAN | 0       | Input signal 6  |
| B7   | BOOLEAN | 0       | Input signal 7  |
| B8   | BOOLEAN | 0       | Input signal 8  |
| B9   | BOOLEAN | 0       | Input signal 9  |
| B10  | BOOLEAN | 0       | Input signal 10 |
| B11  | BOOLEAN | 0       | Input signal 11 |
| B12  | BOOLEAN | 0       | Input signal 12 |
| B13  | BOOLEAN | 0       | Input signal 13 |
| B14  | BOOLEAN | 0       | Input signal 14 |
| B15  | BOOLEAN | 0       | Input signal 15 |
| B16  | BOOLEAN | 0       | Input signal 16 |
| B17  | BOOLEAN | 0       | Input signal 17 |
| B18  | BOOLEAN | 0       | Input signal 18 |
| B19  | BOOLEAN | 0       | Input signal 19 |
| B20  | BOOLEAN | 0       | Input signal 20 |

*Output signal***Table 86: OR Output signal**

| Name | Type    | Description   |
|------|---------|---------------|
| O    | BOOLEAN | Output Signal |

**Table 87: OR6 Output signal**

| Name | Type    | Description   |
|------|---------|---------------|
| O    | BOOLEAN | Output Signal |

**Table 88: OR20 Output signal**

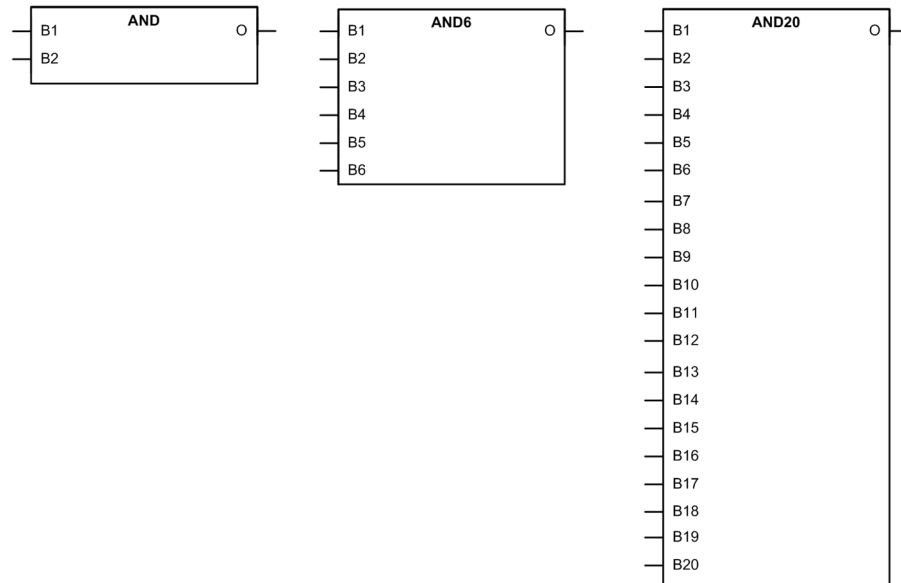
| Name | Type    | Description   |
|------|---------|---------------|
| O    | BOOLEAN | Output Signal |

**Settings**

The function does not have any parameters available in WHMI or Protection and Control IED Manager (PCM600).

**2.14.1.2 AND Function block**

**AND Function block**



*Figure 35: Function blocks*

**Functionality**

AND, AND6 and AND20 are used to form general combinatory expressions with Boolean variables.

The default value in all inputs is logical true, which makes it possible to use only the required number of inputs and leave the rest disconnected.

AND has two inputs, AND6 six inputs and AND20 twenty inputs.

**Signals**

*Input signal*

**Table 89: AND Input signals**

| Name | Type    | Default | Description    |
|------|---------|---------|----------------|
| B1   | BOOLEAN | 1       | Input signal 1 |
| B2   | BOOLEAN | 1       | Input signal 2 |

**Table 90: AND6 Input signals**

| Name | Type    | Default | Description    |
|------|---------|---------|----------------|
| B1   | BOOLEAN | 1       | Input signal 1 |
| B2   | BOOLEAN | 1       | Input signal 2 |
| B3   | BOOLEAN | 1       | Input signal 3 |
| B4   | BOOLEAN | 1       | Input signal 4 |
| B5   | BOOLEAN | 1       | Input signal 5 |
| B6   | BOOLEAN | 1       | Input signal 6 |

**Table 91: Input signals**

| Name | Type    | Default | Description     |
|------|---------|---------|-----------------|
| B1   | BOOLEAN | 1       | Input signal 1  |
| B2   | BOOLEAN | 1       | Input signal 2  |
| B3   | BOOLEAN | 1       | Input signal 3  |
| B4   | BOOLEAN | 1       | Input signal 4  |
| B5   | BOOLEAN | 1       | Input signal 5  |
| B6   | BOOLEAN | 1       | Input signal 6  |
| B7   | BOOLEAN | 1       | Input signal 7  |
| B8   | BOOLEAN | 1       | Input signal 8  |
| B9   | BOOLEAN | 1       | Input signal 9  |
| B10  | BOOLEAN | 1       | Input signal 10 |
| B11  | BOOLEAN | 1       | Input signal 11 |
| B12  | BOOLEAN | 1       | Input signal 12 |
| B13  | BOOLEAN | 1       | Input signal 13 |
| B14  | BOOLEAN | 1       | Input signal 14 |
| B15  | BOOLEAN | 1       | Input signal 15 |
| B16  | BOOLEAN | 1       | Input signal 16 |
| B17  | BOOLEAN | 1       | Input signal 17 |
| B18  | BOOLEAN | 1       | Input signal 18 |
| B19  | BOOLEAN | 1       | Input signal 19 |
| B20  | BOOLEAN | 1       | Input signal 20 |

*Output signal***Table 92: AND Output signal**

| Name | Type    | Description   |
|------|---------|---------------|
| O    | BOOLEAN | Output signal |

**Table 93: AND6 Output signal**

| Name | Type    | Description   |
|------|---------|---------------|
| O    | BOOLEAN | Output signal |

**Table 94: AND20 Output signal**

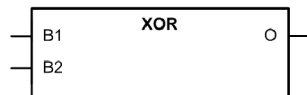
| Name | Type    | Description   |
|------|---------|---------------|
| O    | BOOLEAN | Output signal |

**Settings**

The function does not have any parameters available in WHMI or Protection and Control IED Manager (PCM600).

**2.14.1.3 XOR function block**

**Function block**



*Figure 36: Function block*

**Functionality**

The exclusive OR function XOR is used to generate combinatory expressions with Boolean variables.

The output signal is TRUE if the input signals are different and FALSE if they are equal.

**Signals**

*Input signal*

**Table 95: XOR Input signals**

| Name | Type    | Default | Description    |
|------|---------|---------|----------------|
| B1   | BOOLEAN | 0       | Input signal 1 |
| B2   | BOOLEAN | 0       | Input signal 2 |

*Output signal*

**Table 96: XOR Output signal**

| Name | Type    | Description   |
|------|---------|---------------|
| O    | BOOLEAN | Output signal |

### Settings

The function does not have any parameters available in WHMI or Protection and Control IED Manager (PCM600).

## 2.14.1.4 NOT function block

### Function block

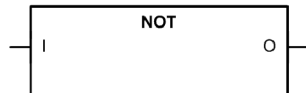


Figure 37: Function block

### Functionality

NOT is used to generate combinatory expressions with Boolean variables.  
NOT inverts the input signal.

### Signals

#### Input signal

Table 97: NOT Input signal

| Name | Type    | Default | Description  |
|------|---------|---------|--------------|
| I    | BOOLEAN | 0       | Input signal |

#### Output signal

Table 98: NOT Output signal

| Name | Type    | Description   |
|------|---------|---------------|
| O    | BOOLEAN | Output signal |

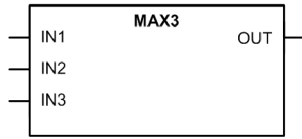
### Settings

The function does not have any parameters available in WHMI or Protection and Control IED Manager (PCM600).

## 2.14.1.5 MAX3 function block

**Function block**

**Function block**



*Figure 38: Function block*

**Functionality**

The maximum function MAX3 selects the maximum value from three analog values. Disconnected inputs and inputs whose quality is bad are ignored. If all inputs are disconnected or the quality is bad, MAX3 output value is set to  $-2^{21}$ .

**Signals**

*Input signal*

**Table 99: MAX3 Input signals**

| Name | Type    | Default | Description    |
|------|---------|---------|----------------|
| IN1  | FLOAT32 | 0       | Input signal 1 |
| IN2  | FLOAT32 | 0       | Input signal 2 |
| IN3  | FLOAT32 | 0       | Input signal 3 |

*Output signal*

**Table 100: MAX3 Output signal**

| Name | Type    | Description   |
|------|---------|---------------|
| OUT  | FLOAT32 | Output signal |

**Settings**

The function does not have any parameters available in WHMI or Protection and Control IED Manager (PCM600).

**2.14.1.6 MIN3 function block**



### Function block

#### Function block

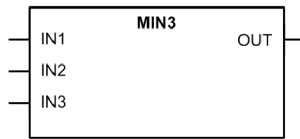


Figure 39: MIN3 function block

### Functionality

The minimum function MIN3 selects the minimum value from three analog values. Disconnected inputs and inputs whose quality is bad are ignored. If all inputs are disconnected or the quality is bad, MIN3 output value is set to  $2^{21}$ .

### Signals

#### Input signal

Table 101: MIN3 Input signals

| Name | Type    | Default | Description    |
|------|---------|---------|----------------|
| IN1  | FLOAT32 | 0       | Input signal 1 |
| IN2  | FLOAT32 | 0       | Input signal 2 |
| IN3  | FLOAT32 | 0       | Input signal 3 |

#### Output signal

Table 102: MIN3 Output signal

| Name | Type    | Description   |
|------|---------|---------------|
| OUT  | FLOAT32 | Output signal |

### Settings

The function does not have any parameters available in WHMI or Protection and Control IED Manager (PCM600).

## 2.14.1.7

### R\_TRIG function block

#### Function block

#### Function block

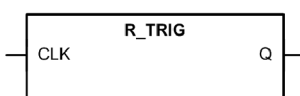


Figure 40: Function block

**Functionality**

R\_Trig is used as a rising edge detector.

R\_Trig detects the transition from FALSE to TRUE at the CLK input. When the rising edge is detected, the element assigns the output to TRUE. At the next execution round, the output is returned to FALSE despite the state of the input.

**Signals**

*Input signal*

**Table 103: R\_TRIG Input signals**

| Name | Type    | Default | Description  |
|------|---------|---------|--------------|
| CLK  | BOOLEAN | 0       | Input signal |

*Output signal*

**Table 104: R\_TRIG Output signal**

| Name | Type    | Description   |
|------|---------|---------------|
| Q    | BOOLEAN | Output signal |

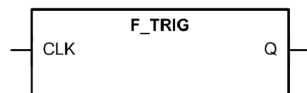
**Settings**

The function does not have any parameters available in WHMI or Protection and Control IED Manager (PCM600).

**2.14.1.8 F\_TRIG function block**

**Function block**

**Function block**



*Figure 41: Function block*

**Functionality**

F\_Trig is used as a falling edge detector.

The function detects the transition from TRUE to FALSE at the CLK input. When the falling edge is detected, the element assigns the Q output to TRUE. At the next execution round, the output is returned to FALSE despite the state of the input.

**Signals**

*Input signal***Table 105: F\_TRIG Input signals**

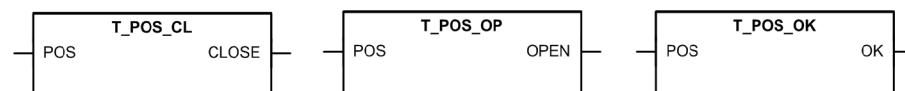
| Name | Type    | Default | Description  |
|------|---------|---------|--------------|
| CLK  | BOOLEAN | 0       | Input signal |

*Output signal***Table 106: F\_TRIG Output signal**

| Name | Type    | Description   |
|------|---------|---------------|
| Q    | BOOLEAN | Output signal |

**Settings**

The function does not have any parameters available in WHMI or Protection and Control IED Manager (PCM600).

**2.14.1.9****T\_POS\_XX function blocks****Function block***Figure 42: Function blocks***Functionality**

The circuit breaker position information can be communicated with the IEC 61850 GOOSE messages. The position information is a double binary data type which is fed to the POS input.

T\_POS\_CL and T\_POS\_OP are used for extracting the circuit breaker status information. Respectively, T\_POS\_OK is used to validate the intermediate or faulty breaker position.

**Table 107: Cross reference between circuit breaker position and the output of the function block**

| Circuit breaker position | Output of the function block |          |          |
|--------------------------|------------------------------|----------|----------|
|                          | T_POS_CL                     | T_POS_OP | T_POS_OK |
| Intermediate '00'        | FALSE                        | FALSE    | FALSE    |
| Close '01'               | TRUE                         | FALSE    | TRUE     |
| Open '10'                | FALSE                        | TRUE     | TRUE     |
| Faulty '11'              | TRUE                         | TRUE     | FALSE    |

**Signals**

*Input signal*

**Table 108: T\_POS\_CL Input signals**

| Name | Type          | Default | Description  |
|------|---------------|---------|--------------|
| POS  | Double binary | 0       | Input signal |

**Table 109: T\_POS\_OP Input signals**

| Name | Type          | Default | Description  |
|------|---------------|---------|--------------|
| POS  | Double binary | 0       | Input signal |

**Table 110: T\_POS\_OK Input signals**

| Name | Type          | Default | Description  |
|------|---------------|---------|--------------|
| POS  | Double binary | 0       | Input signal |

*Output signal*

**Table 111: T\_POS\_CL Output signal**

| Name  | Type    | Description   |
|-------|---------|---------------|
| CLOSE | BOOLEAN | Output signal |

**Table 112: T\_POS\_OP Output signal**

| Name | Type    | Description   |
|------|---------|---------------|
| OPEN | BOOLEAN | Output signal |

**Table 113: T\_POS\_OK Output signal**

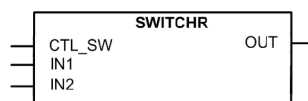
| Name | Type    | Description   |
|------|---------|---------------|
| OK   | BOOLEAN | Output signal |

**Settings**

The function does not have any parameters available in WHMI or Protection and Control IED Manager (PCM600).

**2.14.1.10 SWITCHR function block**

**Function block**



*Figure 43: Function block*

### Functionality

SWITCHR switching block for REAL data type is operated by the CTL\_SW input, selects the output value OUT between the IN1 and IN2 inputs.

| CTL_SW | OUT |
|--------|-----|
| FALSE  | IN2 |
| TRUE   | IN1 |

### Signals

*Input signal*

**Table 114: SWITCHR Input signals**

| Name   | Type    | Default | Description    |
|--------|---------|---------|----------------|
| CTL_SW | BOOLEAN | 1       | Control Switch |
| IN1    | REAL    | 0.0     | Real input 1   |
| IN2    | REAL    | 0.0     | Real input 2   |

*Output signal*

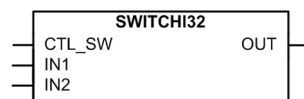
**Table 115: SWITCHR Output signals**

| Name | Type | Description        |
|------|------|--------------------|
| OUT  | REAL | Real switch output |

## 2.14.1.11

### SWITCHI32 function block

#### Function block



*Figure 44: Function block*

### Functionality

SWITCHI32 switching block for 32-bit integer data type is operated by the CTL\_SW input, which selects the output value OUT between the IN1 and IN2 inputs.

**Table 116: SWITCHI32**

| CTL_SW | OUT |
|--------|-----|
| FALSE  | IN2 |
| TRUE   | IN1 |

## Signals

### Input signal

**Table 117: SWITCHI32 input signal**

| Name   | Type    | Default | Description    |
|--------|---------|---------|----------------|
| CTL_SW | BOOLEAN | 1       | Control Switch |
| IN1    | INT32   | 0       | Input signal 1 |
| IN2    | INT32   | 0       | Input signal 2 |

### Output signal

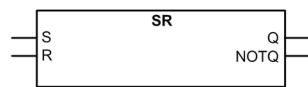
**Table 118: SWITCHI32 output signals**

| Name | Type  | Description   |
|------|-------|---------------|
| OUT  | INT32 | Output signal |

## 2.14.1.12

### SR function block

#### Function block



*Figure 45: Function block*

#### Functionality

The SR flip-flop output  $Q$  can be set or reset from the  $S$  or  $R$  inputs.  $S$  input has a higher priority over the  $R$  input. Output  $NOTQ$  is the negation of output  $Q$ .



The statuses of outputs  $Q$  and  $NOTQ$  are not retained in the nonvolatile memory.

**Table 119: Truth table for SR flip-flop**

| S | R | Q              |
|---|---|----------------|
| 0 | 0 | 0 <sup>1</sup> |
| 0 | 1 | 0              |
| 1 | 0 | 1              |
| 1 | 1 | 1              |

## Signals

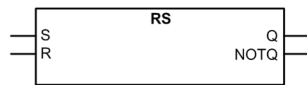
<sup>1</sup> Keep state/no change

*Input signal***Table 120: SR Input signals**

| Name | Type    | Default | Description              |
|------|---------|---------|--------------------------|
| S    | BOOLEAN | 0=False | Set Q output when set    |
| R    | BOOLEAN | 0=False | Resets Q output when set |

*Output signal***Table 121: SR Output signals**

| Name | Type    | Description |
|------|---------|-------------|
| Q    | BOOLEAN | Q status    |
| NOTQ | BOOLEAN | NOTQ status |

**2.14.1.13****RS function block****Function block***Figure 46: Function block***Functionality**

The RS flip-flop output  $Q$  can be set or reset from the  $S$  or  $R$  inputs.  $R$  input has a higher priority over the  $S$  input. Output  $NOTQ$  is the negation of output  $Q$ .



The statuses of outputs  $Q$  and  $NOTQ$  are not retained in the nonvolatile memory.

**Table 122: Truth table for SR flip-flop**

| S | R | Q               |
|---|---|-----------------|
| 0 | 0 | 0 <sup>14</sup> |
| 0 | 1 | 0               |
| 1 | 0 | 1               |
| 1 | 1 | 1               |

**Signals**

<sup>14</sup> Keep state/no change

*Input signal*

**Table 123: RS Input signals**

| Name | Type    | Default | Description              |
|------|---------|---------|--------------------------|
| S    | BOOLEAN | 0=False | Set Q output when set    |
| R    | BOOLEAN | 0=False | Resets Q output when set |

*Output signal*

**Table 124: RS Output signals**

| Name | Type    | Description |
|------|---------|-------------|
| Q    | BOOLEAN | Q status    |
| NOTQ | BOOLEAN | NOTQ status |

**Technical revision history**

**Table 125: RS Technical revision history**

| Technical revision | Change   |
|--------------------|--|
| L                  | The name of the function has been changed from SR to RS. |

**2.14.2 Minimum pulse timer**

**2.14.3 Minimum pulse timer TPGAPC**

**2.14.3.1 Function block**



*Figure 47: Function block*

**2.14.3.2 Functionality**

The Minimum pulse timer function TPGAPC contains two independent timers. The function has a settable pulse length (in milliseconds). The timers are used for setting the minimum pulse length for example, the signal outputs. Once the input is activated, the output is set for a specific duration using the Pulse time setting. Both timers use the same setting parameter.



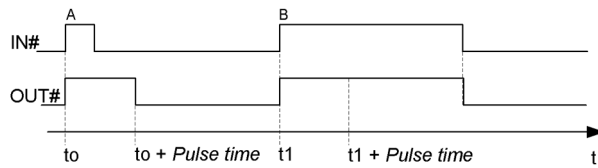


Figure 48: A = Trip pulse is shorter than Pulse time setting, B = Trip pulse is longer than Pulse time setting

### 2.14.3.3 Signals

#### TPGAPC Input signals

Table 126: TPGAPC Input signals

| Name | Type    | Default | Description    |
|------|---------|---------|----------------|
| IN1  | BOOLEAN | 0=False | Input 1 status |
| IN2  | BOOLEAN | 0=False | Input 2 status |

#### TPGAPC Output signals

Table 127: TPGAPC Output signals

| Name | Type    | Description     |
|------|---------|-----------------|
| OUT1 | BOOLEAN | Output 1 status |
| OUT2 | BOOLEAN | Output 2 status |

### 2.14.3.4 Settings

#### TPGAPC Non group settings (Basic)

Table 128: TPGAPC Non group settings (Basic)

| Parameter  | Values (Range) | Unit | Step | Default | Description        |
|------------|----------------|------|------|---------|--------------------|
| Pulse time | 0...60000      | ms   | 1    | 150     | Minimum pulse time |

## 2.14.4 Minimum pulse timer TPSGAPC

### 2.14.4.1 Function block



Figure 49: Function block

### 2.14.4.2 Functionality

The Minimum second pulse timer function TPSGAPC contains two independent timers. The function has a settable pulse length (in seconds). The timers are used for setting the minimum pulse length for example, the signal outputs. Once the input is activated, the output is set for a specific duration using the Pulse time setting. Both timers use the same setting parameter.

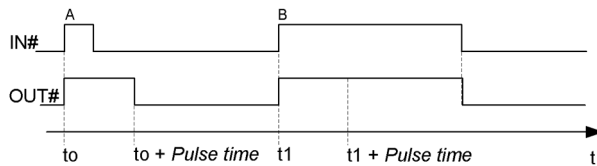


Figure 50: A = Trip pulse is shorter than Pulse time setting, B = Trip pulse is longer than Pulse time setting

### 2.14.4.3 Signals

#### TPSGAPC Input signals

Table 129: TPSGAPC Input signals

| Name | Type    | Default | Description    |
|------|---------|---------|----------------|
| IN1  | BOOLEAN | 0=False | Input 1 status |
| IN2  | BOOLEAN | 0=False | Input 2 status |

#### TPSGAPC Output signals

Table 130: TPSGAPC Output signals

| Name | Type    | Description     |
|------|---------|-----------------|
| OUT1 | BOOLEAN | Output 1 status |
| OUT2 | BOOLEAN | Output 2 status |

### 2.14.4.4 Settings

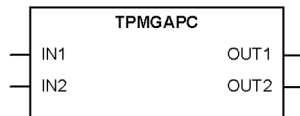
**TPSGAPC Non group settings (Basic)**

**Table 131: TPSGAPC Non group settings (Basic)**

| Parameter  | Values (Range) | Unit | Step | Default | Description        |
|------------|----------------|------|------|---------|--------------------|
| Pulse time | 0...300        | s    | 1    | 150     | Minimum pulse time |

**2.14.5 Minimum pulse timer TPMGAPC**

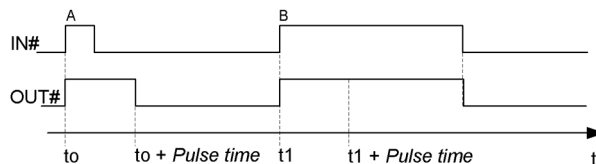
**2.14.5.1 Function block**



*Figure 51: Function block*

**2.14.5.2 Functionality**

The Minimum minute pulse timer function TPMGAPC contains two independent timers. The function has a settable pulse length (in minutes). The timers are used for setting the minimum pulse length for example, the signal outputs. Once the input is activated, the output is set for a specific duration using the Pulse time setting. Both timers use the same setting parameter.



*Figure 52: A = Trip pulse is shorter than Pulse time setting, B = Trip pulse is longer than Pulse time setting*

**2.14.5.3 Signals**

**TPMGAPC Input signals**

**Table 132: TPMGAPC Input signals**

| Name | Type    | Default | Description    |
|------|---------|---------|----------------|
| IN1  | BOOLEAN | 0=False | Input 1 status |
| IN2  | BOOLEAN | 0=False | Input 2 status |

**TPMGAPC Output signals**

**Table 133: TPMGAPC Output signals**

| Name | Type    | Description     |
|------|---------|-----------------|
| OUT1 | BOOLEAN | Output 1 status |
| OUT2 | BOOLEAN | Output 2 status |

**2.14.5.4 Settings**

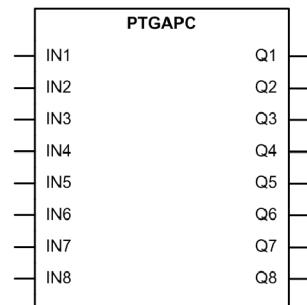
**TPMGAPC Non group settings (Basic)**

**Table 134: TPMGAPC Non group settings (Basic)**

| Parameter  | Values (Range) | Unit | Step | Default | Description        |
|------------|----------------|------|------|---------|--------------------|
| Pulse time | 0...300        | ms   | 1    | 0       | Minimum pulse time |

**2.14.6 Pulse timer function block PTGAPC**

**2.14.6.1 Function block**



*Figure 53: Function block*

**2.14.6.2 Functionality**

The pulse timer function PTGAPC contains eight independent timers. The function has a settable pulse length. Once the input is activated, the output is set for a specific duration using the *Pulse delay time* setting.

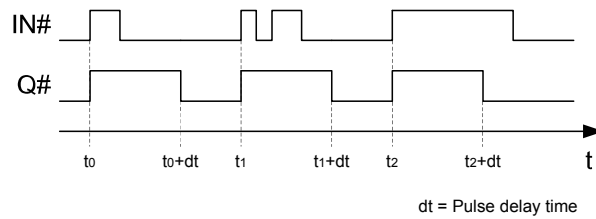


Figure 54: Timer operation

### 2.14.6.3 Signals

#### PTGAPC Input signals

Table 135: PTGAPC Input signals

| Name | Type    | Default | Description    |
|------|---------|---------|----------------|
| IN1  | BOOLEAN | 0=False | Input 1 status |
| IN2  | BOOLEAN | 0=False | Input 2 status |
| IN3  | BOOLEAN | 0=False | Input 3 status |
| IN4  | BOOLEAN | 0=False | Input 4 status |
| IN5  | BOOLEAN | 0=False | Input 5 status |
| IN6  | BOOLEAN | 0=False | Input 6 status |
| IN7  | BOOLEAN | 0=False | Input 7 status |
| IN8  | BOOLEAN | 0=False | Input 8 status |

#### PTGAPC Output signals

Table 136: PTGAPC Output signals

| Name | Type    | Description     |
|------|---------|-----------------|
| OUT1 | BOOLEAN | Output 1 status |
| OUT2 | BOOLEAN | Output 2 status |
| OUT3 | BOOLEAN | Output 3 status |
| OUT4 | BOOLEAN | Output 4 status |
| OUT5 | BOOLEAN | Output 5 status |
| OUT6 | BOOLEAN | Output 6 status |
| OUT7 | BOOLEAN | Output 7 status |
| OUT8 | BOOLEAN | Output 8 status |

### 2.14.6.4 Settings

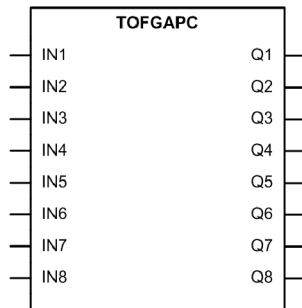
**PTGAPC Non group settings (Basic)**

**Table 137: PTGAPC Non group settings (Basic)**

| Parameter    | Values (Range) | Unit | Step | Default | Description |
|--------------|----------------|------|------|---------|-------------|
| Pulse time 1 | 0...3600000    | ms   | 10   | 0       | Pulse time  |
| Pulse time 2 | 0...3600000    | ms   | 10   | 0       | Pulse time  |
| Pulse time 3 | 0...3600000    | ms   | 10   | 0       | Pulse time  |
| Pulse time 4 | 0...3600000    | ms   | 10   | 0       | Pulse time  |
| Pulse time 5 | 0...3600000    | ms   | 10   | 0       | Pulse time  |
| Pulse time 6 | 0...3600000    | ms   | 10   | 0       | Pulse time  |
| Pulse time 7 | 0...3600000    | ms   | 10   | 0       | Pulse time  |
| Pulse time 8 | 0...3600000    | ms   | 10   | 0       | Pulse time  |

**2.14.7 Time delay off (8 pcs) TOFGAPC**

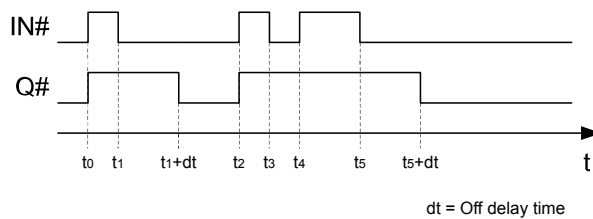
**Function block**



*Figure 55: Function block*

**Functionality**

The time delay off (8 pcs) function TOFGAPC can be used, for example, for a dropoff-delayed output related to the input signal. The function contains eight independent timers. There is a settable delay in the timer. Once the input is activated, the output is set immediately. When the input is cleared, the output stays on until the time set with the *Off delay time* setting has elapsed.



*Figure 56: Timer operation*

## Signals

**Table 138: TOFGAPC Input signals**

| Name | Type    | Default | Description    |
|------|---------|---------|----------------|
| IN1  | BOOLEAN | 0=False | Input 1 status |
| IN2  | BOOLEAN | 0=False | Input 2 status |
| IN3  | BOOLEAN | 0=False | Input 3 status |
| IN4  | BOOLEAN | 0=False | Input 4 status |
| IN5  | BOOLEAN | 0=False | Input 5 status |
| IN6  | BOOLEAN | 0=False | Input 6 status |
| IN7  | BOOLEAN | 0=False | Input 7 status |
| IN8  | BOOLEAN | 0=False | Input 8 status |

**Table 139: TOFGAPC Output signals**

| Name | Type    | Description     |
|------|---------|-----------------|
| OUT1 | BOOLEAN | Output 1 status |
| OUT2 | BOOLEAN | Output 2 status |
| OUT3 | BOOLEAN | Output 3 status |
| OUT4 | BOOLEAN | Output 4 status |
| OUT5 | BOOLEAN | Output 5 status |
| OUT6 | BOOLEAN | Output 6 status |
| OUT7 | BOOLEAN | Output 7 status |
| OUT8 | BOOLEAN | Output 8 status |

## Settings

**Table 140: TOFGAPC Non group settings (Basic)**

| Parameter        | Values (Range) | Unit | Step | Default | Description    |
|------------------|----------------|------|------|---------|----------------|
| Off delay time 1 | 0...3600000    | ms   | 10   | 0       | Off delay time |
| Off delay time 2 | 0...3600000    | ms   | 10   | 0       | Off delay time |
| Off delay time 3 | 0...3600000    | ms   | 10   | 0       | Off delay time |
| Off delay time 4 | 0...3600000    | ms   | 10   | 0       | Off delay time |
| Off delay time 5 | 0...3600000    | ms   | 10   | 0       | Off delay time |
| Off delay time 6 | 0...3600000    | ms   | 10   | 0       | Off delay time |

*Table continues on the next page*

| Parameter        | Values (Range) | Unit | Step | Default | Description    |
|------------------|----------------|------|------|---------|----------------|
| Off delay time 7 | 0...3600000    | ms   | 10   | 0       | Off delay time |
| Off delay time 8 | 0...3600000    | ms   | 10   | 0       | Off delay time |

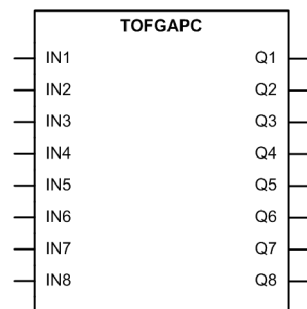
**Technical data**

**Table 141: TOFGAPC Technical data**

| Characteristic        | Value                            |
|-----------------------|----------------------------------|
| Operate time accuracy | ±1.0% of the set value or ±20 ms |

**2.14.7.1**

**Function block**

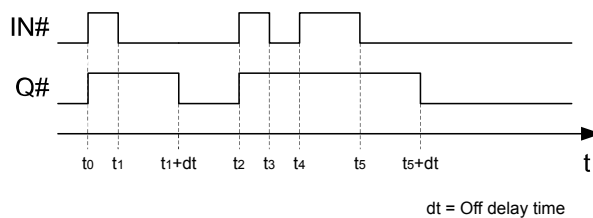


*Figure 57: Function block*

**2.14.7.2**

**Functionality**

The time delay off (8 pcs) function TOFGAPC can be used, for example, for a dropoff-delayed output related to the input signal. The function contains eight independent timers. There is a settable delay in the timer. Once the input is activated, the output is set immediately. When the input is cleared, the output stays on until the time set with the *Off delay time* setting has elapsed.



*Figure 58: Timer operation*

**2.14.7.3**

**Signals**



2.14.7.4 Settings

2.14.8 Time delay on (8 pcs) TONGAPC

Function block

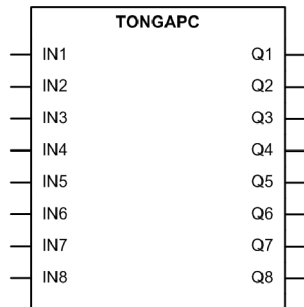


Figure 59: Function block

Functionality

The time delay on (8 pcs) function TONGAPC can be used, for example, for time delaying the output related to the input signal. TONGAPC contains eight independent timers. The timer has a settable time delay. Once the input is activated, the output is set after the time set by the On delay time setting has elapsed.

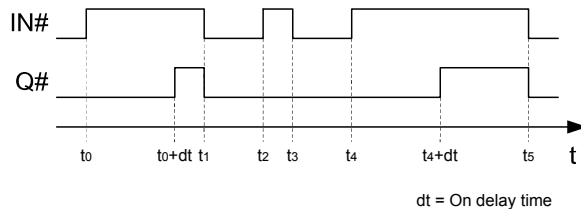


Figure 60: Timer operation

Signals

Table 142: TONGAPC Input signals

| Name | Type    | Default | Description |
|------|---------|---------|-------------|
| IN1  | BOOLEAN | 0=False | Input 1     |
| IN2  | BOOLEAN | 0=False | Input 2     |
| IN3  | BOOLEAN | 0=False | Input 3     |
| IN4  | BOOLEAN | 0=False | Input 4     |
| IN5  | BOOLEAN | 0=False | Input 5     |
| IN6  | BOOLEAN | 0=False | Input 6     |
| IN7  | BOOLEAN | 0=False | Input 7     |
| IN8  | BOOLEAN | 0=False | Input 8     |

**Table 143: TONGAPC Output signals**

| Name | Type    | Description |
|------|---------|-------------|
| Q1   | BOOLEAN | Output 1    |
| Q2   | BOOLEAN | Output 2    |
| Q3   | BOOLEAN | Output 3    |
| Q4   | BOOLEAN | Output 4    |
| Q5   | BOOLEAN | Output 5    |
| Q6   | BOOLEAN | Output 6    |
| Q7   | BOOLEAN | Output 7    |
| Q8   | BOOLEAN | Output 8    |

### Settings

**Table 144: TONGAPC Non group settings (Basic)**

| Parameter       | Values (Range) | Unit | Step | Default | Description   |
|-----------------|----------------|------|------|---------|---------------|
| On delay time 1 | 0...3600000    | ms   | 10   | 0       | On delay time |
| On delay time 2 | 0...3600000    | ms   | 10   | 0       | On delay time |
| On delay time 3 | 0...3600000    | ms   | 10   | 0       | On delay time |
| On delay time 4 | 0...3600000    | ms   | 10   | 0       | On delay time |
| On delay time 5 | 0...3600000    | ms   | 10   | 0       | On delay time |
| On delay time 6 | 0...3600000    | ms   | 10   | 0       | On delay time |
| On delay time 7 | 0...3600000    | ms   | 10   | 0       | On delay time |
| On delay time 8 | 0...3600000    | ms   | 10   | 0       | On delay time |

### Technical data

**Table 145: TONGAPC Technical data**

| Characteristic        | Value                            |
|-----------------------|----------------------------------|
| Operate time accuracy | ±1.0% of the set value or ±20 ms |

## 2.14.9 Set-reset (8 pcs) SRGAPC

Function block

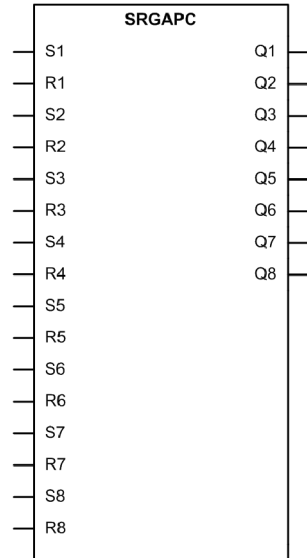


Figure 61: Function block

### Functionality

The set-reset (8 pcs) function SRGAPC is a simple SR flip-flop with a memory that can be set or that can reset an output from the S# or R# inputs, respectively. The function contains eight independent set-reset flip-flop latches where the SET input has the higher priority over the RESET input. The status of each Q# output is retained in the nonvolatile memory. The individual reset for each Q# output is available on the WHMI or through tool via communication

Table 146: Truth table for SRGAPC

| S# | R# | Q#              |
|----|----|-----------------|
| 0  | 0  | 0 <sup>15</sup> |
| 0  | 1  | 0               |
| 1  | 0  | 1               |
| 1  | 1  | 1               |

<sup>15</sup> Keep state/no change

## Signals

**Table 147: SRGAPC Input signals**

| Name | Type    | Default | Description               |
|------|---------|---------|---------------------------|
| S1   | BOOLEAN | 0=False | Set Q1 output when set    |
| R1   | BOOLEAN | 0=False | Resets Q1 output when set |
| S2   | BOOLEAN | 0=False | Set Q2 output when set    |
| R2   | BOOLEAN | 0=False | Resets Q2 output when set |
| S3   | BOOLEAN | 0=False | Set Q3 output when set    |
| R3   | BOOLEAN | 0=False | Resets Q3 output when set |
| S4   | BOOLEAN | 0=False | Set Q4 output when set    |
| R4   | BOOLEAN | 0=False | Resets Q4 output when set |
| S5   | BOOLEAN | 0=False | Set Q5 output when set    |
| R5   | BOOLEAN | 0=False | Resets Q5 output when set |
| S6   | BOOLEAN | 0=False | Set Q6 output when set    |
| R6   | BOOLEAN | 0=False | Resets Q6 output when set |
| S7   | BOOLEAN | 0=False | Set Q7 output when set    |
| R7   | BOOLEAN | 0=False | Resets Q7 output when set |
| S8   | BOOLEAN | 0=False | Set Q8 output when set    |
| R8   | BOOLEAN | 0=False | Resets Q8 output when set |

**Table 148: SRGAPC Output signals**

| Name | Type    | Description |
|------|---------|-------------|
| Q1   | BOOLEAN | Q1 status   |
| Q2   | BOOLEAN | Q2 status   |
| Q3   | BOOLEAN | Q3 status   |
| Q4   | BOOLEAN | Q4 status   |
| Q5   | BOOLEAN | Q5 status   |

*Table continues on the next page*

| Name | Type    | Description |
|------|---------|-------------|
| Q6   | BOOLEAN | Q6 status   |
| Q7   | BOOLEAN | Q7 status   |
| Q8   | BOOLEAN | Q8 status   |

### Settings

**Table 149: SRGAPC Non group settings (Basic)**

| Parameter | Values (Range)      | Unit | Step | Default  | Description               |
|-----------|---------------------|------|------|----------|---------------------------|
| Reset Q1  | 0=Cancel<br>1=Reset |      |      | 0=Cancel | Resets Q1 output when set |
| Reset Q2  | 0=Cancel<br>1=Reset |      |      | 0=Cancel | Resets Q2 output when set |
| Reset Q3  | 0=Cancel<br>1=Reset |      |      | 0=Cancel | Resets Q3 output when set |
| Reset Q4  | 0=Cancel<br>1=Reset |      |      | 0=Cancel | Resets Q4 output when set |
| Reset Q5  | 0=Cancel<br>1=Reset |      |      | 0=Cancel | Resets Q5 output when set |
| Reset Q6  | 0=Cancel<br>1=Reset |      |      | 0=Cancel | Resets Q6 output when set |
| Reset Q7  | 0=Cancel<br>1=Reset |      |      | 0=Cancel | Resets Q7 output when set |
| Reset Q8  | 0=Cancel<br>1=Reset |      |      | 0=Cancel | Resets Q8 output when set |

### Technical data

**Table 150: TONGAPC Technical data**

| Characteristic        | Value                                       |
|-----------------------|---|
| Operate time accuracy | $\pm 1.0\%$ of the set value or $\pm 20$ ms |

### 2.14.10 Move (8 pcs) MVGAPC

**Function block**

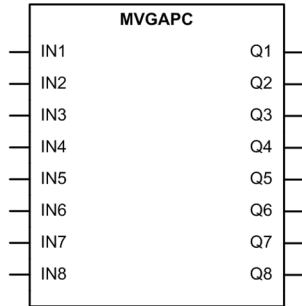


Figure 62: Function block

**Functionality**

The move (8 pcs) function MVGAPC is used for user logic bits. Each input state is directly copied to the output state. This allows the creating of events from advanced logic combinations.

**Signals**

Table 151: MVGAPC Output signals

| Name | Type    | Description |
|------|---------|-------------|
| Q1   | BOOLEAN | Q1 status   |
| Q2   | BOOLEAN | Q2 status   |
| Q3   | BOOLEAN | Q3 status   |
| Q4   | BOOLEAN | Q4 status   |
| Q5   | BOOLEAN | Q5 status   |
| Q6   | BOOLEAN | Q6 status   |
| Q7   | BOOLEAN | Q7 status   |
| Q8   | BOOLEAN | Q8 status   |

**Settings**

Table 152: MVGAPC Non group settings (Basic)

| Parameter   | Values (Range) | Unit | Step | Default    | Description        |
|-------------|----------------|------|------|------------|--------------------|
| Description |                |      |      | MVGAPC1 Q1 | Output description |
| Description |                |      |      | MVGAPC1 Q2 | Output description |
| Description |                |      |      | MVGAPC1 Q3 | Output description |

Table continues on the next page

| Parameter   | Values (Range) | Unit | Step | Default    | Description        |
|-------------|----------------|------|------|------------|--------------------|
| Description |                |      |      | MVGAPC1 Q4 | Output description |
| Description |                |      |      | MVGAPC1 Q5 | Output description |
| Description |                |      |      | MVGAPC1 Q6 | Output description |
| Description |                |      |      | MVGAPC1 Q7 | Output description |
| Description |                |      |      | MVGAPC1 Q8 | Output description |

### 2.14.11 Integer value move MVI4GAPC

#### Function block

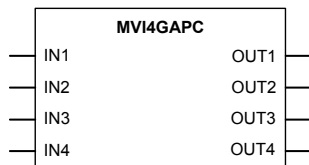


Figure 63: Function block

#### Functionality

The integer value move function MVI4GAPC is used for creation of the events from the integer values. The integer input value is received via IN1 . . . 4 input. The integer output value is available on OUT1 . . . 4 output.



The integer input range is from -2147483648 to 2147483647.

#### Signals

Table 153: MVI4GAPC Input signals

| Name | Type  | Default | Description           |
|------|-------|---------|-----------------------|
| IN1  | INT32 | 0       | Integer input value 1 |
| IN2  | INT32 | 0       | Integer input value 2 |
| IN3  | INT32 | 0       | Integer input value 3 |
| IN4  | INT32 | 0       | Integer input value 4 |

**Table 154: MVI4GAPC Output signals**

| Name | Type  | Description            |
|------|-------|------------------------|
| OUT1 | INT32 | Integer output value 1 |
| OUT2 | INT32 | Integer output value 2 |
| OUT3 | INT32 | Integer output value 3 |
| OUT4 | INT32 | Integer output value 4 |

### 2.14.12 Analog value scaling SCA4GAPC

**Function block**

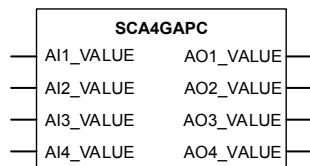


Figure 64: Function block

**Functionality**

The analog value scaling function SCA4GAPC is used for scaling the analog value. It allows creating events from analog values.

The analog value received via the *AI<sub>n</sub>\_VALUE* input is scaled with the *Scale ratio n* setting. The scaled value is available on the *AO<sub>n</sub>\_VALUE* output.



Analog input range is from -10000.0 to 10000.0



Analog output range is from -2000000.0 to 2000000.0.



If the value of the *AI<sub>n</sub>\_VALUE* input exceeds the analog input range, *AO<sub>n</sub>\_VALUE* is set to 0.0.



If the result of *AI<sub>n</sub>\_VALUE* multiplied by the *Scale ratio n* setting exceeds the analog output range, *AO<sub>n</sub>\_VALUE* shows the minimum or maximum value, according to analog value range.



## Signals

**Table 155: SCA4GAPC Input signals**

| Name      | Type    | Default | Description                     |
|-----------|---------|---------|---------------------------------|
| AI1_VALUE | FLOAT32 | 0.0     | Analog input value of channel 1 |
| AI2_VALUE | FLOAT32 | 0.0     | Analog input value of channel 2 |
| AI3_VALUE | FLOAT32 | 0.0     | Analog input value of channel 3 |
| AI4_VALUE | FLOAT32 | 0.0     | Analog input value of channel 4 |

**Table 156: SCA4GAPC Output signals**

| Name      | Type    | Description                  |
|-----------|---------|------------------------------|
| AO1_VALUE | FLOAT32 | Analog value 1 after scaling |
| AO2_VALUE | FLOAT32 | Analog value 2 after scaling |
| AO3_VALUE | FLOAT32 | Analog value 3 after scaling |
| AO4_VALUE | FLOAT32 | Analog value 4 after scaling |

## Settings

**Table 157: SCA4GAPC Non group settings (Basic)**

| Parameter     | Values (Range)   | Unit | Step  | Default | Description                    |
|---------------|------------------|------|-------|---------|--------------------------------|
| Scale ratio 1 | 0.001...1000.000 |      | 0.001 | 1.000   | Scale ratio for analog value 1 |
| Scale ratio 2 | 0.001...1000.000 |      | 0.001 | 1.000   | Scale ratio for analog value 2 |
| Scale ratio 3 | 0.001...1000.000 |      | 0.001 | 1.000   | Scale ratio for analog value 3 |
| Scale ratio 4 | 0.001...1000.000 |      | 0.001 | 1.000   | Scale ratio for analog value 4 |

### 2.14.13

## Local/remote control function block CONTROL

### 2.14.13.1 Function block

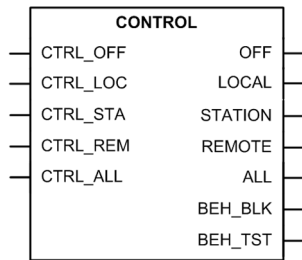


Figure 65: Function block

### 2.14.13.2 Functionality

Local/Remote control is by default realized through the control via binary input. The binary input control requires that the CONTROL function is instantiated in the product configuration.

Local/Remote control supports multilevel access for control operations in substations according to the IEC 61850 standard. Multilevel control access with separate station control access level is not supported by other protocols than IEC 61850.

The actual Local/Remote control state is evaluated by the priority scheme on the function block inputs. If more than one input is active, the input with the highest priority is selected. The priority order is “off”, “local”, “station”, “remote”, “all”.

The actual state is reflected on the CONTROL function outputs. Only one output is active at a time.

Table 158: Truth table for CONTROL

| Input    |          |          |          |          | Output         |
|----------|----------|----------|----------|----------|----------------|
| CTRL_OFF | CTRL_LOC | CTRL_STA | CTRL_REM | CTRL_ALL |                |
| TRUE     | N/A      | N/A      | N/A      | N/A      | OFF = TRUE     |
| FALSE    | TRUE     | N/A      | N/A      | N/A      | LOCAL = TRUE   |
| FALSE    | FALSE    | TRUE     | N/A      | N/A      | STATION = TRUE |
| FALSE    | FALSE    | FALSE    | TRUE     | TRUE     | REMOTE = TRUE  |
| FALSE    | FALSE    | FALSE    | FALSE    | TRUE     | ALL = TRUE     |
| FALSE    | FALSE    | FALSE    | FALSE    | FALSE    | OFF = TRUE     |

### 2.14.13.3 L/R control access

Four different Local/Remote control access scenarios are possible depending on the selected station authority level: “L,R”, “L,R,L+R”, “L,S,R” and “L, S, S+R, L+S, L+S+R”. If control commands need to be allowed from multiple levels, multilevel access can be used. Multilevel access is possible only by using the station authority levels “L,R,L+R” and “L, S, S+R, L+S, L+S+R”. Multilevel access status is available from IEC 61850 data object CTRL.LLN0.MltLev.

Control access selection is made with R/L button or CONTROL function block and IEC 61850 data object CTRL.LLN0.LocSta. When writing CTRL.LLN0.LocSta IEC 61850 data object, IEC 61850 command originator category station must be used by the client, and remote IEC 61850 control access must be allowed by the relay station authority. CTRL.LLN0.LocSta data object value is retained in the nonvolatile memory. The present control status can be monitored in the HMI or PCM600 via **Monitoring > Control command** with the *LR state* parameter or from the IEC 61850 data object CTRL.LLN0.LocKeyHMI.

IEC 61850 command originator category is always set by the IEC 61850 client. The relay supports station and remote IEC 61850 command originator categories, depending on the selected station authority level.

**2.14.13.4 Station authority level “L,R”**

Relay default station authority level is “L,R”. In this scenario only local or remote control access is allowed. Control access with IEC61850 command originator category station is interpreted as remote access. There is no multilevel access

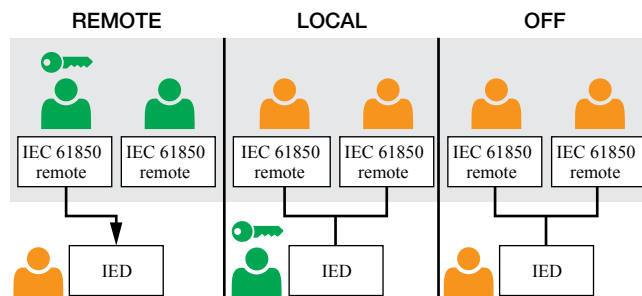


Figure 66: Station authority is “L,R”

When station authority level “L,R” is used, control access can be selected using R/L button or CONTROL function block. IEC 61850 data object CTRL.LLN0.LocSta and CONTROL function block inputs CTRL\_STA and CTRL\_ALL are not applicable for this station authority level.

**Table 159: Station authority level “L,R” using R/L button**

| L/R control |                  | L/R control status |                                | Control access |                               |
|-------------|------------------|--------------------|--------------------------------|----------------|-------------------------------|
| R/L button  | CTRL.LLN0.LocSta | CTRL.LLN0.MltLev   | L/R state CTRL.LLN0.LocKey HMI | Local user     | IEC 61850 client <sup>1</sup> |
| Local       | N/A              | FALSE              | 1                              | x              |                               |
| Remote      | N/A              | FALSE              | 2                              |                | x                             |
| Off         | N/A              | FALSE              | 0                              |                |                               |

<sup>1</sup> Client IEC 61850 command originator category check is not performed.

**Table 160: Station authority “L,R” using CONTROL function block**

| L/R control      |                  | L/R control status |                                      | Control access |                               |
|------------------|------------------|--------------------|--------------------------------------|----------------|-------------------------------|
| Control FB input | CTRL.LLN0.LocSta | CTRL.LLN0.MltLev   | L/R state<br>CTRL.LLN0.LocKey<br>HMI | Local user     | IEC 61850 client <sup>2</sup> |
| CTRL_OFF         | N/A              | FALSE              | 0                                    |                |                               |
| CTRL_LOC         | N/A              | FALSE              | 1                                    | x              |                               |
| CTRL_STA         | N/A              | FALSE              | 0                                    |                |                               |
| CTRL_REM         | N/A              | FALSE              | 2                                    |                | x                             |
| CTRL_ALL         | N/A              | FALSE              | 0                                    |                |                               |

<sup>2</sup> Client IEC 61850 command originator category check is not performed.

### 2.14.13.5 Station authority level "L,R,L+R"

Station authority level "L,R, L+R" adds multilevel access support. Control access can also be simultaneously permitted from local or remote location. Simultaneous local or remote control operation is not allowed as one client and location at time can access controllable objects and they remain reserved until the previously started control operation is first completed by the client. Control access with IEC61850 originator category station is interpreted as remote access.

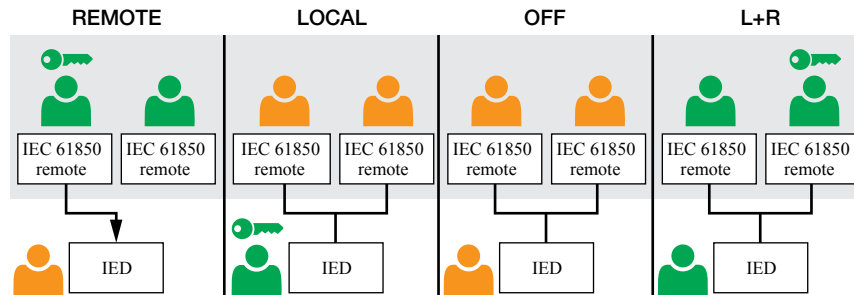


Figure 67: Station authority is "L,R,L+R"

When station authority level "L,R, L+R" is used, the control access can be selected using R/L button or CONTROL function block. IEC 61850 data object CTRL.LLN0.LocSta and CONTROL function block input CTRL\_STA are not applicable for this station authority level.

Table 161: Station authority level "L,R,L+R" using R/L button

| L/R Control    |                  | L/R Control status |                                      | Control access |                               |
|----------------|------------------|--------------------|--------------------------------------|----------------|-------------------------------|
| R/L button     | CTRL.LLN0.LocSta | CTRL.LLN0.MitLev   | L/R state<br>CTRL.LLN0.LocKey<br>HMI | Local user     | IEC 61850 client <sup>1</sup> |
| Local          | N/A              | FALSE              | 1                                    | x              |                               |
| Remote         | N/A              | FALSE              | 2                                    |                | x                             |
| Local + Remote | N/A              | TRUE               | 4                                    | x              | x                             |
| Off            | N/A              | FALSE              | 0                                    |                |                               |

Table 162: Station authority "L,R,L+R" using CONTROL function block

| L/R Control      |                  | L/R Control status |                                      | Control access |                               |
|------------------|------------------|--------------------|--------------------------------------|----------------|-------------------------------|
| Control FB input | CTRL.LLN0.LocSta | CTRL.LLN0.MitLev   | L/R state<br>CTRL.LLN0.LocKey<br>HMI | Local user     | IEC 61850 client <sup>2</sup> |
| CTRL_OFF         | N/A              | FALSE              | 0                                    |                |                               |
| CTRL_LOC         | N/A              | FALSE              | 1                                    | x              |                               |
| CTRL_STA         | N/A              | FALSE              | 0                                    |                |                               |
| CTRL_REM         | N/A              | FALSE              | 2                                    |                | x                             |
| CTRL_ALL         | N/A              | TRUE               | 4                                    | x              | x                             |

<sup>1</sup> Client IEC 61850 command originator category check is not performed.

<sup>2</sup> Client IEC 61850 command originator category check is not performed.

### 2.14.13.6 Station authority level "L,S,R"

Station authority level "L,S,R" adds station control access. In this level IEC 61850 command originator category validation is performed to distinguish control commands with IEC 61850 command originator category set to "Remote" or "Station". There is no multilevel access.

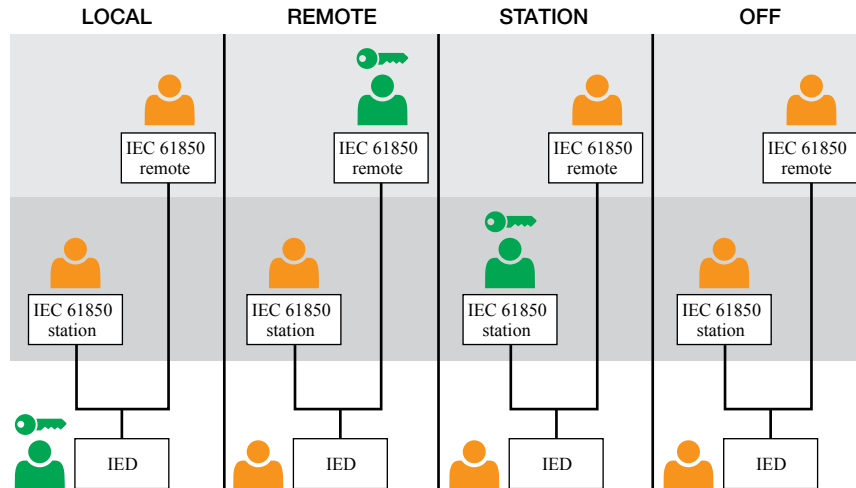


Figure 68: Station authority is "L,S,R"

When the station authority level "L,S,R" is used, the control access can be selected using R/L button or CONTROL function block. IEC 61850 data object CTRL.LLN0.LocSta and CONTROL function block input CTRL\_STA are applicable for this station authority level.

Station control access can be reserved by using R/L button or CONTROL function block together with IEC 61850 data object CTRL.LLN0.LocSta

Table 163: Station authority level "L,S,R" using R/L button

| L/R Control |                               | L/R Control status |                               | Control access |                               |                               |
|-------------|-------------------------------|--------------------|-------------------------------|----------------|-------------------------------|-------------------------------|
| R/L button  | CTRL.LLN0.LocSta <sup>1</sup> | CTRL.LLN0.MitLev   | L/R state CTRL.LLN0.LocKeyHMI | Local user     | IEC 61850 client <sup>2</sup> | IEC 61850 client <sup>3</sup> |
| Local       | FALSE                         | FALSE              | 1                             | x              |                               |                               |
| Remote      | FALSE                         | FALSE              | 2                             |                | x                             |                               |
| Remote      | TRUE                          | FALSE              | 3                             |                |                               | x                             |
| Off         | FALSE                         | FALSE              | 0                             |                |                               |                               |

<sup>1</sup> Station client reserves the control operating by writing controllable point LocSta.

<sup>2</sup> Client IEC 61850 command originator category is remote.

<sup>3</sup> Client IEC 61850 command originator category is station.

**Table 164: Station authority level “L,S,R” using CONTROL function block**

| L/R Control           |                               | L/R Control status |                                  | Control access |                               |                               |
|-----------------------|-------------------------------|--------------------|----------------------------------|----------------|-------------------------------|-------------------------------|
| R/L button            | CTRL.LLN0.LocSta <sup>4</sup> | CTRL.LLN0.MitLev   | L/R state<br>CTRL.LLN0.LocKeyHMI | Local user     | IEC 61850 client <sup>5</sup> | IEC 61850 client <sup>6</sup> |
| CTRL_OFF              | FALSE                         | FALSE              | 0                                |                |                               |                               |
| CTRL_LOC              | FALSE                         | FALSE              | 1                                | x              |                               |                               |
| CTRL_STA              | TRUE                          | FALSE              | 3                                |                |                               |                               |
| CTRL_REM <sup>7</sup> | TRUE                          | FALSE              | 3                                |                |                               | x                             |
| CTRL_REM              | FALSE                         | FALSE              | 2                                |                | x                             |                               |
| CTRL_ALL              | FALSE                         | FALSE              | 0                                |                |                               |                               |

### 2.14.13.7 Station authority level “L,S,S+R,L+S,L+S+R”

Station authority level "L,S,S+R,L+S,L+S+R" adds station control access together with several different multilevel access scenarios. Control access can also be simultaneously permitted from local, station or remote location. Simultaneous local, station or remote control operation is not allowed as one client and location at time can access controllable objects and they remain reserved until the previously started control operation is first completed by the client.

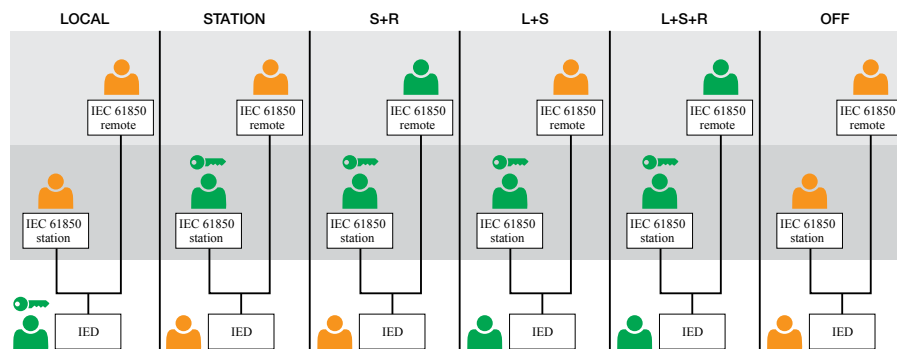


Figure 69: Station authority is “L,S,S+R,L+S,L+S+R”

When station authority level “L,S,S+R,L+S,L+S+R” is used, control access can be selected using R/L button or CONTROL function block. IEC 61850 data object CTRL.LLN0.LocSta and CONTROL function block input CTRL\_STA are applicable for this station authority level.

“Station” and “Local + Station” control access can be reserved by using R/L button or CONTROL function block in combination with IEC 61850 data object CTRL.LLN0.LocSta.

<sup>4</sup> Station client reserves the control operating by writing controllable point LocSta.

<sup>5</sup> Client IEC 61850 command originator category is remote.

<sup>6</sup> Client IEC 61850 command originator category is station.

<sup>7</sup> CTRL\_STA unconnected in application configuration. Station client reserves the control operating by writing controllable point LocSta.

**Table 165: Station authority level “L,S,S+R,L+S,L+S+R” using R/L button**

| L/R Control    |                               | L/R Control status |                                  | Control access |                               |                               |
|----------------|-------------------------------|--------------------|----------------------------------|----------------|-------------------------------|-------------------------------|
| R/L button     | CTRL.LLN0.LocSta <sup>1</sup> | CTRL.LLN0.MitLev   | L/R state<br>CTRL.LLN0.LocKeyHMI | Local user     | IEC 61850 client <sup>2</sup> | IEC 61850 client <sup>3</sup> |
| Local          | FALSE                         | FALSE              | 1                                | x              |                               |                               |
| Remote         | FALSE                         | TRUE               | 7                                |                | x                             | x                             |
| Remote         | TRUE                          | FALSE              | 3                                |                |                               | x                             |
| Local + Remote | FALSE                         | TRUE               | 6                                | x              | x                             | x                             |
| Local + Remote | TRUE                          | TRUE               | 5                                | x              |                               | x                             |
| Off            | FALSE                         | FALSE              | 0                                |                |                               |                               |

**Table 166: Station authority level “L,S,S+R,L+S,L+S+R” using CONTROL function block**

| L/R Control           |                               | L/R Control status |                                  | Control access |                               |                               |
|-----------------------|-------------------------------|--------------------|----------------------------------|----------------|-------------------------------|-------------------------------|
| R/L button            | CTRL.LLN0.LocSta <sup>4</sup> | CTRL.LLN0.MitLev   | L/R state<br>CTRL.LLN0.LocKeyHMI | Local user     | IEC 61850 client <sup>5</sup> | IEC 61850 client <sup>6</sup> |
| CTRL_OFF              | FALSE                         | FALSE              | 0                                |                |                               |                               |
| CTRL_LOC              | FALSE                         | FALSE              | 1                                | x              |                               |                               |
| CTRL_STA              | FALSE                         | FALSE              | 3                                |                |                               | x                             |
| CTRL_REM <sup>7</sup> | TRUE                          | TRUE               | 3                                |                |                               | x                             |
| CTRL_REM              | FALSE                         | TRUE               | 7                                |                | x                             | x                             |
| CTRL_ALL              | FALSE                         | TRUE               | 6                                | x              | x                             | x                             |
| CTRL_ALL <sup>7</sup> | TRUE                          | TRUE               | 5                                | x              |                               | x                             |

### 2.14.13.8 Signals

#### CONTROL input signals

**Table 167: CONTROL input signals**

| Name     | Type    | Default | Description           |
|----------|---------|---------|-----------------------|
| CTRL_OFF | BOOLEAN | 0       | Control input OFF     |
| CTRL_LOC | BOOLEAN | 0       | Control input Local   |
| CTRL_STA | BOOLEAN | 0       | Control input Station |
| CTRL_REM | BOOLEAN | 0       | Control input Remote  |
| CTRL_ALL | BOOLEAN | 0       | Control input All     |

<sup>1</sup> Station client reserves the control operating by writing controllable point LocSta.

<sup>2</sup> Client IEC 61850 command originator category is remote.

<sup>3</sup> Client IEC 61850 command originator category is station.

<sup>4</sup> Station client reserves the control operating by writing controllable point LocSta.

<sup>5</sup> Client IEC 61850 command originator category is remote.

<sup>6</sup> Client IEC 61850 command originator category is station.

<sup>7</sup> CTRL\_STA unconnected in application configuration. Station client reserves the control operating by writing controllable point LocSta.



**CONTROL output signals****Table 168: CONTROL output signals**

| Name    | Type    | Description            |
|---------|---------|------------------------|
| OFF     | BOOLEAN | Control output OFF     |
| LOCAL   | BOOLEAN | Control output Local   |
| STATION | BOOLEAN | Control output Station |
| REMOTE  | BOOLEAN | Control output Remote  |
| ALL     | BOOLEAN | Control output All     |

**2.14.13.9****Settings****CONTROL Settings****Table 169: Non group settings**

| Parameter         | Values (Range)  | Unit | Step | Default        | Description                               |
|-------------------|---|------|------|----------------|---|
| LR control        | 2=Binary input  |      |      | 2=Binary input | LR control through binary input           |
| Station authority | 1=L,R<br>2=L,S,R<br>3=L,R,L+R<br>4=L,S,S+R,L+S<br>,L +S+R |      |      | 1=L,R          | Control command originator category usage |
| Control mode      | 1=On<br>2=Blocked<br>5=Off                                |      |      | 1=On           | Enabling and disabling control            |

**2.14.13.10****Monitored data****CONTROL Monitored data****Table 170: Monitored data**

| Name             | Type | Values (Range)   | Unit | Description             |
|------------------|------|--|------|-------------------------|
| Command response | Enum | 0=No commands<br>1=Select open<br>2=Select close<br>3=Operate open |      | Latest command response |

*Table continues on the next page*

| Name     | Type | Values (Range)   | Unit | Description         |
|----------|------|--|------|---------------------|
|          |      | 4=Operate close<br>5=Direct open<br>6=Direct close<br>7=Cancel<br>8=Position reached<br>9=Position time-out<br>10=Object status only<br>11=Object direct<br>12=Object select<br>13=RL local allowed<br>14=RL remote allowed<br>15=RL off<br>16=Function off<br>17=Function blocked<br>18=Command progress<br>19=Select time-out<br>20=Missing authority<br>21=Close not enabled<br>22=Open not enabled<br>23=Internal fault<br>24=Already close<br>25=Wrong client<br>26=RL station allowed<br>27=RL change<br>28=Abortion by trip |      |                     |
| LR state | Enum | 0=Off<br>1=Local<br>2=Remote   |      | LR state monitoring |

| Name | Type | Values (Range)                                  | Unit | Description |
|------|------|---|------|-------------|
|      |      | 3=Station<br>4=L+R<br>5=L+S<br>6=L+S+R<br>7=S+R |      |             |

The actual Local/Remote control state is evaluated by the priority scheme on the function block inputs. If more than one input is active, the input with the highest priority is selected. The priority order is “off”, “local”, “station”, “remote”, “all”.



Also the FALSE inputs needs to have an connection in Application Configuration.

### 2.14.13.11 Technical revision history

Table 171: CONTROL Technical revision history

| Technical revision | Change              |
|--------------------|---------------------|
| B                  | Modified for SSC600 |

## 2.14.14 Generic control point (16 pcs) SPCGAPC

### 2.14.14.1 Function block

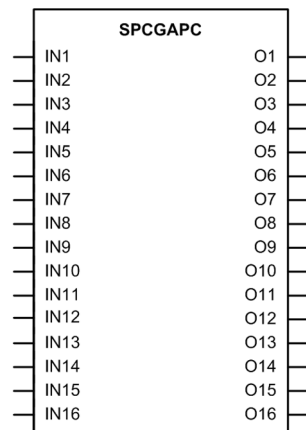


Figure 70: Function block

### 2.14.14.2 Functionality

The generic control points function SPCGAPC contains 16 independent control points. SPCGAPC offers the capability to activate its outputs through a local or

remote control. The local control request can be issued through the buttons in the single-line diagram or via inputs and the remote control request through communication. The rising edge of the input signal is interpreted as a control request, and the output operation is triggered. When remote control requests are used the control points behaves as persistent.

The *Loc Rem restriction* setting is used for enabling or disabling the restriction for SPCGAPC to follow the R/L button state. If *Loc Rem restriction* is "True", as it is by default, the local or remote control operations are accepted according to the R/L button state.

Each of the 16 generic control point outputs has the *Operation mode*, *Pulse length* and *Description* setting. If *Operation mode* is "Toggle", the output state is toggled for every control request received. If *Operation mode* is "Pulsed", the output pulse of a preset duration (the *Pulse length* setting) is generated for every control request received. The *Description* setting can be used for storing information on the actual use of the control point in application, for instance.

For example, if the *Operation mode* is "Toggle", the output O# is initially "False". The rising edge in IN# sets O# to "True". The falling edge of IN# has no effect. Next rising edge of IN# sets O# to "False".

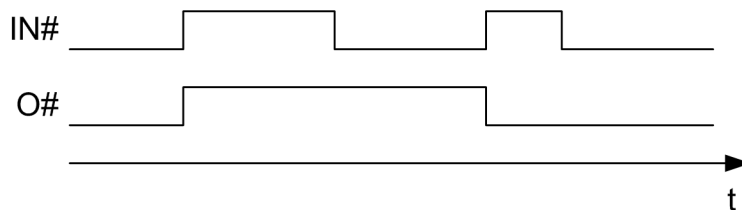


Figure 71: Operation in "Toggle" mode

The BLOCK input can be used for blocking the functionality of the outputs. The operation of the BLOCK input depends on the *Operation mode* setting. If *Operation mode* is "Toggle", the output state freezes and cannot be changed while the BLOCK input is active. If *Operation mode* is "Pulsed", the activation of the BLOCK input resets the outputs to the "False" state and further control requests are ignored while the BLOCK input is active.



From the remote communication point of view SPCGAPC toggled operation mode is always working as persistent mode. The output O# follows the value written to the input IN#.

### 2.14.14.3 Signals

**SPCGAPC Input signals****Table 172: SPCGAPC Input signals**

| Name  | Type    | Default | Description                                   |
|-------|---------|---------|---|
| BLOCK | BOOLEAN | 0=False | Block signal for activating the blocking mode |
| IN1   | BOOLEAN | 0=False | Input of control point 1                      |
| IN2   | BOOLEAN | 0=False | Input of control point 2                      |
| IN3   | BOOLEAN | 0=False | Input of control point 3                      |
| IN4   | BOOLEAN | 0=False | Input of control point 4                      |
| IN5   | BOOLEAN | 0=False | Input of control point 5                      |
| IN6   | BOOLEAN | 0=False | Input of control point 6                      |
| IN7   | BOOLEAN | 0=False | Input of control point 7                      |
| IN8   | BOOLEAN | 0=False | Input of control point 8                      |
| IN9   | BOOLEAN | 0=False | Input of control point 9                      |
| IN10  | BOOLEAN | 0=False | Input of control point 10                     |
| IN11  | BOOLEAN | 0=False | Input of control point 11                     |
| IN12  | BOOLEAN | 0=False | Input of control point 12                     |
| IN13  | BOOLEAN | 0=False | Input of control point 13                     |
| IN14  | BOOLEAN | 0=False | Input of control point 14                     |
| IN15  | BOOLEAN | 0=False | Input of control point 15                     |
| IN16  | BOOLEAN | 0=False | Input of control point 16                     |

**SPCGAPC Output signals****Table 173: SPCGAPC Output signals**

| Name | Type    | Description      |
|------|---------|------------------|
| O1   | BOOLEAN | Output 1 status  |
| O2   | BOOLEAN | Output 2 status  |
| O3   | BOOLEAN | Output 3 status  |
| O4   | BOOLEAN | Output 4 status  |
| O5   | BOOLEAN | Output 5 status  |
| O6   | BOOLEAN | Output 6 status  |
| O7   | BOOLEAN | Output 7 status  |
| O8   | BOOLEAN | Output 8 status  |
| O9   | BOOLEAN | Output 9 status  |
| O10  | BOOLEAN | Output 10 status |
| O11  | BOOLEAN | Output 11 status |
| O12  | BOOLEAN | Output 12 status |
| O13  | BOOLEAN | Output 13 status |
| O14  | BOOLEAN | Output 14 status |
| O15  | BOOLEAN | Output 15 status |
| O16  | BOOLEAN | Output 16 status |

**2.14.14.4 Settings****SPCGAPC Non group settings (Basic)****Table 174: SPCGAPC Non group settings (Basic)**

| Parameter           | Values (Range)                            | Unit | Step | Default           | Description                              |
|---------------------|---|------|------|-------------------|--|
| Loc Rem restriction | 0=False<br>1=True                         |      |      | 1=True            | Local remote switch restriction          |
| Operation mode      | 0=Pulsed<br>1=Toggle/Persistent<br>-1=Off |      |      | -1=Off            | Operation mode for generic control point |
| Pulse length        | 10...3600000                              | ms   | 10   | 1000              | Pulse length for pulsed operation mode   |
| Description         |   |      |      | SPCGAPC1 Output 1 | Generic control point description        |
| Operation mode      | 0=Pulsed<br>1=Toggle/Persistent<br>-1=Off |      |      | -1=Off            | Operation mode for generic control point |
| Pulse length        | 10...3600000                              | ms   | 10   | 1000              | Pulse length for pulsed operation mode   |

*Table continues on the next page*

| Parameter      | Values (Range)                            | Unit | Step | Default           | Description                              |
|----------------|---|------|------|-------------------|--|
| Description    |   |      |      | SPCGAPC1 Output 2 | Generic control point description        |
| Operation mode | 0=Pulsed<br>1=Toggle/Persistent<br>-1=Off |      |      | -1=Off            | Operation mode for generic control point |
| Pulse length   | 10...3600000                              | ms   | 10   | 1000              | Pulse length for pulsed operation mode   |
| Description    |   |      |      | SPCGAPC1 Output 3 | Generic control point description        |
| Operation mode | 0=Pulsed<br>1=Toggle/Persistent<br>-1=Off |      |      | -1=Off            | Operation mode for generic control point |
| Pulse length   | 10...3600000                              | ms   | 10   | 1000              | Pulse length for pulsed operation mode   |
| Description    |   |      |      | SPCGAPC1 Output 4 | Generic control point description        |
| Operation mode | 0=Pulsed<br>1=Toggle/Persistent<br>-1=Off |      |      | -1=Off            | Operation mode for generic control point |
| Pulse length   | 10...3600000                              | ms   | 10   | 1000              | Pulse length for pulsed operation mode   |
| Description    |   |      |      | SPCGAPC1 Output 5 | Generic control point description        |
| Operation mode | 0=Pulsed<br>1=Toggle/Persistent<br>-1=Off |      |      | -1=Off            | Operation mode for generic control point |
| Pulse length   | 10...3600000                              | ms   | 10   | 1000              | Pulse length for pulsed operation mode   |
| Description    |   |      |      | SPCGAPC1 Output 6 | Generic control point description        |
| Operation mode | 0=Pulsed<br>1=Toggle/Persistent<br>-1=Off |      |      | -1=Off            | Operation mode for generic control point |
| Pulse length   | 10...3600000                              | ms   | 10   | 1000              | Pulse length for pulsed operation mode   |
| Description    |   |      |      | SPCGAPC1 Output 7 | Generic control point description        |
| Operation mode | 0=Pulsed<br>1=Toggle/Persistent<br>-1=Off |      |      | -1=Off            | Operation mode for generic control point |
| Pulse length   | 10...3600000                              | ms   | 10   | 1000              | Pulse length for pulsed operation mode   |
| Description    |   |      |      | SPCGAPC1 Output 8 | Generic control point description        |

Table continues on the next page

| Parameter      | Values (Range)                            | Unit | Step | Default            | Description                              |
|----------------|---|------|------|--------------------|--|
| Operation mode | 0=Pulsed<br>1=Toggle/Persistent<br>-1=Off |      |      | -1=Off             | Operation mode for generic control point |
| Pulse length   | 10...3600000                              | ms   | 10   | 1000               | Pulse length for pulsed operation mode   |
| Description    |   |      |      | SPCGAPC1 Output 9  | Generic control point description        |
| Operation mode | 0=Pulsed<br>1=Toggle/Persistent<br>-1=Off |      |      | -1=Off             | Operation mode for generic control point |
| Pulse length   | 10...3600000                              | ms   | 10   | 1000               | Pulse length for pulsed operation mode   |
| Description    |   |      |      | SPCGAPC1 Output 10 | Generic control point description        |
| Operation mode | 0=Pulsed<br>1=Toggle/Persistent<br>-1=Off |      |      | -1=Off             | Operation mode for generic control point |
| Pulse length   | 10...3600000                              | ms   | 10   | 1000               | Pulse length for pulsed operation mode   |
| Description    |   |      |      | SPCGAPC1 Output 11 | Generic control point description        |
| Operation mode | 0=Pulsed<br>1=Toggle/Persistent<br>-1=Off |      |      | -1=Off             | Operation mode for generic control point |
| Pulse length   | 10...3600000                              | ms   | 10   | 1000               | Pulse length for pulsed operation mode   |
| Description    |   |      |      | SPCGAPC1 Output 12 | Generic control point description        |
| Operation mode | 0=Pulsed<br>1=Toggle/Persistent<br>-1=Off |      |      | -1=Off             | Operation mode for generic control point |
| Pulse length   | 10...3600000                              | ms   | 10   | 1000               | Pulse length for pulsed operation mode   |
| Description    |   |      |      | SPCGAPC1 Output 13 | Generic control point description        |
| Operation mode | 0=Pulsed<br>1=Toggle/Persistent<br>-1=Off |      |      | -1=Off             | Operation mode for generic control point |
| Pulse length   | 10...3600000                              | ms   | 10   | 1000               | Pulse length for pulsed operation mode   |
| Description    |   |      |      | SPCGAPC1 Output 14 | Generic control point description        |
| Operation mode | 0=Pulsed<br>1=Toggle/Persistent<br>-1=Off |      |      | -1=Off             | Operation mode for generic control point |

Table continues on the next page



| Parameter      | Values (Range)                            | Unit | Step | Default            | Description                              |
|----------------|---|------|------|--------------------|--|
|                | -1=Off                                    |      |      |                    |  |
| Pulse length   | 10...3600000                              | ms   | 10   | 1000               | Pulse length for pulsed operation mode   |
| Description    |   |      |      | SPCGAPC1 Output 15 | Generic control point description        |
| Operation mode | 0=Pulsed<br>1=Toggle/Persistent<br>-1=Off |      |      | -1=Off             | Operation mode for generic control point |
| Pulse length   | 10...3600000                              | ms   | 10   | 1000               | Pulse length for pulsed operation mode   |
| Description    |   |      |      | SPCGAPC1 Output 16 | Generic control point description        |

## 2.14.15 Voltage switch VMSWI (ANSI VSWI)

### 2.14.15.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|----------------------|--------------------------|--------------------------|-------------------------------|
| Voltage switch       | VMSWI                    | VSWI                     | VSWI                          |

### 2.14.15.2 Function block

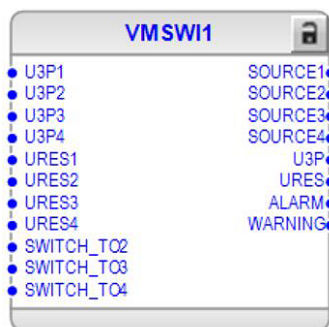


Figure 72: Function block

### 2.14.15.3 Functionality

The voltage switch function VMSWI performs the switching function between up to four voltage groups (Bus1, Bus 2, Bus 3 and Bus 4).

Residual voltage input can be optional and depends of the application configuration. The switching operation can also be associated with the residual voltage if available.

### 2.14.15.4 Analog channel configuration

VMSWI has eight analog group inputs which must be properly configured.

**Table 175: Analog inputs**

| Input               | Description                               |
|---------------------|---|
| U3P1 <sup>16</sup>  | Three-phase voltages                      |
| U3P2 <sup>16</sup>  | Three-phase voltages                      |
| U3P3 <sup>16</sup>  | Three-phase voltages                      |
| U3P4 <sup>16</sup>  | Three-phase voltages                      |
| URES1 <sup>16</sup> | Residual voltage (measured or calculated) |
| URES2 <sup>16</sup> | Residual voltage (measured or calculated) |
| URES3 <sup>16</sup> | Residual voltage (measured or calculated) |
| URES4 <sup>16</sup> | Residual voltage (measured or calculated) |



See the preprocessing function blocks in this document for the possible signal sources. The GRPOFF signal is available in the function block called Protection.

### 2.14.15.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".



For this function, the setting is hidden and fixed to "On".

The switch logic depends on inputs SWITCH\_TO2, SWITCH\_TO3 and SWITCH\_TO4. Source 1 is selected as default and switching is done on increased priority.



GRPOFF signal must be connected to unused voltage inputs. GRPOFF signal is available as output from the Protection function block.

**Table 176: Switching operation**

| Control input signals |                 |             | Outputs |         |         |         |                |                 |
|-----------------------|-----------------|-------------|---------|---------|---------|---------|----------------|-----------------|
| SWITCH_TO 2           | SWITCH_TO 3     | SWITCH_TO 4 | SOURCE1 | SOURCE2 | SOURCE3 | SOURCE4 | Source for U3P | Source for URES |
| FALSE                 | FALSE           | FALSE       | TRUE    | FALSE   | FALSE   | FALSE   | U3P1           | URES1           |
| TRUE                  | FALSE           | FALSE       | FALSE   | TRUE    | FALSE   | FALSE   | U3P2           | URES2           |
| x <sup>17</sup>       | TRUE            | FALSE       | FALSE   | FALSE   | TRUE    | FALSE   | U3P3           | URES3           |
| x <sup>17</sup>       | x <sup>17</sup> | TRUE        | FALSE   | FALSE   | FALSE   | TRUE    | U3P4           | URES4           |

<sup>16</sup> Can be connected to GRPOFF

<sup>17</sup> No difference



If the numbers of channels connected to U3P1 . . . U3P4 and URES1 . . . URES4 does not match with the number of connected SWITCH\_TOx inputs, the configuration of the function fails.

Outputs ALARM and URES\_ALARM indicate bad quality data of system measurements for selected U3P and URES, respectively.

Outputs WARNING and URES\_WARNING indicate questionable quality data of system measurements for selected U3P and URES, respectively.



Depending on the connected U3P channels to the voltage switch, the *Primary voltage* settings between the source U3P must match. Respectively, depending on the connected URES channels, the *Primary voltage* settings between the source URES must match. Setting validation for the primary voltages fails unless they are all stored simultaneously to the protection relay.

## 2.14.15.6 Signals

### VMSWI Input signals

Table 177: VMSWI Input signals

| Name       | Type    | Default | Description            |
|------------|---------|---------|------------------------|
| U3P1       | SIGNAL  | -       | Three-phase voltages 1 |
| U3P2       | SIGNAL  | -       | Three-phase voltages 2 |
| U3P3       | SIGNAL  | -       | Three-phase voltages 3 |
| U3P4       | SIGNAL  | -       | Three-phase voltages 4 |
| URES1      | SIGNAL  | -       | Residual voltage 1     |
| URES2      | SIGNAL  | -       | Residual voltage 2     |
| URES3      | SIGNAL  | -       | Residual voltage 3     |
| URES4      | SIGNAL  | -       | Residual voltage 4     |
| SWITCH_TO2 | BOOLEAN | 0=False | Switch to source 2     |
| SWITCH_TO3 | BOOLEAN | 0=False | Switch to source 3     |
| SWITCH_TO4 | BOOLEAN | 0=False | Switch to source 4     |

### VMSWI Output signals

Table 178: VMSWI Output signals

| Name    | Type    | Description                         |
|---------|---------|-------------------------------------|
| SOURCE1 | BOOLEAN | Selected voltage source is source 1 |
| SOURCE2 | BOOLEAN | Selected voltage source is source 2 |
| SOURCE3 | BOOLEAN | Selected voltage source is source 3 |
| SOURCE4 | BOOLEAN | Selected voltage source is source 4 |
| U3P     | SIGNAL  | Three-phase voltages                |

Table continues on the next page

| Name    | Type    | Description      |
|---------|---------|------------------|
| URES    | SIGNAL  | Residual voltage |
| ALARM   | BOOLEAN | Alarm            |
| WARNING | BOOLEAN | Warning          |

### 2.14.15.7 Monitored data

#### VMSWI Monitored data

Table 179: VMSWI Monitored data

| Name       | Type | Values (Range)                                       | Unit | Description     |
|------------|------|--|------|-----------------|
| SWITCH_POS | Enum | 1=Source 1<br>2=Source 2<br>3=Source 3<br>4=Source 4 |      | Switch position |

### 2.14.16 Current switch CMSWI

#### 2.14.16.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|----------------------|--------------------------|--------------------------|-------------------------------|
| Current switch       | CMSWI                    | CMSWI                    | CMSWI                         |

#### 2.14.16.2 Function block

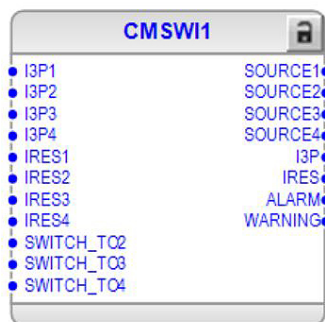


Figure 73: Function block

#### 2.14.16.3 Functionality

The current switch function CMSWI performs the switching function between up to four current groups. The residual current input is optional and depends of the

application configuration. Switching operation can also be associated with the residual current if this is available.

#### 2.14.16.4 Analog channel configuration

CMSWI has eight analog group inputs which must be properly configured.

**Table 180: Analog inputs**

| Input               | Description                               |
|---------------------|---|
| I3P1 <sup>18</sup>  | Three-phase currents                      |
| I3P2 <sup>18</sup>  | Three-phase currents                      |
| I3P3 <sup>18</sup>  | Three-phase currents                      |
| I3P4 <sup>18</sup>  | Three-phase currents                      |
| IRES1 <sup>18</sup> | Residual voltage (measured or calculated) |
| IRES2 <sup>18</sup> | Residual voltage (measured or calculated) |
| IRES3 <sup>18</sup> | Residual voltage (measured or calculated) |
| IRES4 <sup>18</sup> | Residual voltage (measured or calculated) |



See the preprocessing function blocks in this document for the possible signal sources. The GRPOFF signal is available in the function block called Protection.

#### 2.14.16.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".



For this function, the setting is hidden and fixed to "On".

The switch logic depends on inputs SWITCH\_TO2, SWITCH\_TO3 and SWITCH\_TO4. Source 1 is selected as default and switching is done on increased priority.



GRPOFF signal must be connected to unused current inputs. GRPOFF signal is available as output from the Protection function block.

**Table 181: Switching operation**

| Control input signals |             |             | Outputs |         |         |         |                |                 |
|-----------------------|-------------|-------------|---------|---------|---------|---------|----------------|-----------------|
| SWITCH_TO 2           | SWITCH_TO 3 | SWITCH_TO 4 | SOURCE1 | SOURCE2 | SOURCE3 | SOURCE4 | Source for I3P | Source for IRES |
| FALSE                 | FALSE       | FALSE       | TRUE    | FALSE   | FALSE   | FALSE   | I3P1           | IRES1           |
| TRUE                  | FALSE       | FALSE       | FALSE   | TRUE    | FALSE   | FALSE   | I3P2           | IRES2           |

*Table continues on the next page*

<sup>18</sup> Can be connected to GRPOFF

| Control input signals |                 |             | Outputs |         |         |         |                |                 |
|-----------------------|-----------------|-------------|---------|---------|---------|---------|----------------|-----------------|
| SWITCH_TO 2           | SWITCH_TO 3     | SWITCH_TO 4 | SOURCE1 | SOURCE2 | SOURCE3 | SOURCE4 | Source for I3P | Source for IRES |
| x <sup>19</sup>       | TRUE            | FALSE       | FALSE   | FALSE   | TRUE    | FALSE   | I3P3           | IRES3           |
| x <sup>19</sup>       | x <sup>19</sup> | TRUE        | FALSE   | FALSE   | FALSE   | TRUE    | I3P4           | IRES4           |



If the numbers of channels connected to I3P1 . . . I3P4 and IRES1 . . . IRES4 does not match with the number of connected SWITCH\_TOx inputs, the configuration of the function fails.

Outputs ALARM and IRES\_ALARM indicate bad quality data of system measurements for selected I3P and IRES, respectively.

Outputs WARNING and IRES\_WARNING indicate questionable quality data of system measurements for selected I3P and IRES, respectively.



Depending on the connected I3P channels to the current switch, the *Primary current* settings between the source I3P must match. Depending on the connected IRES channels, the *Primary current* settings between the source IRES must match. Setting validation for the primary current fails unless they are all stored simultaneously to the protection relay.

## 2.14.16.6

### Signals

#### CMSWI Input signals

Table 182: CMSWI Input signals

| Name       | Type    | Default | Description            |
|------------|---------|---------|------------------------|
| I3P1       | SIGNAL  | -       | Three-phase currents 1 |
| I3P2       | SIGNAL  | -       | Three-phase currents 2 |
| I3P3       | SIGNAL  | -       | Three-phase currents 3 |
| I3P4       | SIGNAL  | -       | Three-phase currents 4 |
| IRES1      | SIGNAL  | -       | Residual current 1     |
| IRES2      | SIGNAL  | -       | Residual current 2     |
| IRES3      | SIGNAL  | -       | Residual current 3     |
| IRES4      | SIGNAL  | -       | Residual current 4     |
| SWITCH_TO2 | BOOLEAN | 0=False | Switch to source 2     |
| SWITCH_TO3 | BOOLEAN | 0=False | Switch to source 3     |
| SWITCH_TO4 | BOOLEAN | 0=False | Switch to source 4     |

<sup>19</sup> No difference

**CMSWI Output signals**

**Table 183: CMSWI Output signals**

| Name    | Type    | Description                         |
|---------|---------|-------------------------------------|
| SOURCE1 | BOOLEAN | Selected current source is source 1 |
| SOURCE2 | BOOLEAN | Selected current source is source 2 |
| SOURCE3 | BOOLEAN | Selected current source is source 3 |
| SOURCE4 | BOOLEAN | Selected current source is source 4 |
| I3P     | SIGNAL  | Three-phase currents                |
| IRES    | SIGNAL  | Residual current                    |
| ALARM   | BOOLEAN | Alarm                               |
| WARNING | BOOLEAN | Warning                             |

**2.14.16.7 Monitored data**

**CMSWI Monitored data**

**Table 184: CMSWI Monitored data**

| Name       | Type | Values (Range)                                       | Unit | Description     |
|------------|------|--|------|-----------------|
| SWITCH_POS | Enum | 1=Source 1<br>2=Source 2<br>3=Source 3<br>4=Source 4 |      | Switch position |

**2.14.17 Current sum CMSUM (ANSI CSUM)**

**2.14.17.1 Identification**

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|----------------------|--------------------------|--------------------------|-------------------------------|
| Current sum          | CMSUM                    | CSUM                     | CSUM                          |

**2.14.17.2 Function block**



*Figure 74: Function block*

### 2.14.17.3 Functionality

The current sum function CMSUM is a phase-by-phase specific summing function for two current triplets. CMSUM functions can be also chained together to sum more than two current triples. Output I3P can be used as normal current input for the application functions using current. Different measurement modes (DFT, RMS, Peak-to-peak) are supported. Also, positive, negative and zero-sequence components are calculated for the summed currents. Output IRES provides the summed residual current based on the summed currents. Output IRES\_CALC provides the calculated residual current based on the summed currents.

Example configuration:



Figure 75: Current summing configuration

### 2.14.17.4 Analog channel configuration

CMSUM has two analog group inputs which must be properly configured.




-  While it's possible to create feedback loop by chaining different CMSUM instances, it is not supported by the device and the loop is ignored.
-  If summed SMV streams have different current angle correction settings, the summed current will use an average current angle correction of the summed SMV streams.

Table 185: Analog signals

| Input | Description          |
|-------|----------------------|
| I3P1  | Three-phase currents |
| I3P2  | Three-phase currents |

-  See the preprocessing function blocks in this document for the possible signal sources.



## 2.14.17.5 Signals

### CMSUM Input signals

Table 186: CMSUM Input signals

| Name | Type   | Default | Description            |
|------|--------|---------|------------------------|
| I3P1 | SIGNAL | -       | Three-phase currents 1 |
| I3P2 | SIGNAL | -       | Three-phase currents 2 |

### CMSUM Output signals

Table 187: CMSUM Output signals

| Name      | Description   |
|-----------|---|
| ALARM     | Combined alarm state of the summed current triplets.        |
| WARNING   | Combined warning state of the summed current triplets.      |
| IRES_CALC | Residual current calculated of the summed current triplets. |
| IRES      | Summed residual current of the current triplets.            |

## 2.15 Factory settings restoration

In case of configuration data loss or any other file system error that prevents the IED from working properly, the whole file system can be restored to the original factory state. All default settings and configuration files stored in the factory are restored. For further information on restoring factory settings, see the operation manual.

## 2.16 ETHERNET channel supervision function blocks

### 2.16.1 Redundant Ethernet channel supervision RCHLCCH

### 2.16.1.1 Function block

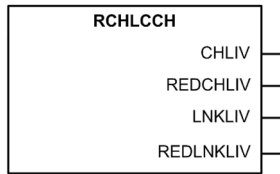


Figure 76: Function block

### 2.16.1.2 Functionality

Redundant Ethernet channel supervision RCHLCCH represents LAN A and LAN B redundant Ethernet channels.

Redundant Ethernet according to PRP can be enabled with setting *Redundant mode*, but also the setting *Bus mode* will impact the available connections and overall functionality.

If setting *Bus mode* is set to *Separated*, Process Bus communication and Station communication is separated to two different Ethernet ports. Process Bus communication IEC 61850-9-2, GOOSE communication IEC 61850-8-1 and time synchronization IEEE 1588v2 is handled via LAN3 port. LAN5 will then be used for other Station Bus communication.

If setting *Bus mode* is set to *Combined*, all communication is combined to LAN3 port, and LAN5 port is not used. The combined port (LAN3) will use the IP specified for LAN5.

If redundant communication based on PRP is enabled, only the communication of LAN3 port is impacted. In this case LAN3 will be the LAN A connection, and LAN4 will be the LAN B connection. Communication in LAN5 port (if *Bus mode* setting is *Separated*) will not be covered by PRP functionality.

Please note that if the device is equipped with fiber optic module, LAN3 and LAN4 ports will be replaced by fiber optic module ports.

### 2.16.1.3 Signals

#### RCHLCCH output signals

Table 188: RCHLCCH output signals

| Parameter | Values (Range) | Unit | Step | Default | Description  |
|-----------|----------------|------|------|---------|--|
| CHLIV     | True<br>False  |      |      |         | Status of redundant Ethernet channel LAN A. When <i>Redundant mode</i> is set to "PRP", value is "True" if the IED is receiving redundancy supervision frames. Otherwise value is "False". |
| REDCHLIV  | True<br>False  |      |      |         | Status of redundant Ethernet channel LAN B. When <i>Redundant mode</i> is set to "PRP", value is "True" if   |

Table continues on the next page

| Parameter | Values (Range) | Unit | Step | Default | Description   |
|-----------|----------------|------|------|---------|---|
|           |                |      |      |         | the IED is receiving redundancy supervision frames. Otherwise value is "False".             |
| LNKLIV    | Up<br>Down     |      |      |         | Link status of redundant port LAN A. Valid only when <i>Redundant mode</i> is set to "PRP". |
| REDLNKLIV | Up<br>Down     |      |      |         | Link status of redundant port LAN B. Valid only when <i>Redundant mode</i> is set to "PRP". |

### 2.16.1.4 Settings

#### RCHLCCH settings

Table 189: Redundancy settings

| Parameter              | Values (Range)        | Unit | Step | Default   | Description  |
|------------------------|-----------------------|------|------|-----------|--|
| Redundant mode         | None<br>PRP           |      |      | None      | Mode selection for Ethernet switch on redundant communication modules. The "None" mode is used with normal and Self-healing Ethernet topologies. |
| Bus mode <sup>20</sup> | Separated<br>Combined |      |      | Separated | Configuration of Station Bus and Process Bus   |

### 2.16.1.5 Monitored data

Monitored data is available in four locations.

- **Monitoring > Communication > Ethernet > Activity > CHLIV\_A**
- **Monitoring > Communication > Ethernet > Activity > REDCHLIV\_B**
- **Monitoring > Communication > Ethernet > Link statuses > LNKLIV\_A**
- **Monitoring > Communication > Ethernet > Link statuses > REDLNKLIV\_B**

<sup>20</sup> After changing this parameter the device needs to be restarted.

### 2.16.1.6 Technical revision history

Table 190: RCHLCCH Technical revision history

| Technical revision | Change              |
|--------------------|---------------------|
| B                  | Modified for SSC600 |

## 2.16.2 Ethernet channel supervision SCHLCCH

### 2.16.2.1 Function block

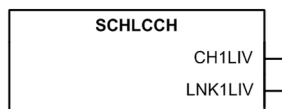


Figure 77: Function block

### 2.16.2.2 Functionality

Ethernet channel supervision SCHLCCH represents Ethernet channels.

Ethernet ports used for station and process bus communication (LAN3, LAN4, LAN5) can be set of with settings in **Configuration > Communication > Ethernet > SCHLCHH1**. The settings for disabling the communication in other Ethernet ports (LAN2, LAN7) can be found in **Configuration > Communication > Ethernet > Communication**. Closing an unused Ethernet port enhances the cyber security of the device.

### 2.16.2.3 Signals

#### SCHLCCH output signals

Table 191: SCHLCCH1 output signals

| Parameter | Values (Range) | Unit | Step | Default | Description   |
|-----------|----------------|------|------|---------|---|
| CH1LIV    | True<br>False  |      |      |         | Status of Ethernet channel X1/LAN. Value is "True" if the port is receiving Ethernet frames. Valid only when <i>Redundant mode</i> is set to "None" or port is not one of the redundant ports (LAN A or LAN B). |
| LNK1LIV   | Up<br>Down     |      |      |         | Link status of Ethernet port X1/LAN.  |

### 2.16.2.4 Settings

## SCHLCCH Settings

**Table 192: Port mode settings**

| Parameter                            | Values (Range) | Unit | Step | Default | Description                                       |
|--------------------------------------|----------------|------|------|---------|---|
| Process bus interface mode           | Off<br>On      |      |      | On      | Operation of process bus interface LAN3           |
| Process bus redundant interface mode | Off<br>On      |      |      | On      | Operation of redundant process bus interface LAN4 |
| Main interface mode                  | Off<br>On      |      |      | On      | Operation of station bus interface LAN5           |

### 2.16.2.5

#### Monitored data

Monitored data is available in ten locations.

- **Monitoring > Communication > Ethernet > Activity > CHLIV (LAN3)**
- **Monitoring > Communication > Ethernet > Activity > CHLIVP (LAN4)**
- **Monitoring > Communication > Ethernet > Activity > CHLIVM (LAN5)**
- **Monitoring > Communication > Ethernet > Activity > CHLIVL (LAN1)**
- **Monitoring > Communication > Ethernet > Activity > CHLIVR (LAN2)**
- **Monitoring > Communication > Ethernet > Link statuses > LNKLIV (LAN3)**
- **Monitoring > Communication > Ethernet > Link statuses > LNKLIVP (LAN4)**
- **Monitoring > Communication > Ethernet > Link statuses > LNKLIVM (LAN5)**
- **Monitoring > Communication > Ethernet > Link statuses > LNKLIVL (LAN1)**
- **Monitoring > Communication > Ethernet > Link statuses > LNKLIVR (LAN2)**

### 2.16.2.6

#### Technical revision history

**Table 193: SCHLCCH Technical revision history**

| Technical revision | Change              |
|--------------------|---------------------|
| B                  | Modified for SSC600 |

### 3 Protection functions

In this chapter all protection functions for SSC600 are presented. The technical description is made from the point of view component to protect (feeder, transformer, motor) and not from the point of view of SSC600. Although all functions are executed in one centralized SSC600 device, logically they are related to different components and this context is highlighted in the documentation.

In applications, where traditionally several bay level protection and control relays are communicating with each other, application logic can be built entirely within SSC600 unit, without the need for horizontal communication. In the documentation however the traditional convention is preserved, and the signal paths are shown, for better comparison to traditional protection schemes.

Provided Technical data is valid, when 615 series IEDs are used as merging units.

### 3.1 Three-phase current protection

#### 3.1.1 Three-phase non-directional overcurrent protection PHxPTOC

##### 3.1.1.1 Identification

| Function description  | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|--------------------------|--------------------------|-------------------------------|
| Three-phase non-directional overcurrent protection, low stage           | PHLPTOC                  | 3I>                      | 51P-1                         |
| Three-phase non-directional overcurrent protection, high stage          | PHHPTOC                  | 3I>>                     | 51P-2                         |
| Three-phase non-directional overcurrent protection, instantaneous stage | PHIPTOC                  | 3I>>>                    | 50P/51P                       |

##### 3.1.1.2 Function block

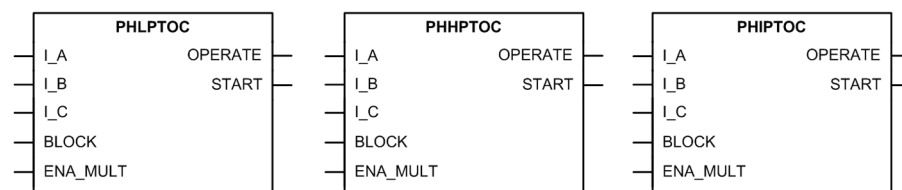


Figure 78: Function block

### 3.1.1.3 Functionality

The three-phase non-directional overcurrent protection function PHxPTOC is used as one-phase, two-phase or three-phase non-directional overcurrent and short-circuit protection.

The function starts when the current exceeds the set limit. The operate time characteristics for low stage PHLPTOC and high stage PHHPTOC can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). The instantaneous stage PHIPTOC always operates with the DT characteristic.

In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

### 3.1.1.4 Operation principle

The function can be enabled and disabled with the *Operation setting*. The corresponding parameter values are "On" and "Off".

The operation of three-phase non-directional overcurrent protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

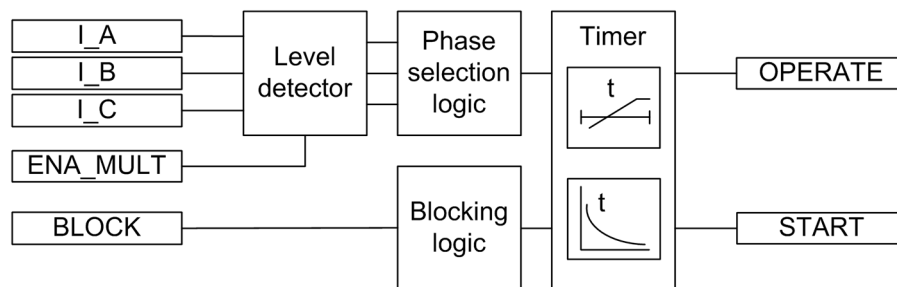


Figure 79: Functional module diagram.  $I_A$ ,  $I_B$  and  $I_C$  represent phase currents.

#### Level detector

The measured phase currents are compared phase-wise to the set Start value. If the measured value exceeds the set Start value, the level detector reports the exceeding of the value to the phase selection logic. If the ENA\_MULT input is active, the Start value setting is multiplied by the *Start value Mult* setting.



The IED does not accept the *Start value* or *Start value Mult* setting if the product of these settings exceeds the *Start value* setting range.

The start value multiplication is normally done when the inrush detection function (INRPHAR) is connected to the ENA\_MULT input.

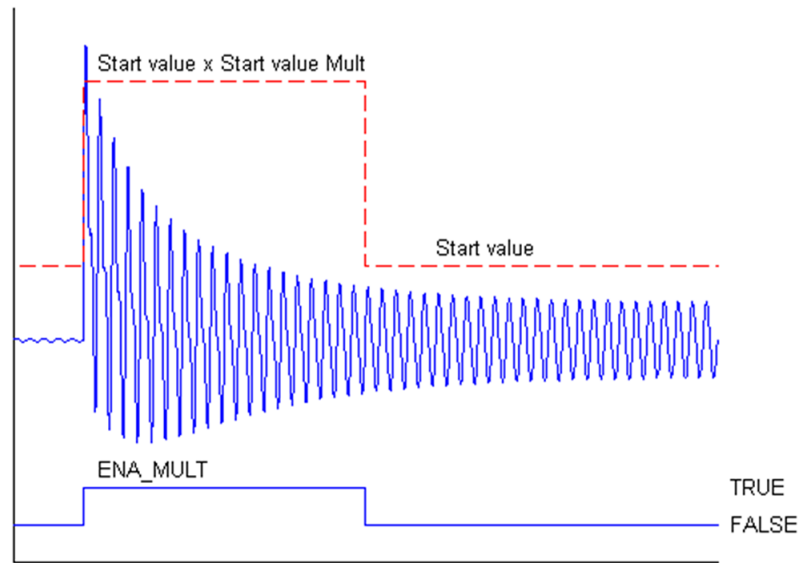


Figure 80: Start value behavior with *ENA\_MULT* input activated

### Phase selection logic

If the fault criteria are fulfilled in the level detector, the phase selection logic detects the phase or phases in which the measured current exceeds the setting. If the phase information matches the Num of start phases setting, the phase selection logic activates the timer module.

### Timer

Once activated, the timer activates the `START` output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of Operate delay time in the DT mode or the maximum value defined by the inverse time curve, the `OPERATE` output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters Curve parameter A, Curve parameter B, Curve parameter C, Curve parameter D and Curve parameter E.

If a drop-off situation happens, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the Operating curve type, Type of reset curve and Reset delay time settings. When the DT characteristic is selected, the reset timer runs until the set Reset delay time value is exceeded. When the IDMT curves are selected, the Type of reset curve setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the Reset delay time setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation. The `START` output is deactivated when the reset timer has elapsed.





The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter Minimum operate time defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.



The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the Minimum operate time setting. For more information, see the IDMT curves for overcurrent protection section in this manual.

The timer calculates the start duration value `START_DUR`, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration > System > Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the `OPERATE` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block `OPERATE` output" mode, the function operates normally but the `OPERATE` output is not activated.

### 3.1.1.5

#### Measurement modes

The function operates on four alternative measurement modes: "RMS", "DFT", "Peak-to-Peak" and "P-to-P + backup". Additionally, there is "Wide P-to-P" measurement mode in some products variants. The measurement mode is selected with the setting *Measurement mode*.

**Table 194: Measurement modes supported by PHxPTOC stages**

| Measurement mode | PHLPTOC | PHHPTOC | PHIPTOC |
|------------------|---------|---------|---------|
| RMS              | x       | x       |         |
| DFT              | x       | x       |         |
| Peak-to-Peak     | x       | x       |         |
| P-to-P + backup  |         |         | x       |
| Wide P-to-P      | x       |         |         |



For a detailed description of the measurement modes, see [Chapter 10.5 Measurement modes](#) in this manual.

### 3.1.1.6 Timer characteristics

PHxPTOC supports both DT and IDMT characteristics. The user can select the timer characteristics with the *Operating curve type* and *Type of reset curve* settings. When the DT characteristic is selected, it is only affected by the *Operate delay time* and *Reset delay time* settings.

The IED provides 16 IDMT characteristics curves, of which seven comply with the IEEE C37.112 and six with the IEC 60255-3 standard. Two curves follow the special characteristics of ABB praxis and are referred to as RI and RD. In addition to this, a user programmable curve can be used if none of the standard curves are applicable. The DT characteristics can be chosen by selecting the *Operating curve type* values "ANSI Def. Time" or "IEC Def. Time". The functionality is identical in both cases.

The timer characteristics supported by different stages comply with the list in the IEC 61850-7-4 specification, indicate the characteristics supported by different stages:

**Table 195: Timer characteristics supported by different stages**

| Operating curve type            | PHLPTOC | PHHPTOC |
|---------------------------------|---------|---------|
| (1) ANSI Extremely Inverse      | x       | x       |
| (2) ANSI Very Inverse           | x       |         |
| (3) ANSI Normal Inverse         | x       | x       |
| (4) ANSI Moderately Inverse     | x       |         |
| (5) ANSI Definite Time          | x       | x       |
| (6) Long Time Extremely Inverse | x       |         |
| (7) Long Time Very Inverse      | x       |         |
| (8) Long Time Inverse           | x       |         |
| (9) IEC Normal Inverse          | x       | x       |
| (10) IEC Very Inverse           | x       | x       |
| (11) IEC Inverse                | x       |         |
| (12) IEC Extremely Inverse      | x       | x       |
| (13) IEC Short Time Inverse     | x       |         |
| (14) IEC Long Time Inverse      | x       |         |
| (15) IEC Definite Time          | x       | x       |
| (17) User programmable          | x       | x       |
| (18) RI type                    | x       |         |
| (19) RD type                    | x       |         |



PHIPTOC supports only definite time characteristic.



For a detailed description of timers, see [Chapter 10 General function block features](#) in this manual.

**Table 196: Reset time characteristics supported by different stages**

| Reset curve type   | PHLPTOC | PHHPTOC | Note  |
|--------------------|---------|---------|---|
| (1) Immediate      | x       | x       | Available for all operate time curves                 |
| (2) Def time reset | x       | x       | Available for all operate time curves                 |
| (3) Inverse reset  | x       | x       | Available only for AN-SI and user programmable curves |



The *Type of reset curve* setting does not apply to PHIPTOC or when the DT operation is selected. The reset is purely defined by the *Reset delay time* setting.

### 3.1.1.7

#### Application

PHxPTOC is used in several applications in the power system. The applications include but are not limited to:

- Selective overcurrent and short-circuit protection of feeders in distribution and subtransmission systems
- Backup overcurrent and short-circuit protection of power transformers and generators
- Overcurrent and short-circuit protection of various devices connected to the power system, for example shunt capacitor banks, shunt reactors and motors
- General backup protection

PHxPTOC is used for single-phase, two-phase and three-phase non-directional overcurrent and short-circuit protection. Typically, overcurrent protection is used for clearing two and three-phase short circuits. Therefore, the user can choose how many phases, at minimum, must have currents above the start level for the function to operate. When the number of start-phase settings is set to "1 out of 3", the operation of PHxPTOC is enabled with the presence of high current in one-phase.



When the setting is "2 out of 3" or "3 out of 3", single-phase faults are not detected. The setting "3 out of 3" requires the fault to be present in all three phases.

Many applications require several steps using different current start levels and time delays. PHxPTOC consists of three protection stages.

- Low PHLPTOC
- High PHHPTOC
- Instantaneous PHIPTOC

PHLPTOC is used for overcurrent protection. The function contains several types of time-delay characteristics. PHHPTOC and PHIPTOC are used for fast clearance of very high overcurrent situations

#### Transformer overcurrent protection

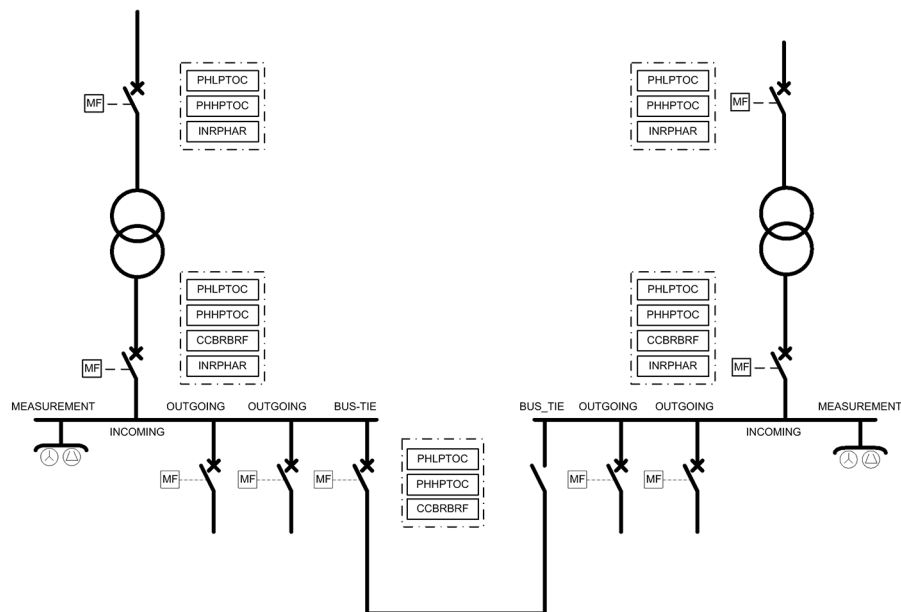
The purpose of transformer overcurrent protection is to operate as main protection, when differential protection is not used. It can also be used as coarse back-up protection for differential protection in faults inside the zone of protection, that is, faults occurring in incoming or outgoing feeders, in the region of transformer

terminals and tank cover. This means that the magnitude range of the fault current can be very wide. The range varies from  $6xI_n$  to several hundred times  $I_n$ , depending on the impedance of the transformer and the source impedance of the feeding network. From this point of view, it is clear that the operation must be both very fast and selective, which is usually achieved by using coarse current settings.

The purpose is also to protect the transformer from short circuits occurring outside the protection zone, that is through-faults. Transformer overcurrent protection also provides protection for the LV-side busbars. In this case the magnitude of the fault current is typically lower than  $12xI_n$  depending on the fault location and transformer impedance. Consequently, the protection must operate as fast as possible taking into account the selectivity requirements, switching-in currents, and the thermal and mechanical withstand of the transformer and outgoing feeders.

Traditionally, overcurrent protection of the transformer has been arranged as shown in *Figure 81*. The low-set stage PHLPTOC operates time-selectively both in transformer and LV-side busbar faults. The high-set stage PHHPTOC operates instantaneously making use of current selectivity only in transformer HV-side faults. If there is a possibility, that the fault current can also be fed from the LV-side up to the HV-side, the transformer must also be equipped with LV-side overcurrent protection.

Inrush current detectors are used in start-up situations to multiply the current start value setting in each particular IED where the inrush current can occur. The overcurrent and contact based circuit breaker failure protection CCBRRBF is used to confirm the protection scheme in case of circuit breaker malfunction.



*Figure 81: Example of traditional time selective transformer overcurrent protection*

The operating times of the main and backup overcurrent protection of the above scheme become quite long, this applies especially in the busbar faults and also in the transformer LV-terminal faults. In order to improve the performance of the above scheme, a multiple-stage overcurrent protection with reverse blocking is proposed. *Figure 82* shows this arrangement.

### Transformer and busbar overcurrent protection with reverse blocking principle

By implementing a full set of overcurrent protection stages and blocking channels between the protection stages of the incoming feeders, bus-tie and outgoing feeders, it is possible to speed up the operation of overcurrent protection in the busbar and transformer LV-side faults without impairing the selectivity. Also, the security degree of busbar protection is increased, because there is now a dedicated, selective and fast busbar protection functionality which is based on the blockable overcurrent protection principle. The additional time selective stages on the transformer HV and LV-sides provide increased security degree of backup protection for the transformer, busbar and also for the outgoing feeders.

Depending on the overcurrent stage in question, the selectivity of the scheme in [Figure 82](#) is based on the operating current, operating time or blockings between successive overcurrent stages. With blocking channels, the operating time of the protection can be drastically shortened if compared to the simple time selective protection. In addition to the busbar protection, this blocking principle is applicable for the protection of transformer LV terminals and short lines. The functionality and performance of the proposed overcurrent protections can be summarized as seen in the table.

**Table 197: Proposed functionality of numerical transformer and busbar overcurrent protection. DT = definite time, IDMT = inverse definite minimum time**

| O/C-stage | Operating char. | Selectivity mode         | Operation speed | Sensitivity |
|-----------|-----------------|--------------------------|-----------------|-------------|
| HV/3I>    | DT/IDMT         | time selective           | low             | very high   |
| HV/3I>>   | DT              | blockable/time selective | high/low        | high        |
| HV/3I>>>  | DT              | current selective        | very high       | low         |
| LV/3I>    | DT/IDMT         | time selective           | low             | very high   |
| LV/3I>>   | DT              | time selective           | low             | high        |
| LV/3I>>>  | DT              | blockable                | high            | high        |

In case the bus-tie breaker is open, the operating time of the blockable overcurrent protection is approximately 100 ms (relaying time). When the bus-tie breaker is closed, that is, the fault current flows to the faulted section of the busbar from two directions, the operation time becomes as follows: first the bus-tie relay unit trips the tie breaker in the above 100 ms, which reduces the fault current to a half. After this the incoming feeder relay unit of the faulted bus section trips the breaker in approximately 250 ms (relaying time), which becomes the total fault clearing time in this case.

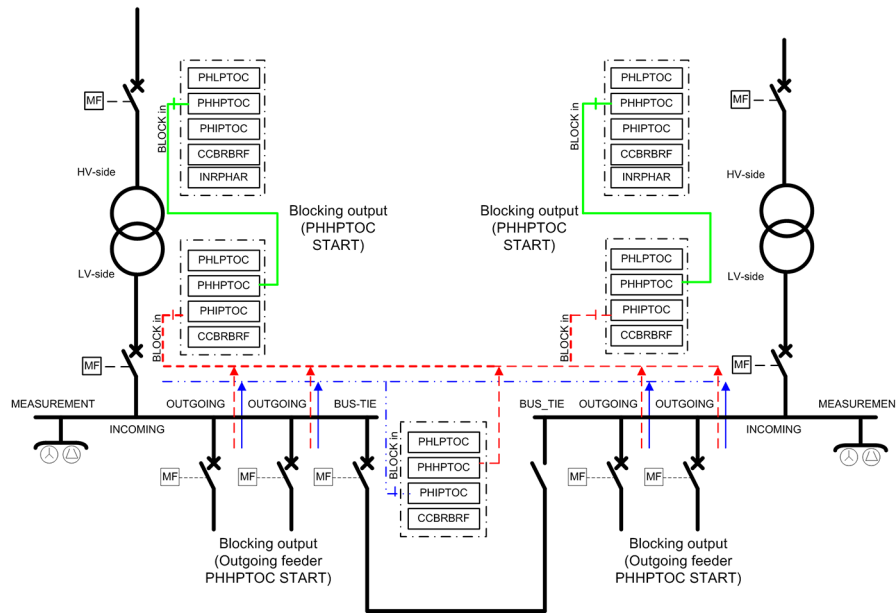


Figure 82: Numerical overcurrent protection functionality for a typical subtransmission/distribution substation (feeder protection not shown). Blocking output = digital output signal from the start of a protection stage, Blocking in = digital input signal to block the operation of a protection stage

The operating times of the time selective stages are very short, because the grading margins between successive protection stages can be kept short. This is mainly due to the advanced measuring principle allowing a certain degree of CT saturation, good operating accuracy and short retardation times of the numerical units. So, for example, a grading margin of 150 ms in the DT mode of operation can be used, provided that the circuit breaker interrupting time is shorter than 60 ms.

The sensitivity and speed of the current-selective stages become as good as possible due to the fact that the transient overreach is very low. Also, the effects of switching inrush currents on the setting values can be reduced by using the IED's logic, which recognizes the transformer energizing inrush current and blocks the operation or multiplies the current start value setting of the selected overcurrent stage with a predefined multiplier setting.

Finally, a dependable trip of the overcurrent protection is secured by both a proper selection of the settings and an adequate ability of the measuring transformers to reproduce the fault current. This is important in order to maintain selectivity and also for the protection to operate without additional time delays. For additional information about available measuring modes and current transformer requirements, see [Chapter 10.5 Measurement modes](#) in this manual.

### Radial outgoing feeder overcurrent protection

The basic requirements for feeder overcurrent protection are adequate sensitivity and operation speed taking into account the minimum and maximum fault current levels along the protected line, selectivity requirements, inrush currents and the thermal and mechanical withstand of the lines to be protected.

In many cases the above requirements can be best fulfilled by using multiple-stage overcurrent units. [Figure 83](#) shows an example of this. A brief coordination study has been carried out between the incoming and outgoing feeders.

The protection scheme is implemented with three-stage numerical overcurrent protection, where the low-set stage PHLPTOC operates in IDMT-mode and the two higher stages PHHPTOC and PHIPTOC in DT-mode. Also the thermal withstand of the line types along the feeder and maximum expected inrush currents of the feeders are shown. Faults occurring near the station where the fault current levels are the highest are cleared rapidly by the instantaneous stage in order to minimize the effects of severe short circuit faults. The influence of the inrush current is taken into consideration by connecting the inrush current detector to the start value multiplying input of the instantaneous stage. By this way the start value is multiplied with a predefined setting during the inrush situation and nuisance tripping can be avoided.

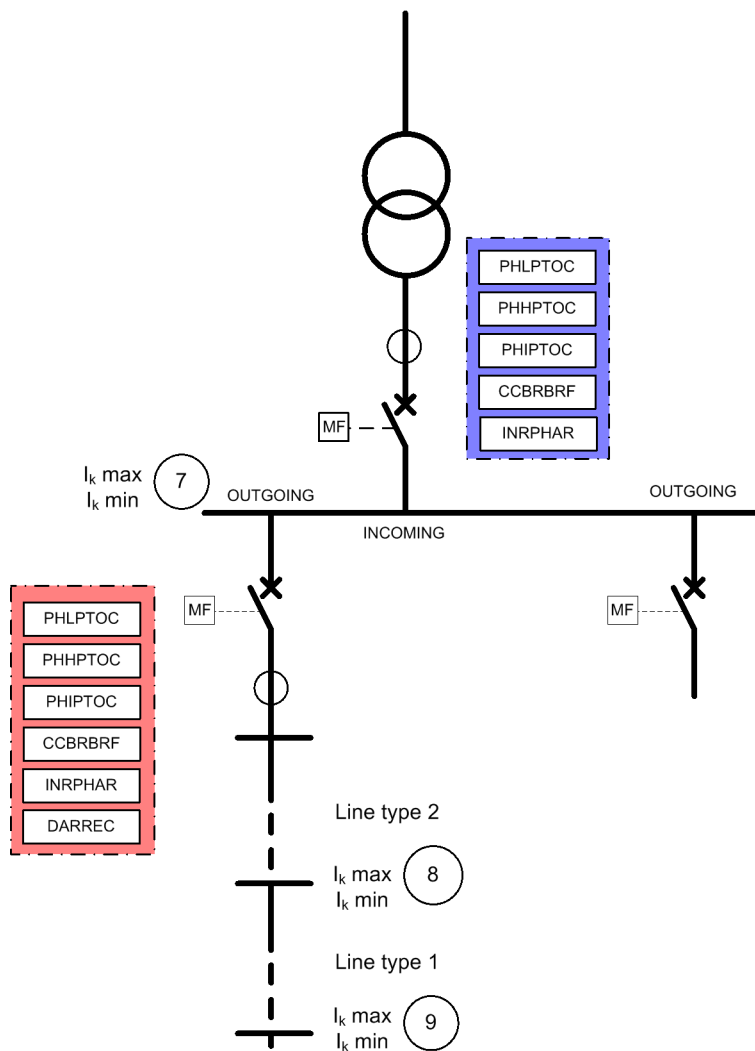


Figure 83: Functionality of numerical multiple-stage overcurrent protection

The coordination plan is an effective tool to study the operation of time selective operation characteristics. All the points mentioned earlier, required to define the overcurrent protection parameters, can be expressed simultaneously in a coordination plan. In [Figure 83](#), the coordination plan shows an example of operation characteristics in the LV-side incoming feeder and radial outgoing feeder.

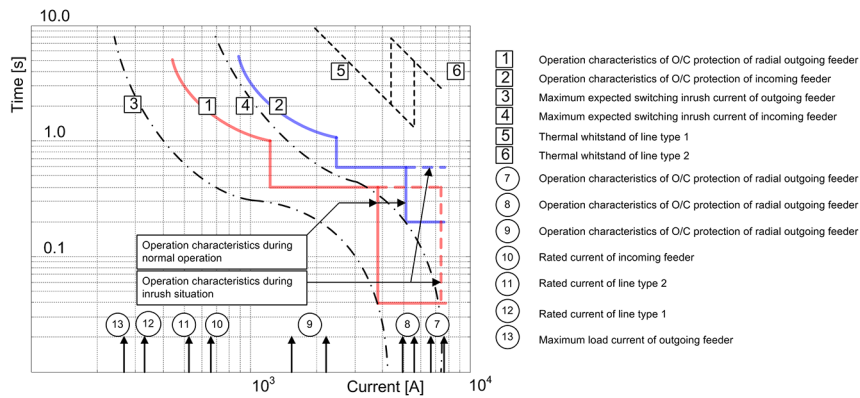


Figure 84: Example coordination of numerical multiple-stage overcurrent protection

3.1.1.8

Signals

PHLPTOC Input signals

Table 198: PHLPTOC Input signals

| Name     | Type    | Default | Description                                   |
|----------|---------|---------|---|
| I_A      | SIGNAL  | 0       | Phase A current                               |
| I_B      | SIGNAL  | 0       | Phase B current                               |
| I_C      | SIGNAL  | 0       | Phase C current                               |
| BLOCK    | BOOLEAN | 0=False | Block signal for activating the blocking mode |
| ENA_MULT | BOOLEAN | 0=False | Enable signal for current multiplier          |

PHHPTOC Input signals

Table 199: PHHPTOC Input signals

| Name     | Type    | Default | Description                                   |
|----------|---------|---------|---|
| I_A      | SIGNAL  | 0       | Phase A current                               |
| I_B      | SIGNAL  | 0       | Phase B current                               |
| I_C      | SIGNAL  | 0       | Phase C current                               |
| BLOCK    | BOOLEAN | 0=False | Block signal for activating the blocking mode |
| ENA_MULT | BOOLEAN | 0=False | Enable signal for current multiplier          |



**PHIPTOC Input signals****Table 200: PHIPTOC Input signals**

| Name     | Type    | Default | Description                                   |
|----------|---------|---------|---|
| I_A      | SIGNAL  | 0       | Phase A current                               |
| I_B      | SIGNAL  | 0       | Phase B current                               |
| I_C      | SIGNAL  | 0       | Phase C current                               |
| BLOCK    | BOOLEAN | 0=False | Block signal for activating the blocking mode |
| ENA_MULT | BOOLEAN | 0=False | Enable signal for current multiplier          |

**PHLPTOC Output signals****Table 201: PHLPTOC Output signals**

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

**PHHPTOC Output signals****Table 202: PHHPTOC Output signals**

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

**PHIPTOC Output signals****Table 203: PHIPTOC Output signals**

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

**3.1.1.9****Settings**

**PHLPTOC Settings**

**Table 204: PHLPTOC Group settings (Basic)**

| Parameter            | Values (Range)   | Unit | Step | Default          | Description                             |
|----------------------|--|------|------|------------------|---|
| Start value          | 0.05...5.00  | xIn  | 0.01 | 0.05             | Start value                             |
| Start value Mult     | 0.8...10.0   |      | 0.1  | 1.0              | Multiplier for scaling the start value  |
| Time multiplier      | 0.05...15.00   |      | 0.01 | 1.00             | Time multiplier in IEC/ANSI IDMT curves |
| Operate delay time   | 40...200000  | ms   | 10   | 40               | Operate delay time                      |
| Operating curve type | 1=ANSI Ext. inv.<br>2=ANSI Very inv.<br>3=ANSI Norm. inv.<br>4=ANSI Mod. inv.<br>5=ANSI Def. Time<br>6=L.T.E. inv.<br>7=L.T.V. inv.<br>8=L.T. inv.<br>9=IEC Norm. inv.<br>10=IEC Very inv.<br>11=IEC inv.<br>12=IEC Ext. inv.<br>13=IEC S.T. inv.<br>14=IEC L.T. inv.<br>15=IEC Def. Time<br>17=Programmable<br>18=RI type<br>19=RD type |      |      | 15=IEC Def. Time | Selection of time delay curve type      |

**Table 205: PHLPTOC Group settings (Advanced)**

| Parameter           | Values (Range)                                       | Unit | Step | Default     | Description                   |
|---------------------|--|------|------|-------------|-------------------------------|
| Type of reset curve | 1=Immediate<br>2=Def time re-set<br>3=Inverse re-set |      |      | 1=Immediate | Selection of reset curve type |

**Table 206: PHLPTOC Non group settings (Basic)**

| Parameter           | Values (Range)                               | Unit | Step | Default      | Description                                      |
|---------------------|--|------|------|--------------|--|
| Operation           | 1=on<br>5=off                                |      |      | 1=on         | Operation Off / On                               |
| Num of start phases | 1=1 out of 3<br>2=2 out of 3<br>3=3 out of 3 |      |      | 1=1 out of 3 | Number of phases required for operate activation |
| Curve parameter A   | 0.0086...120.000                             |      | 1    | 28.2000      | Parameter A for customer programmable curve      |
| Curve parameter B   | 0.0000...0.7120                              |      | 1    | 0.1217       | Parameter B for customer programmable curve      |
| Curve parameter C   | 0.02...2.00                                  |      | 1    | 2.00         | Parameter C for customer programmable curve      |
| Curve parameter D   | 0.46...30.00                                 |      | 1    | 29.10        | Parameter D for customer programmable curve      |
| Curve parameter E   | 0.0...1.0                                    |      | 1    | 1.0          | Parameter E for customer programmable curve      |

**Table 207: PHLPTOC Non group settings (Advanced)**

| Parameter            | Values (Range)                                    | Unit | Step | Default | Description                          |
|----------------------|---|------|------|---------|--------------------------------------|
| Minimum operate time | 20...60000  | ms   | 1    | 20      | Minimum operate time for IDMT curves |
| Reset delay time     | 0...60000   | ms   | 1    | 20      | Reset delay time                     |
| Measurement mode     | 1=RMS<br>2=DFT<br>3=Peak-to-Peak<br>5=Wide P-to-P |      |      | 2=DFT   | Selects used measurement mode        |

**PHHPTOC Settings**

**Table 208: PHHPTOC Group settings (Basic)**

| Parameter            | Values (Range)  | Unit | Step | Default          | Description                             |
|----------------------|---|------|------|------------------|---|
| Start value          | 0.10...40.00  | xIn  | 0.01 | 0.10             | Start value                             |
| Start value Mult     | 0.8...10.0  |      | 0.1  | 1.0              | Multiplier for scaling the start value  |
| Time multiplier      | 0.05...15.00  |      | 0.01 | 1.00             | Time multiplier in IEC/ANSI IDMT curves |
| Operate delay time   | 40...200000   | ms   | 10   | 40               | Operate delay time                      |
| Operating curve type | 1=ANSI Ext. inv.<br>3=ANSI Norm. inv.<br>5=ANSI Def. Time<br>9=IEC Norm. inv.<br>10=IEC Very inv.<br>12=IEC Ext. inv.<br>15=IEC Def. Time |      |      | 15=IEC Def. Time | Selection of time delay curve type      |

| Parameter | Values (Range)  | Unit | Step | Default | Description |
|-----------|-----------------|------|------|---------|-------------|
|           | 17=Programmable |      |      |         |             |

**Table 209: PHHPTOC Group settings (Advanced)**

| Parameter           | Values (Range)                                     | Unit | Step | Default     | Description                   |
|---------------------|--|------|------|-------------|-------------------------------|
| Type of reset curve | 1=Immediate<br>2=Def time reset<br>3=Inverse reset |      |      | 1=Immediate | Selection of reset curve type |

**Table 210: PHHPTOC Non group settings (Basic)**

| Parameter           | Values (Range)                               | Unit | Step | Default      | Description                                      |
|---------------------|--|------|------|--------------|--|
| Operation           | 1=on<br>5=off                                |      |      | 1=on         | Operation Off / On                               |
| Num of start phases | 1=1 out of 3<br>2=2 out of 3<br>3=3 out of 3 |      |      | 1=1 out of 3 | Number of phases required for operate activation |
| Curve parameter A   | 0.0086...120.0000                            |      | 1    | 28.2000      | Parameter A for customer programmable curve      |
| Curve parameter B   | 0.0000...0.7120                              |      | 1    | 0.1217       | Parameter B for customer programmable curve      |
| Curve parameter C   | 0.02...2.00                                  |      | 1    | 2.00         | Parameter C for customer programmable curve      |
| Curve parameter D   | 0.46...30.00                                 |      | 1    | 29.10        | Parameter D for customer programmable curve      |
| Curve parameter E   | 0.0...1.0                                    |      | 1    | 1.0          | Parameter E for customer programmable curve      |

**Table 211: PHHPTOC Non group settings (Advanced)**

| Parameter            | Values (Range)                   | Unit | Step | Default | Description                          |
|----------------------|----------------------------------|------|------|---------|--------------------------------------|
| Minimum operate time | 20...60000                       | ms   | 1    | 20      | Minimum operate time for IDMT curves |
| Reset delay time     | 0...60000                        | ms   | 1    | 20      | Reset delay time                     |
| Measurement mode     | 1=RMS<br>2=DFT<br>3=Peak-to-Peak |      |      | 2=DFT   | Selects used measurement mode        |

**PHIPTOC Settings****Table 212: PHIPTOC Group settings (Basic)**

| Parameter          | Values (Range) | Unit | Step | Default | Description                            |
|--------------------|----------------|------|------|---------|--|
| Start value        | 1.00...40.00   | xIn  | 0.01 | 1.00    | Start value                            |
| Start value Mult   | 0.8...10.0     |      | 0.1  | 1.0     | Multiplier for scaling the start value |
| Operate delay time | 20...200000    | ms   | 10   | 20      | Operate delay time                     |

**Table 213: PHIPTOC Non group settings (Basic)**

| Parameter           | Values (Range)                               | Unit | Step | Default      | Description                                      |
|---------------------|--|------|------|--------------|--|
| Operation           | 1=on<br>5=off                                |      |      | 1=on         | Operation Off / On                               |
| Num of start phases | 1=1 out of 3<br>2=2 out of 3<br>3=3 out of 3 |      |      | 1=1 out of 3 | Number of phases required for operate activation |

**Table 214: PHIPTOC Non group settings (Advanced)**

| Parameter        | Values (Range) | Unit | Step | Default | Description      |
|------------------|----------------|------|------|---------|------------------|
| Reset delay time | 0...60000      | ms   | 1    | 20      | Reset delay time |

### 3.1.1.10 Monitored data

#### PHLPTOC Monitored data

Table 215: PHLPTOC Monitored data

| Name      | Type    | Values (Range)   | Unit | Description                        |
|-----------|---------|--|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time |
| PHLPTOC   | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                             |

#### PHHPTOC Monitored data

Table 216: PHHPTOC Monitored data

| Name      | Type    | Values (Range)   | Unit | Description                        |
|-----------|---------|--|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time |
| PHHPTOC   | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                             |

#### PHIPTOC Monitored data

Table 217: PHIPTOC Monitored data

| Name      | Type    | Values (Range)   | Unit | Description                        |
|-----------|---------|--|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time |
| PHIPTOC   | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                             |

### 3.1.1.11 Technical data

| Characteristic                              |  | Value  |                |                |
|---|--|--|----------------|----------------|
| Operation accuracy                          | PHLPTOC  | Depending on the frequency of the measured current:<br>$f_n \pm 2 \text{ Hz}$  |                |                |
|   |  | $\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$   |                |                |
|   | PHHPTOC and PHIPTOC  | $\pm 1.5\%$ of set value or $\pm 0.002 \times I_n$ (at currents in the range of $0.1 \dots 10 \times I_n$ ) $\pm 5.0\%$ of the set value (at currents in the range of $10 \dots 40 \times I_n$ ) |                |                |
| Start time <sup>2122</sup>                  | PHIPTOC: $I_{\text{Fault}} = 2 \times \text{set Start value}$<br>$I_{\text{Fault}} = 10 \times \text{set Start value}$ | Minimum  | Typical        | Maximum        |
|   |  | 16 ms<br>11 ms   | 19 ms<br>12 ms | 23 ms<br>14 ms |
|   | PHHPTOC and PHLPTOC: $I_{\text{Fault}} = 2 \times \text{set Start value}$  | 23 ms  | 26 ms          | 29 ms          |
| Reset time                                  |  | Typically 40 ms  |                |                |
| Reset ratio                                 |  | Typically 0.96   |                |                |
| Retardation time                            |  | <30 ms   |                |                |
| Operate time accuracy in definite time mode |  | $\pm 1.0\%$ of the set value or $\pm 20 \text{ ms}$  |                |                |
| Operate time accuracy in inverse time mode  |  | $\pm 5.0\%$ of the theoretical value or $\pm 20 \text{ ms}$ <sup>23</sup>  |                |                |
| Suppression of harmonics                    |  | RMS: No suppression DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$ Peak-to-Peak: No suppression P-to-P+backup: No suppression   |                |                |

### 3.1.1.12 Technical revision history

Table 218: PHxPTOC Technical revision history

| Technical revision | Change              |
|--------------------|---------------------|
| B                  | Modified for SSC600 |

## 3.1.2 Three-phase directional overcurrent protection DPHxPDOC

<sup>21</sup> Measurement mode = default (depends on stage), current before fault =  $0.0 \times I_n$ ,  $f_n = 50 \text{ Hz}$ , fault current in one phase with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements

<sup>22</sup> Includes the delay of the signal output contact

<sup>23</sup> Maximum Start value =  $2.5 \times I_n$ , Start value multiples in range of 1.5...20



### 3.1.2.1 Identification

| Function description                                       | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--|--------------------------|--------------------------|-------------------------------|
| Three-phase directional overcurrent protection, low stage  | DPHLPDOC                 | 3I> ->                   | 67-1                          |
| Three-phase directional overcurrent protection, high stage | DPHHPDOC                 | 3I>> ->                  | 67-2                          |

### 3.1.2.2 Function block

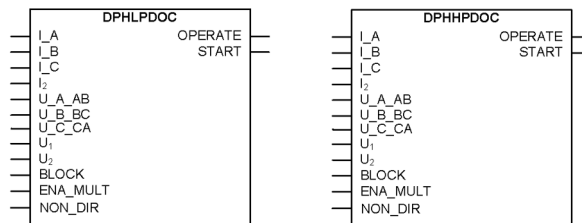


Figure 85: Function block

### 3.1.2.3 Functionality

The three-phase directional overcurrent protection function DPHxPDOC is used as one-phase, two-phase or three-phase directional overcurrent and short-circuit protection for feeders.

DPHxPDOC starts up when the value of the current exceeds the set limit and directional criterion is fulfilled. The operate time characteristics for low stage DPHLPDOC and high stage DPHHPDOC can be selected to be either definite time (DT) or inverse definite minimum time (IDMT).

In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

### 3.1.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of DPHxPDOC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

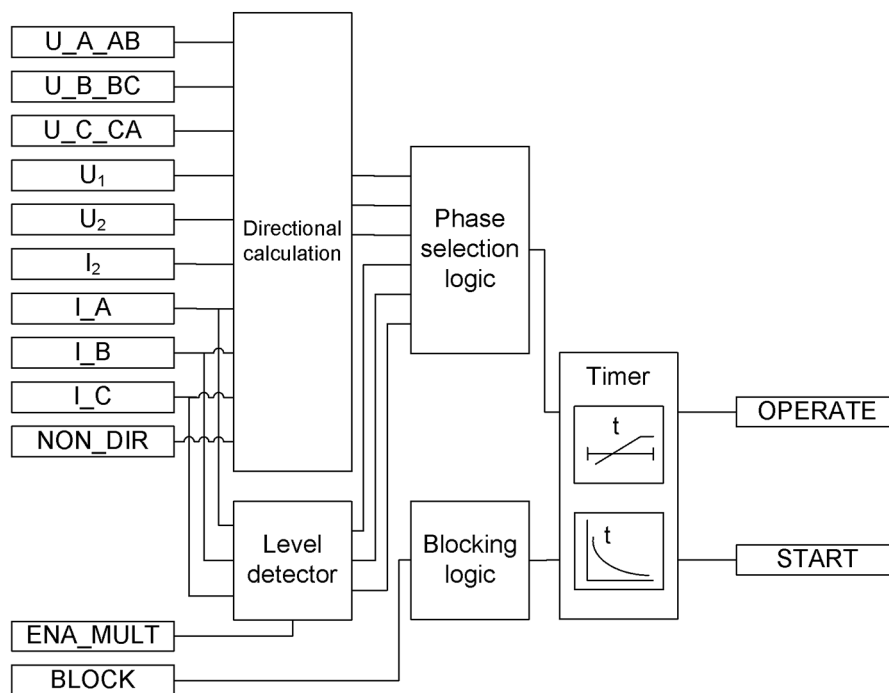


Figure 86: Functional module diagram

**Directional calculation**

The directional calculation compares the current phasors to the polarizing phasor. A suitable polarization quantity can be selected from the different polarization quantities, which are the positive sequence voltage, negative sequence voltage, self-polarizing (faulted) voltage and cross-polarizing voltages (healthy voltages). The polarizing method is defined with the Pol quantity setting.

**Table 219: Polarizing quantities**

| Polarizing quantity | Description               |
|---------------------|---------------------------|
| Pos. seq. volt      | Positive sequence voltage |
| Neg. seq. volt      | Negative sequence voltage |
| Self pol            | Self-polarization         |
| Cross pol           | Cross-polarization        |

The directional operation can be selected with the *Directional mode* setting. The user can select either "Non-directional", "Forward" or "Reverse" operation. By setting the value of *Allow Non Dir* to "True", the non-directional operation is allowed when the directional information is invalid.

The *Characteristic angle* setting is used to turn the directional characteristic. The value of *Characteristic angle* should be chosen in such a way that all the faults in the operating direction are seen in the operating zone and all the faults in the opposite direction are seen in the non-operating zone. The value of *Characteristic angle* depends on the network configuration.

Reliable operation requires both the operating and polarizing quantities to exceed certain minimum amplitude levels. The minimum amplitude level for the operating quantity (current) is set with the *Min operate current* setting. The minimum

amplitude level for the polarizing quantity (voltage) is set with the *Min operate voltage* setting. If the amplitude level of the operating quantity or polarizing quantity is below the set level, the direction information of the corresponding phase is set to "Unknown".

The polarizing quantity validity can remain valid even if the amplitude of the polarizing quantity falls below the value of the *Min operate voltage* setting. In this case, the directional information is provided by a special memory function for a time defined with the *Voltage Mem time* setting.

DPHxPDOC is provided with a memory function to secure a reliable and correct directional IED operation in case of a close short circuit or an earth fault characterized by an extremely low voltage. At sudden loss of the polarization quantity, the angle difference is calculated on the basis of a fictive voltage. The fictive voltage is calculated using the positive phase sequence voltage measured before the fault occurred, assuming that the voltage is not affected by the fault. The memory function enables the function to operate up to a maximum of three seconds after a total loss of voltage. This time can be set with the *Voltage Mem time* setting. The voltage memory cannot be used for the "Negative sequence voltage" polarization because it is not possible to substitute the positive sequence voltage for negative sequence voltage without knowing the network unsymmetry level. This is the reason why the fictive voltage angle and corresponding direction information are frozen immediately for this polarization mode when the need for a voltage memory arises and these are kept frozen until the time set with *Voltage Mem time* elapses.



The value for the *Min operate voltage* setting should be carefully selected since the accuracy in low signal levels is strongly affected by the measuring device accuracy.

When the voltage falls below *Min operate voltage* at a close fault, the fictive voltage is used to determine the phase angle. The measured voltage is applied again as soon as the voltage rises above *Min operate voltage* and hysteresis. The fictive voltage is also discarded if the measured voltage stays below *Min operate voltage* and hysteresis for longer than *Voltage Mem time* or if the fault current disappears while the fictive voltage is in use. When the voltage is below *Min operate voltage* and hysteresis and the fictive voltage is unusable, the fault direction cannot be determined. The fictive voltage can be unusable for two reasons:

- The fictive voltage is discarded after *Voltage Mem time*
- The phase angle cannot be reliably measured before the fault situation.

DPHxPDOC can be forced to the non-directional operation with the NON\_DIR input. When the NON\_DIR input is active, DPHxPDOC operates as a non-directional overcurrent protection, regardless of the *Directional mode* setting.

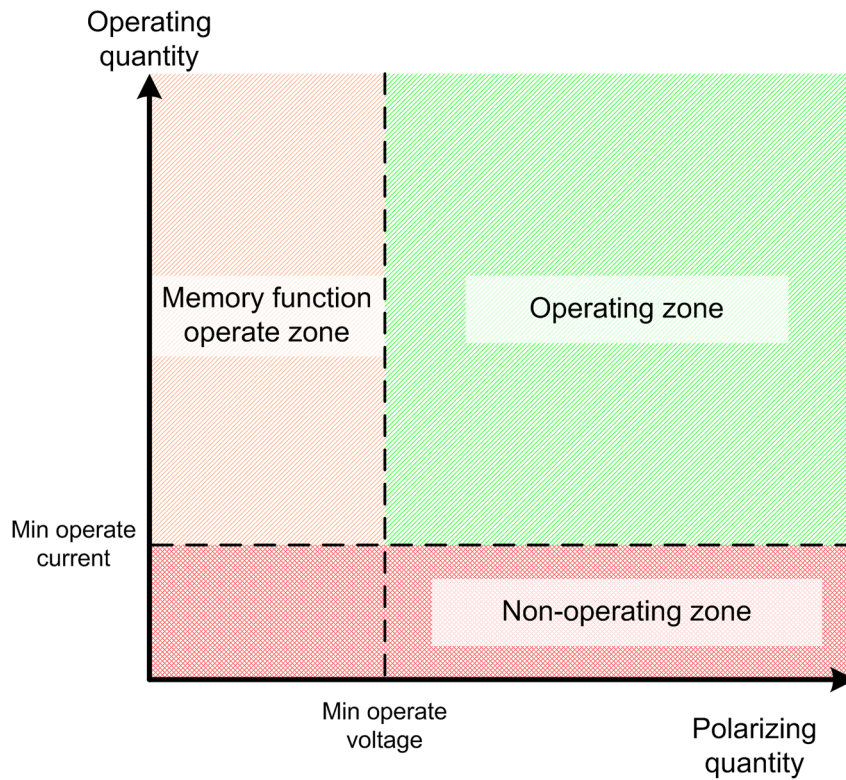


Figure 87: Operating zones at minimum magnitude levels

**Level detector**

The measured phase currents are compared phase-wise to the set *Start value*. If the measured value exceeds the set *Start value*, the level detector reports the exceeding of the value to the phase selection logic. If the ENA\_MULT input is active, the *Start value* setting is multiplied by the *Start value Mult* setting.



The IED does not accept the *Start value* or *Start value Mult* setting if the product of these settings exceeds the *Start value* setting range.

The start value multiplication is normally done when the inrush detection function (INRPHAR) is connected to the ENA\_MULT input.

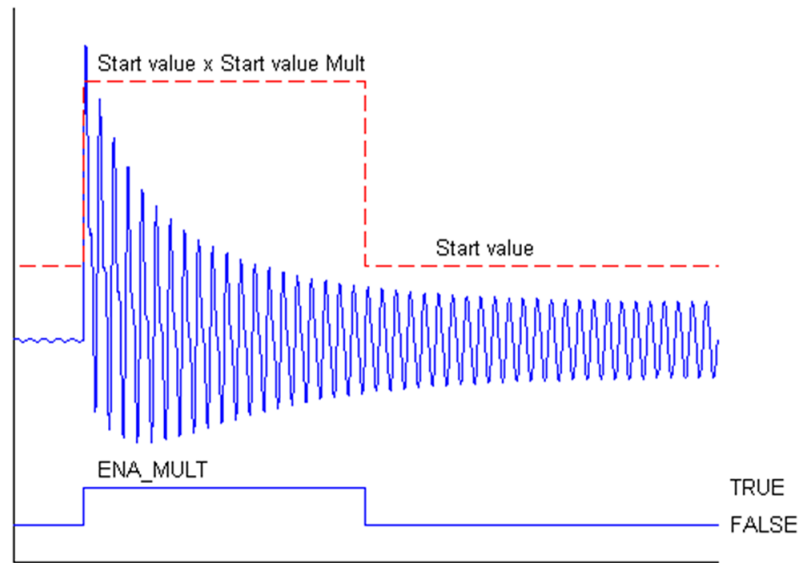


Figure 88: Start value behavior with ENA\_MULT input activated

### Phase selection logic

If the fault criteria are fulfilled in the level detector and the directional calculation, the phase selection logic detects the phase or phases in which the measured current exceeds the setting. If the phase information matches the *Num of start phases* setting, the phase selection logic activates the timer module.

### Timer

Once activated, the timer activates the START output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the OPERATE output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation happens, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation. The START output is deactivated when the reset timer has elapsed.



The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.



The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see the IDMT curves for overcurrent protection section in this manual.

The timer calculates the start duration value *START\_DUR*, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

**Blocking logic**

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration > System > Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

**3.1.2.5**

**Measurement modes**

The function operates on three alternative measurement modes: "RMS", "DFT" and "Peak-to-Peak" . The measurement mode is selected with the *Measurement mode* setting.

**Table 220: Measurement modes supported by DPHxPDOC stages**

| Measurement mode | DPHLPDOC | DPHHPDOC |
|------------------|----------|----------|
| RMS              | x        | x        |
| DFT              | x        | x        |
| Peak-to-Peak     | x        | x        |

**3.1.2.6**

**Directional overcurrent characteristics**

The forward and reverse sectors are defined separately. The forward operation area is limited with the *Min forward angle* and *Max forward angle* settings. The reverse operation area is limited with the *Min reverse angle* and *Max reverse angle* settings.



The sector limits are always given as positive degree values.

In the forward operation area, the *Max forward angle* setting gives the counterclockwise sector and the *Min forward angle* setting gives the corresponding clockwise sector, measured from the *Characteristic angle* setting.

In the backward operation area, the *Max reverse angle* setting gives the counterclockwise sector and the *Min reverse angle* setting gives the corresponding clockwise sector, a measurement from the *Characteristic angle* setting that has been rotated 180 degrees.

Relay characteristic angle (RCA) is set positive if the operating current lags the polarizing quantity and negative if the operating current leads the polarizing quantity.

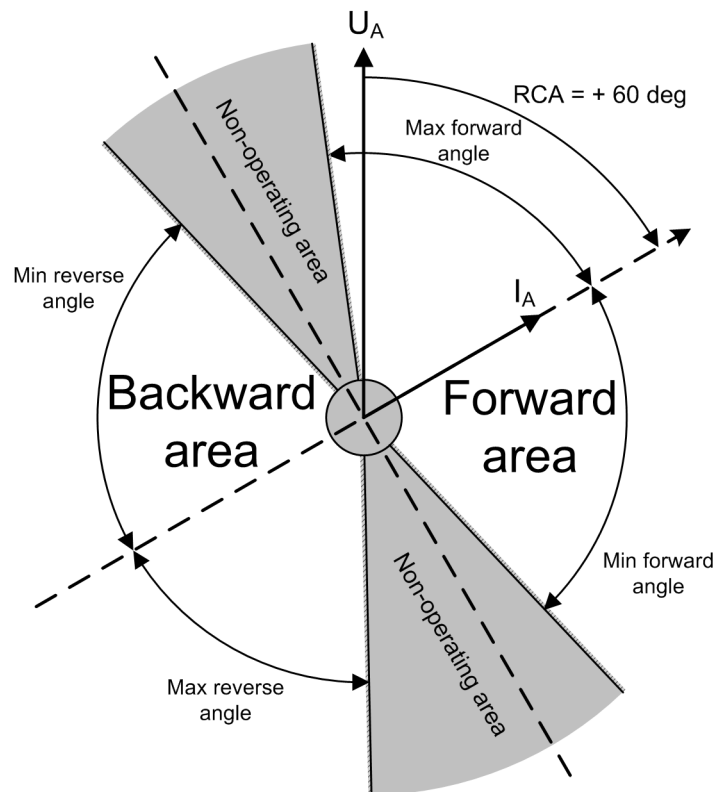


Figure 89: Configurable operating sectors

Table 221: Momentary per phase direction value for monitored data view

| Criterion for per phase direction information  | The value for DIR_A/_B/_C |
|--|---------------------------|
| The ANGLE_X is not in any of the defined sectors, or the direction cannot be defined due too low amplitude | 0 = unknown               |
| The ANGLE_X is in the forward sector   | 1 = forward               |

Table continues on the next page

| Criterion for per phase direction information   | The value for DIR_A/_B/_C |
|---|---------------------------|
| The ANGLE_X is in the reverse sector  | 2 = backward              |
| (The ANGLE_X is in both forward and reverse sectors, that is, when the sectors are overlapping) | 3 = both                  |

**Table 222: Momentary phase combined direction value for monitored data view**

| Criterion for phase combined direction information   | The value for DIRECTION |
|--|-------------------------|
| The direction information (DIR_X) for all phases is unknown                                | 0 = unknown             |
| The direction information (DIR_X) for at least one phase is forward, none being in reverse | 1 = forward             |
| The direction information (DIR_X) for at least one phase is reverse, none being in forward | 2 = backward            |
| The direction information (DIR_X) for some phase is forward and for some phase is reverse  | 3 = both                |

FAULT\_DIR gives the detected direction of the fault during fault situations, that is, when the START output is active

#### Self-polarizing as polarizing method

| Faulted phases | Used fault current | Used polarizing voltage | Angle difference   |
|----------------|--------------------|-------------------------|--|
| A              | $I_A$              | $U_A$                   | $ANGLE\_A = \phi(U_A) - \phi(I_A) - \phi_{RCA}$          |
| B              | $I_B$              | $U_B$                   | $ANGLE\_B = \phi(U_B) - \phi(I_B) - \phi_{RCA}$          |
| C              | $I_C$              | $U_C$                   | $ANGLE\_C = \phi(U_C) - \phi(I_C) - \phi_{RCA}$          |
| A-B            | $I_A - I_B$        | $U_{AB}$                | $ANGLE\_A = \phi(U_{AB}) - \phi(I_A - I_B) - \phi_{RCA}$ |
| B-C            | $I_B - I_C$        | $U_{BC}$                | $ANGLE\_B = \phi(U_{BC}) - \phi(I_B - I_C) - \phi_{RCA}$ |
| C-A            | $I_C - I_A$        | $U_{CA}$                | $ANGLE\_B = \phi(U_{CA}) - \phi(I_C - I_A) - \phi_{RCA}$ |

In an example case of the phasors in a single-phase earth fault where the faulted phase is phase A, the angle difference between the polarizing quantity  $U_A$  and operating quantity  $I_A$  is marked as  $\phi$ . In the self-polarization method, there is no need to rotate the polarizing quantity.



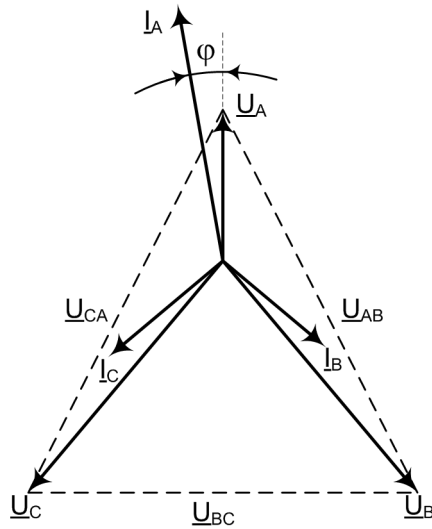


Figure 90: Single-phase earth fault, phase A

In an example case of a two-phase short-circuit failure where the fault is between phases B and C, the angle difference is measured between the polarizing quantity  $U_{BC}$  and operating quantity  $I_B - I_C$  in the self-polarizing method.

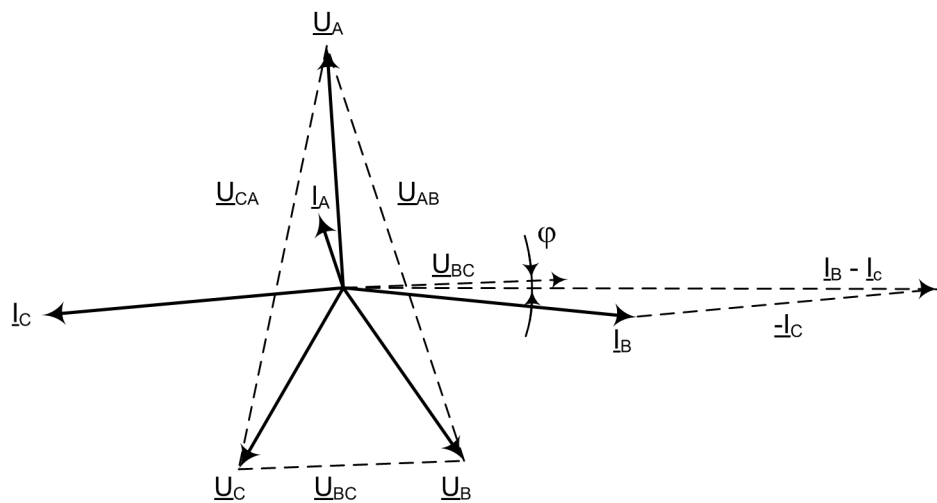


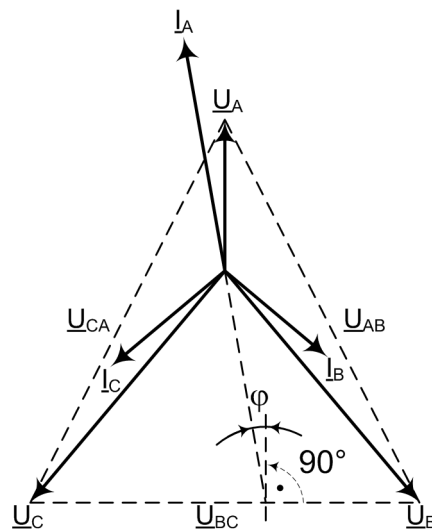
Figure 91: Two-phase short circuit, short circuit is between phases B and C

**Cross-polarizing as polarizing quantity**

**Table 223: Equations for calculating angle difference for cross-polarizing method**

| Faulted phases | Used fault current | Used polarizing voltage | Angle difference   |
|----------------|--------------------|-------------------------|--|
| A              | $I_A$              | $U_{BC}$                | $ANGLE\_A = \phi(U_{BC}) - \phi(I_A) - \phi_{RCA} + 90^\circ$                |
| B              | $I_B$              | $U_{CA}$                | $ANGLE\_A = \phi(U_{CA}) - \phi(I_B) - \phi_{RCA} + 90^\circ$                |
| C              | $I_C$              | $U_{AB}$                | $ANGLE\_A = \phi(U_{AB}) - \phi(I_C) - \phi_{RCA} + 90^\circ$                |
| A - B          | $I_A - I_B$        | $U_{BC} - U_{CA}$       | $ANGLE\_A = \phi(U_{BC} - U_{CA}) - \phi(I_A - I_B) - \phi_{RCA} + 90^\circ$ |
| B - C          | $I_B - I_C$        | $U_{CA} - U_{AB}$       | $ANGLE\_A = \phi(U_{CA} - U_{AB}) - \phi(I_B - I_C) - \phi_{RCA} + 90^\circ$ |
| C - A          | $I_C - I_A$        | $U_{AB} - U_{BC}$       | $ANGLE\_A = \phi(U_{AB} - U_{BC}) - \phi(I_C - I_A) - \phi_{RCA} + 90^\circ$ |

The angle difference between the polarizing quantity  $U_{BC}$  and operating quantity  $I_A$  is marked as  $\phi$  in an example of the phasors in a single-phase earth fault where the faulted phase is phase A. The polarizing quantity is rotated with 90 degrees. The characteristic angle is assumed to be  $\sim 0$  degrees.



*Figure 92: Single-phase earth fault, phase A*

In an example of the phasors in a two-phase short-circuit failure where the fault is between the phases B and C, the angle difference is measured between the polarizing quantity  $U_{AB}$  and operating quantity  $I_B - I_C$  marked as  $\phi$ .

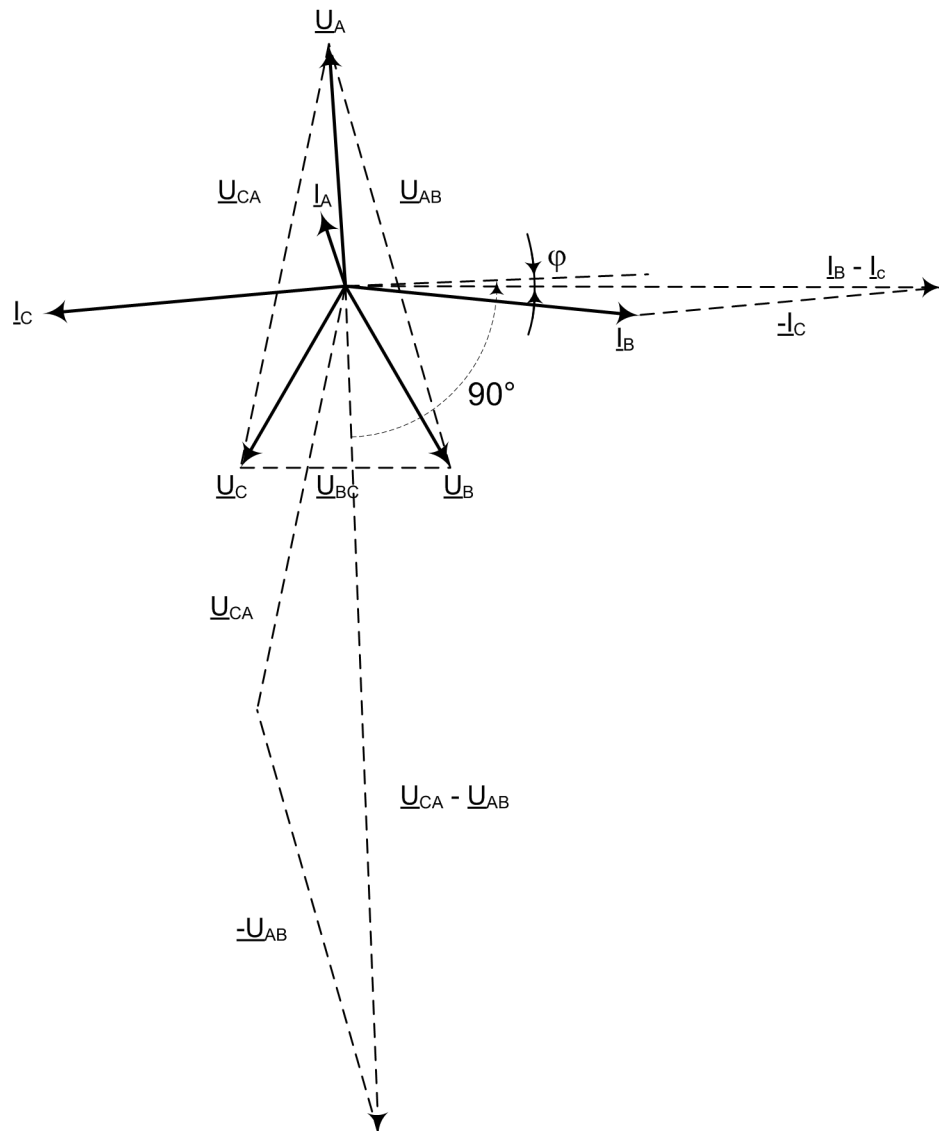


Figure 93: Two-phase short circuit, short circuit is between phases B and C



The equations are valid when network rotating direction is counterclockwise, that is, ABC. If the network rotating direction is reversed, 180 degrees is added to the calculated angle difference. This is done automatically with a system parameter *Phase rotation*.

**Negative sequence voltage as polarizing quantity**

When the negative voltage is used as the polarizing quantity, the angle difference between the operating and polarizing quantity is calculated with the same formula for all fault types:

$$ANGLE\_X = \phi(-\underline{U}_2) - \phi(\underline{I}_2) - \phi_{RCA}$$

(Equation 1)

This means that the actuating polarizing quantity is  $-\underline{U}_2$ .

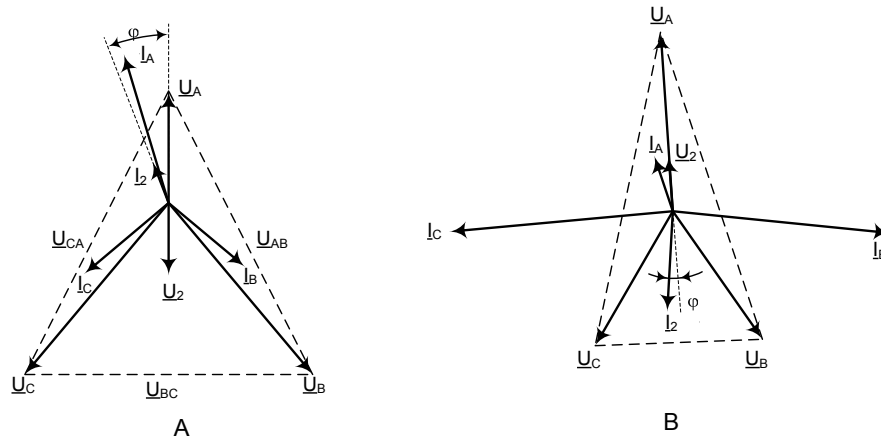


Figure 94: Phasors in a single-phase earth fault, phases A-N, and two-phase short circuit, phases B and C, when the actuating polarizing quantity is the negative-sequence voltage  $-U_2$

**Positive sequence voltage as polarizing quantity**

**Table 224: Equations for calculating angle difference for positive-sequence quantity polarizing method**

| Faulted phases | Used fault current | Used polarizing voltage | Angle difference  |
|----------------|--------------------|-------------------------|---|
| A              | $I_A$              | $U_1$                   | $ANGLE\_A = \phi(U_1) - \phi(I_A) - \phi_{RCA}$                   |
| B              | $I_B$              | $U_1$                   | $ANGLE\_B = \phi(U_1) - \phi(I_B) - \phi_{RCA} - 120^\circ$       |
| C              | $I_C$              | $U_1$                   | $ANGLE\_C = \phi(U_1) - \phi(I_C) - \phi_{RCA} + 120^\circ$       |
| A - B          | $I_A - I_B$        | $U_1$                   | $ANGLE\_A = \phi(U_1) - \phi(I_A - I_B) - \phi_{RCA} + 30^\circ$  |
| B - C          | $I_B - I_C$        | $U_1$                   | $ANGLE\_B = \phi(U_1) - \phi(I_B - I_C) - \phi_{RCA} - 90^\circ$  |
| C - A          | $I_C - I_A$        | $U_1$                   | $ANGLE\_C = \phi(U_1) - \phi(I_C - I_A) - \phi_{RCA} + 150^\circ$ |

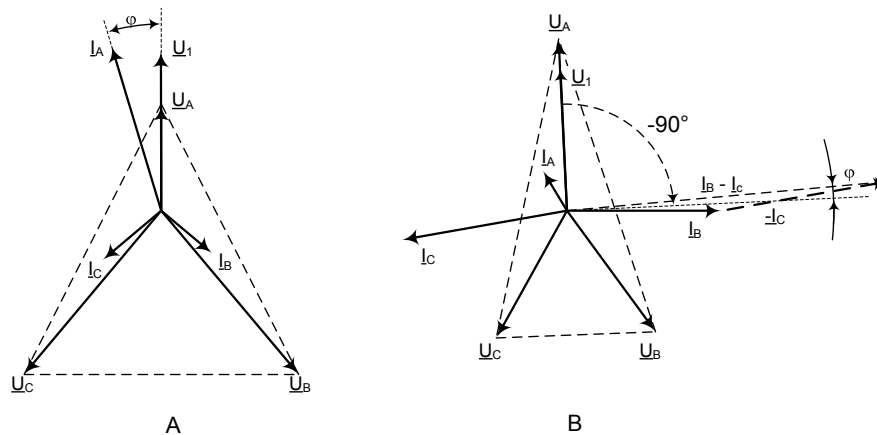


Figure 95: Phasors in a single-phase earth fault, phase A to ground, and a twophase short circuit, phases B-C, are short-circuited when the polarizing quantity is the positive-sequence voltage  $U_1$

**Network rotation direction**

Typically, the network rotating direction is counter-clockwise and defined as "ABC". If the network rotating direction is reversed, meaning clockwise, that is, "ACB", the equations for calculating the angle difference needs to be changed. The network rotating direction is defined with a system parameter Phase rotation. The change in the network rotating direction affects the phase-to-phase voltages polarization method where the calculated angle difference needs to be rotated 180 degrees. Also, when the sequence components are used, which are, the positive sequence voltage or negative sequence voltage components, the calculation of the components are affected but the angle difference calculation remains the same. When the phase-to-ground voltages are used as the polarizing method, the network rotating direction change has no effect on the direction calculation.



The network rotating direction is set in the IED using the parameter in the WHMI menu **Configuration > System > Phase rotation**. The default parameter value is "ABC".

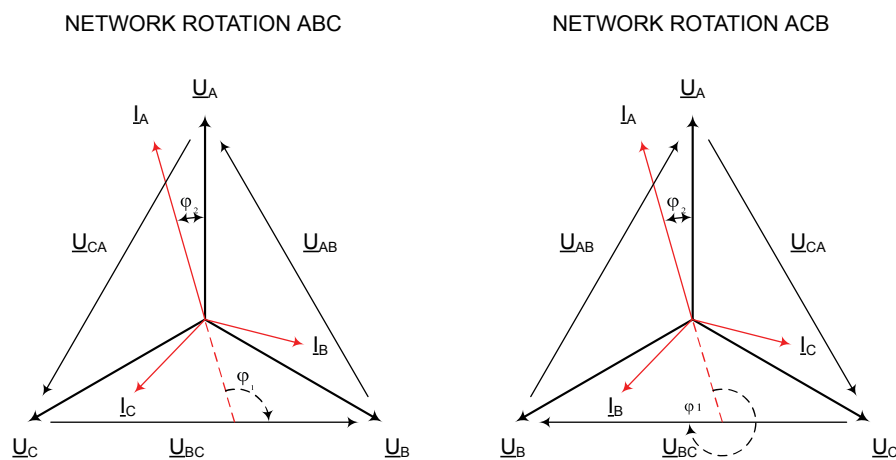


Figure 96: Examples of network rotating direction

### 3.1.2.7 Application

DPHxPDOC is used as short-circuit protection in three-phase distribution or sub transmission networks operating at 50 or 60 Hz.

In radial networks, phase overcurrent IEDs are often sufficient for the short circuit protection of lines, transformers and other equipment. The current-time characteristic should be chosen according to the common practice in the network. It is recommended to use the same current-time characteristic for all overcurrent IEDs in the network. This includes the overcurrent protection of transformers and other equipment.

The phase overcurrent protection can also be used in closed ring systems as short circuit protection. Because the setting of a phase overcurrent protection system in closed ring networks can be complicated, a large number of fault current calculations are needed. There are situations with no possibility to have the selectivity with a protection system based on overcurrent IEDs in a closed ring system.

In some applications, the possibility of obtaining the selectivity can be improved significantly if DPHxPDOC is used. This can also be done in the closed ring networks and radial networks with the generation connected to the remote in the system thus giving fault current infeed in reverse direction. Directional overcurrent IEDs are also used to have a selective protection scheme, for example in case of parallel distribution lines or power transformers fed by the same single source. In ring connected supply feeders between substations or feeders with two feeding sources, DPHxPDOC is also used.

#### Parallel lines or transformers

When the lines are connected in parallel and if a fault occurs in one of the lines, it is practical to have DPHxPDOC to detect the direction of the fault. Otherwise, there is a risk that the fault situation in one part of the feeding system can de-energize the whole system connected to the LV side.

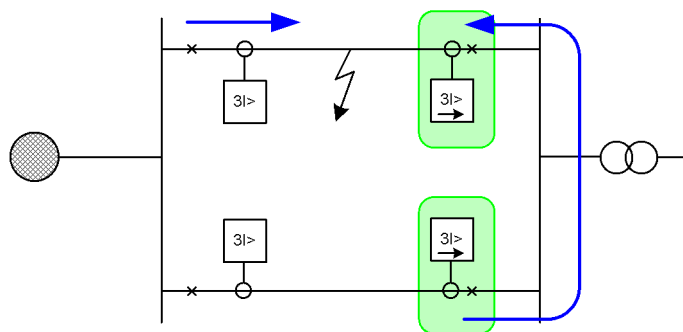


Figure 97: Overcurrent protection of parallel lines using directional IEDs

DPHxPDOC can be used for parallel operating transformer applications. In these applications, there is a possibility that the fault current can also be fed from the LV side up to the HV-side. Therefore, the transformer is also equipped with directional overcurrent protection.

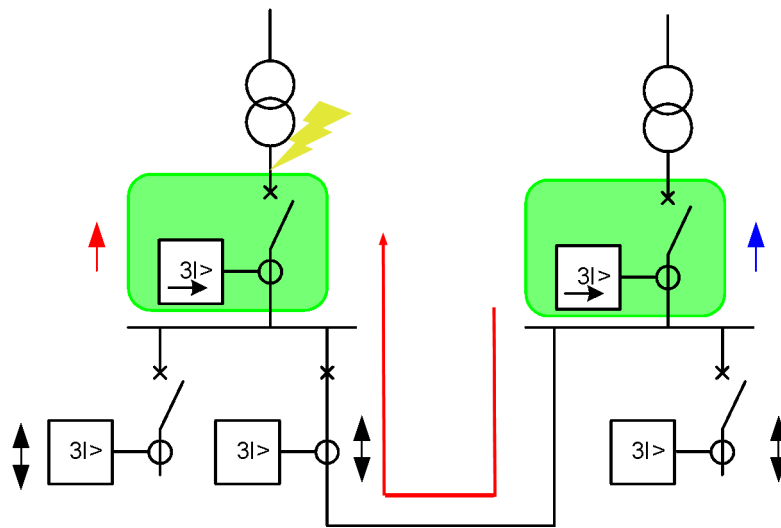


Figure 98: Overcurrent protection of parallel operating transformers

### Closed ring network topology

The closed ring network topology is used in applications where electricity distribution for the consumers is secured during network fault situations. The power is fed at least from two directions which means that the current direction can be varied. The time grading between the network level stages is challenging without unnecessary delays in the time settings. In this case, it is practical to use the directional overcurrent IEDs to achieve a selective protection scheme. Directional overcurrent functions can be used in closed ring applications. The arrows define the operating direction of the directional functionality. The double arrows define the nondirectional functionality where faults can be detected in both directions.

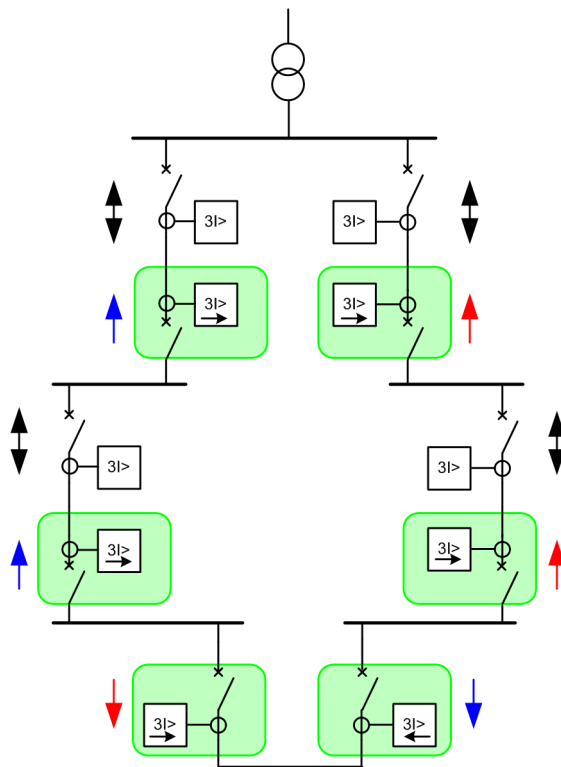


Figure 99: Closed ring network topology where feeding lines are protected with directional overcurrent IEDs

### 3.1.2.8

## Signals

### DPHLPDOC Input signals

Table 225: DPHLPDOC Input signals

| Name           | Type   | Default | Description   |
|----------------|--------|---------|---|
| I_A            | SIGNAL | 0       | Phase A current                                       |
| I_B            | SIGNAL | 0       | Phase B current                                       |
| I_C            | SIGNAL | 0       | Phase C current                                       |
| I <sub>2</sub> | SIGNAL | 0       | Negative phase sequence current                       |
| U_A_AB         | SIGNAL | 0       | Phase-to-earth voltage A or phase-to-phase voltage AB |
| U_B_BC         | SIGNAL | 0       | Phase-to-earth voltage B or phase-to-phase voltage BC |
| U_C_CA         | SIGNAL | 0       | Phase-to-earth voltage C or phase-to-phase voltage CA |

Table continues on the next page



| Name           | Type    | Default | Description                                   |
|----------------|---------|---------|---|
| U <sub>1</sub> | SIGNAL  | 0       | Positive phase sequence voltage               |
| U <sub>2</sub> | SIGNAL  | 0       | Negative phase sequence voltage               |
| BLOCK          | BOOLEAN | 0=False | Block signal for activating the blocking mode |
| ENA_MULT       | BOOLEAN | 0=False | Enabling signal for current multiplier        |
| NON_DIR        | BOOLEAN | 0=False | Forces protection to non-directional          |

### DPHHPDOC Input signals

Table 226: DPHHPDOC Input signals

| Name              | Type    | Default | Description   |
|-------------------|---------|---------|---|
| I <sub>A</sub>    | SIGNAL  | 0       | Phase A current                                       |
| I <sub>B</sub>    | SIGNAL  | 0       | Phase B current                                       |
| I <sub>C</sub>    | SIGNAL  | 0       | Phase C current                                       |
| I <sub>2</sub>    | SIGNAL  | 0       | Negative phase sequence current                       |
| U <sub>A_AB</sub> | SIGNAL  | 0       | Phase to earth voltage A or phase to phase voltage AB |
| U <sub>B_BC</sub> | SIGNAL  | 0       | Phase to earth voltage B or phase to phase voltage BC |
| U <sub>C_CA</sub> | SIGNAL  | 0       | Phase to earth voltage C or phase to phase voltage CA |
| U <sub>1</sub>    | SIGNAL  | 0       | Positive phase sequence voltage                       |
| U <sub>2</sub>    | SIGNAL  | 0       | Negative phase sequence voltage                       |
| BLOCK             | BOOLEAN | 0=False | Block signal for activating the blocking mode         |
| ENA_MULT          | BOOLEAN | 0=False | Enabling signal for current multiplier                |
| NON_DIR           | BOOLEAN | 0=False | Forces protection to non-directional                  |

**DPHLPDOC Output signals****Table 227: DPHLPDOC Output signals**

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

**DPHHPDOC Output signals****Table 228: DPHHPDOC Output signals**

| Name    | Type    | Description |
|---------|---------|-------------|
| START   | BOOLEAN | Start       |
| OPERATE | BOOLEAN | Operate     |

**3.1.2.9****Settings****DPHLPDOC Settings****Table 229: DPHLPDOC Group settings (Basic)**

| Parameter            | Values (Range)  | Unit | Step | Default          | Description                             |
|----------------------|---|------|------|------------------|---|
| Start value          | 0.05...5.00   | xIn  | 0.01 | 0.05             | Start value                             |
| Start value Mult     | 0.8...10.0  |      | 0.1  | 1.0              | Multiplier for scaling the start value  |
| Time multiplier      | 0.05...15.00  |      | 0.01 | 1.00             | Time multiplier in IEC/ANSI IDMT curves |
| Operate delay time   | 40...200000   | ms   | 10   | 40               | Operate delay time                      |
| Operating curve type | 1=ANSI Ext. inv.<br>2=ANSI Very inv.<br>3=ANSI Norm. inv.<br>4=ANSI Mod. inv.<br>5=ANSI Def. Time<br>6=L.T.E. inv.<br>7=L.T.V. inv. |      |      | 15=IEC Def. Time | Selection of time delay curve type      |

*Table continues on the next page*

| Parameter            | Values (Range)   | Unit | Step | Default   | Description                              |
|----------------------|--|------|------|-----------|--|
|                      | 8=L.T. inv.<br>9=IEC Norm. inv.<br>10=IEC Very inv.<br>11=IEC inv.<br>12=IEC Ext. inv.<br>13=IEC S.T. inv.<br>14=IEC L.T. inv.<br>15=IEC Def. Time<br>17=Program-mable<br>18=RI type<br>19=RD type |      |      |           |  |
| Directional mode     | 1=Non-directional<br>2=Forward<br>3=Reverse  |      |      | 2=Forward | Directional mode                         |
| Characteristic angle | -179...180   | deg  | 1    | 60        | Characteristic angle                     |
| Max forward angle    | 0...90   | deg  | 1    | 80        | Maximum phase angle in forward direction |
| Max reverse angle    | 0...90   | deg  | 1    | 80        | Maximum phase angle in reverse direction |
| Min forward angle    | 0...90   | deg  | 1    | 80        | Minimum phase angle in forward direction |
| Min reverse angle    | 0...90   | deg  | 1    | 80        | Minimum phase angle in reverse direction |

**Table 230: DPHLPDOC Group settings (Advanced)**

| Parameter           | Values (Range)  | Unit | Step | Default     | Description  |
|---------------------|---|------|------|-------------|--|
| Type of reset curve | 1=Immediate<br>2=Def time re-set<br>3=Inverse re-set                |      |      | 1=Immediate | Selection of reset curve type                        |
| Voltage Mem time    | 0...3000  | ms   | 1    | 40          | Voltage memory time                                  |
| Pol quantity        | 1=Self pol<br>4=Neg. seq. volt.<br>5=Cross pol<br>7=Pos. seq. volt. |      |      | 5=Cross pol | Reference quantity used to determine fault direction |

**Table 231: DPHLPDOC Non group settings (Basic)**

| Parameter           | Values (Range)                               | Unit | Step | Default      | Description                                      |
|---------------------|--|------|------|--------------|--|
| Operation           | 1=on<br>5=off                                |      |      | 1=on         | Operation Off / On                               |
| Num of start phases | 1=1 out of 3<br>2=2 out of 3<br>3=3 out of 3 |      |      | 1=1 out of 3 | Number of phases required for operate activation |
| Curve parameter A   | 0.0086...120.000                             |      | 1    | 28.2000      | Parameter A for customer programmable curve      |
| Curve parameter B   | 0.0000...0.7120                              |      | 1    | 0.1217       | Parameter B for customer programmable curve      |
| Curve parameter C   | 0.02...2.00                                  |      | 1    | 2.00         | Parameter C for customer programmable curve      |
| Curve parameter D   | 0.46...30.00                                 |      | 1    | 29.10        | Parameter D for customer programmable curve      |
| Curve parameter E   | 0.0...1.0                                    |      | 1    | 1.0          | Parameter E for customer                         |

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
|           |                |      |      |         | programmable curve |

**Table 232: DPHLPDOC Non group settings (Advanced)**

| Parameter            | Values (Range)                   | Unit | Step | Default | Description  |
|----------------------|----------------------------------|------|------|---------|--|
| Minimum operate time | 20...60000                       | ms   | 1    | 20      | Minimum operate time for IDMT curves                       |
| Reset delay time     | 0...60000                        | ms   | 1    | 20      | Reset delay time   |
| Measurement mode     | 1=RMS<br>2=DFT<br>3=Peak-to-Peak |      |      | 2=DFT   | Selects used measurement mode                              |
| Allow Non Dir        | 0=False<br>1=True                |      |      | 0=False | Allows prot activation as non-dir when dir info is invalid |
| Min operate current  | 0.01...1.00                      | xIn  | 0.01 | 0.01    | Minimum operating current                                  |
| Min operate voltage  | 0.01...1.00                      | xUn  | 0.01 | 0.01    | Minimum operating voltage                                  |

**DPHHPDOC Settings****Table 233: DPHHPDOC Group settings (Basic)**

| Parameter        | Values (Range)                              | Unit | Step | Default   | Description                            |
|------------------|---|------|------|-----------|--|
| Start value      | 0.10...40.00                                | xIn  | 0.01 | 0.10      | Start value                            |
| Start value Mult | 0.8...10.0                                  |      | 0.1  | 1.0       | Multiplier for scaling the start value |
| Directional mode | 1=Non-directional<br>2=Forward<br>3=Reverse |      |      | 2=Forward | Directional mode                       |

*Table continues on the next page*

| Parameter            | Values (Range)   | Unit | Step | Default          | Description                              |
|----------------------|--|------|------|------------------|--|
| Time multiplier      | 0.05...15.00   |      | 0.01 | 1.00             | Time multiplier in IEC/ANSI IDMT curves  |
| Operating curve type | 1=ANSI Ext. inv.<br>3=ANSI Norm. inv.<br>5=ANSI Def. Time<br>9=IEC Norm. inv.<br>10=IEC Very inv.<br>12=IEC Ext. inv.<br>15=IEC Def. Time<br>17=Programmable |      |      | 15=IEC Def. Time | Selection of time delay curve type       |
| Operate delay time   | 40...200000  | ms   | 10   | 40               | Operate delay time                       |
| Characteristic angle | -179...180   | deg  | 1    | 60               | Characteristic angle                     |
| Max forward angle    | 0...90   | deg  | 1    | 80               | Maximum phase angle in forward direction |
| Max reverse angle    | 0...90   | deg  | 1    | 80               | Maximum phase angle in reverse direction |
| Min forward angle    | 0...90   | deg  | 1    | 80               | Minimum phase angle in forward direction |
| Min reverse angle    | 0...90   | deg  | 1    | 80               | Minimum phase angle in reverse direction |

**Table 234: DPHHPDOC Group settings (Advanced)**

| Parameter           | Values (Range)  | Unit | Step | Default     | Description  |
|---------------------|---|------|------|-------------|--|
| Type of reset curve | 1=Immediate<br>2=Def time re-set<br>3=Inverse re-set                |      |      | 1=Immediate | Selection of reset curve type                        |
| Voltage Mem time    | 0...3000  | ms   | 1    | 40          | Voltage memory time                                  |
| Pol quantity        | 1=Self pol<br>4=Neg. seq. volt.<br>5=Cross pol<br>7=Pos. seq. volt. |      |      | 5=Cross pol | Reference quantity used to determine fault direction |

**Table 235: DPHHPDOC Non group settings (Basic)**

| Parameter           | Values (Range)               | Unit | Step | Default      | Description                                 |
|---------------------|------------------------------|------|------|--------------|---|
| Operation           | 1=on<br>5=off                |      |      | 1=on         | Operation Off / On                          |
| Curve parameter A   | 0.0086...120.0000            |      | 1    | 28.2000      | Parameter A for customer programmable curve |
| Curve parameter B   | 0.0000...0.7120              |      | 1    | 0.1217       | Parameter B for customer programmable curve |
| Curve parameter C   | 0.02...2.00                  |      | 1    | 2.00         | Parameter C for customer programmable curve |
| Curve parameter D   | 0.46...30.00                 |      | 1    | 29.10        | Parameter D for customer programmable curve |
| Curve parameter E   | 0.0...1.0                    |      | 1    | 1.0          | Parameter E for customer programmable curve |
| Num of start phases | 1=1 out of 3<br>2=2 out of 3 |      |      | 1=1 out of 3 | Number of phases required for op-           |

| Parameter | Values (Range) | Unit | Step | Default | Description      |
|-----------|----------------|------|------|---------|------------------|
|           | 3=3 out of 3   |      |      |         | erate activation |

**Table 236: DPHHPDOC Non group settings (Advanced)**

| Parameter            | Values (Range)                   | Unit | Step | Default | Description  |
|----------------------|----------------------------------|------|------|---------|--|
| Reset delay time     | 0...60000                        | ms   | 1    | 20      | Reset delay time   |
| Minimum operate time | 20...60000                       | ms   | 1    | 20      | Minimum operate time for IDMT curves                       |
| Allow Non Dir        | 0=False<br>1=True                |      |      | 0=False | Allows prot activation as non-dir when dir info is invalid |
| Measurement mode     | 1=RMS<br>2=DFT<br>3=Peak-to-Peak |      |      | 2=DFT   | Selects used measurement mode                              |
| Min operate current  | 0.01...1.00                      | xIn  | 0.01 | 0.01    | Minimum operating current                                  |
| Min operate voltage  | 0.01...1.00                      | xUn  | 0.01 | 0.01    | Minimum operating voltage                                  |

**3.1.2.10**

**Monitored data**

**DPHLPDOC Monitored data**

**Table 237: DPHLPDOC Monitored data**

| Name      | Type    | Values (Range)                                 | Unit | Description                        |
|-----------|---------|--|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00                                  | %    | Ratio of start time / operate time |
| FAULT_DIR | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Detected fault direction           |

*Table continues on the next page*



| Name      | Type    | Values (Range)   | Unit | Description                          |
|-----------|---------|--|------|--------------------------------------|
| DIRECTION | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both         |      | Direction information                |
| DIR_A     | Enum    | 0=unknown<br>1=forward<br>2=backward<br>-1=both        |      | Direction phase A                    |
| DIR_B     | Enum    | 0=unknown<br>1=forward<br>2=backward<br>-1=both        |      | Direction phase B                    |
| DIR_C     | Enum    | 0=unknown<br>1=forward<br>2=backward<br>-1=both        |      | Direction phase C                    |
| ANGLE_A   | FLOAT32 | -180.00...180.00                                       | deg  | Calculated angle difference, Phase A |
| ANGLE_B   | FLOAT32 | -180.00...180.00                                       | deg  | Calculated angle difference, Phase B |
| ANGLE_C   | FLOAT32 | -180.00...180.00                                       | deg  | Calculated angle difference, Phase C |
| VMEM_USED | BOOLEAN | 0=False<br>1=True                                      |      | Voltage memory in use status         |
| DPHLPDOC  | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                               |

**DPHHPDOC Monitored data****Table 238: DPHHPDOC Monitored data**

| Name      | Type    | Values (Range)                                  | Unit | Description                          |
|-----------|---------|---|------|--------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00                                   | %    | Ratio of start time / operate time   |
| FAULT_DIR | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both  |      | Detected fault direction             |
| DIRECTION | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both  |      | Direction information                |
| DIR_A     | Enum    | 0=unknown<br>1=forward<br>2=backward<br>-1=both |      | Direction phase A                    |
| DIR_B     | Enum    | 0=unknown<br>1=forward<br>2=backward<br>-1=both |      | Direction phase B                    |
| DIR_C     | Enum    | 0=unknown<br>1=forward<br>2=backward<br>-1=both |      | Direction phase C                    |
| ANGLE_A   | FLOAT32 | -180.00...180.00                                | deg  | Calculated angle difference, Phase A |
| ANGLE_B   | FLOAT32 | -180.00...180.00                                | deg  | Calculated angle difference, Phase B |
| ANGLE_C   | FLOAT32 | -180.00...180.00                                | deg  | Calculated angle difference, Phase C |

*Table continues on the next page*

| Name      | Type    | Values (Range)   | Unit | Description                  |
|-----------|---------|--|------|------------------------------|
| VMEM_USED | BOOLEAN | 0=False<br>1=True                                      |      | Voltage memory in use status |
| DPHHPDOC  | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                       |

### 3.1.2.11 Technical data

Table 239: DPHxPDOC Technical data

| Characteristic                              |  | Value   |         |         |
|---|--|---|---------|---------|
| Operation accuracy                          |  | Depending on the frequency of the current/voltage measured: $f_n \pm 2$ Hz  |         |         |
|   | DPHLPDOC   | Current:<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$<br>Voltage:<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times U_n$<br>Phase angle: $\pm 2^\circ$  |         |         |
|   | DPHHPDOC   | Current:<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$<br>(at currents in the range of $0.1 \dots 10 \times I_n$ )<br>$\pm 5.0\%$ of the set value<br>(at currents in the range of $10 \dots 40 \times I_n$ )<br>Voltage:<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times U_n$<br>Phase angle: $\pm 2^\circ$ |         |         |
| Start time <sup>2425</sup>                  |  | Minimum   | Typical | Maximum |
|   | $I_{\text{Fault}} = 2.0 \times \text{set Start value}$ | 39 ms   | 43 ms   | 47 ms   |
| Reset time                                  |  | Typically 40 ms   |         |         |
| Reset ratio                                 |  | Typically 0.96  |         |         |
| Retardation time                            |  | <35 ms  |         |         |
| Operate time accuracy in definite time mode |  | $\pm 1.0\%$ of the set value or $\pm 20$ ms   |         |         |

Table continues on the next page

<sup>24</sup> Measurement mode and Pol quantity = default, current before fault =  $0.0 \times I_n$ , voltage before fault =  $1.0 \times U_n$ ,  $f_n = 50$  Hz, fault current in one phase with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements

<sup>25</sup> Includes the delay of the signal output contact

| Characteristic                             | Value   |
|--|---|
| Operate time accuracy in inverse time mode | ±5.0% of the theoretical value or ±20 ms                          |
| Suppression of harmonics                   | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$ |

### 3.1.3 Three-phase thermal protection for feeders, cables and distribution transformers T1PTTR

#### 3.1.3.1 Identification

| Function description   | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--|--------------------------|--------------------------|-------------------------------|
| Three-phase thermal protection for feeders, cables and distribution transformers | T1PTTR                   | 3Ith>F                   | 49F                           |

#### 3.1.3.2 Function block

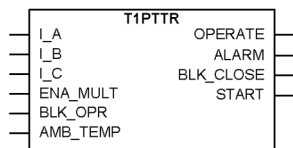


Figure 100: Function block

#### 3.1.3.3 Functionality

The increased utilization of power systems closer to the thermal limits has generated a need for a thermal overload function also for power lines.

A thermal overload is in some cases not detected by other protection functions, and the introduction of the three-phase thermal protection for feeders, cables and distribution transformers function T1PTTR allows the protected circuit to operate closer to the thermal limits.

An alarm level gives an early warning to allow operators to take action before the line trips. The early warning is based on the three-phase current measuring function using a thermal model with first order thermal loss with the settable time constant. If the temperature rise continues the function will operate based on the thermal model of the line.

Re-energizing of the line after the thermal overload operation can be inhibited during the time the cooling of the line is in progress. The cooling of the line is estimated by the thermal model.

<sup>26</sup> Maximum Start value =  $2.5 \times I_n$ , Start value multiples in range of 1.5...20

### 3.1.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of T1PTTR can be described using a module diagram. All the modules in the diagram are explained in the next sections.

The function uses ambient temperature which can be measured remotely. Remote measurement uses analog GOOSE to connect AMB\_TEMP input.



If the quality of remotely measured temperature is invalid or communication channel fails the function uses ambient temperature set in *Env temperature Set*.

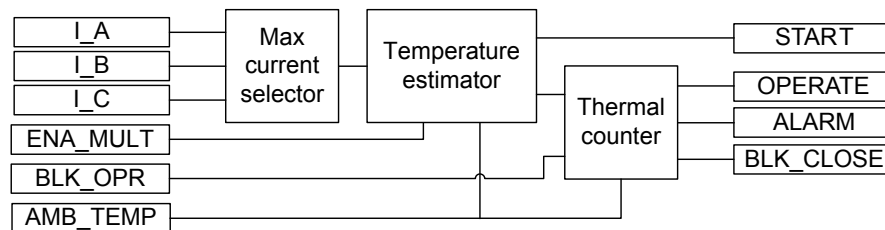


Figure 101: Functional module diagram

#### Max current selector

The max current selector of the function continuously checks the highest measured TRMS phase current value. The selector reports the highest value to the temperature estimator.

#### Temperature estimator

The final temperature rise is calculated from the highest of the three-phase currents according to the expression:

$$\Theta_{final} = \left( \frac{I}{I_{ref}} \right)^2 \cdot T_{ref}$$

|           |                              |
|-----------|------------------------------|
| $I$       | the largest phase current    |
| $I_{ref}$ | set <i>Current reference</i> |
| $T_{ref}$ | set <i>Temperature rise</i>  |

The ambient temperature is added to the calculated final temperature rise estimation, and the ambient temperature value used in the calculation is also available in the monitored data as TEMP\_AMB in degrees. If the final temperature estimation is larger than the set *Maximum temperature*, the START output is activated.

*Current reference* and *Temperature rise* setting values are used in the final temperature estimation together with the ambient temperature. It is suggested to set these values to the maximum steady state current allowed for the line or cable under emergency operation for a few hours per years. Current values with the corresponding conductor temperatures are given in cable manuals. These values

are given for conditions such as ground temperatures, ambient air temperature, the way of cable laying and ground thermal resistivity.

### Thermal counter

The actual temperature at the actual execution cycle is calculated as:

$$\Theta_n = \Theta_{n-1} + (\Theta_{final} - \Theta_{n-1}) \cdot \left( 1 - e^{-\frac{\Delta t}{\tau}} \right)$$

|                  |  |
|------------------|--|
| $\Theta_n$       | calculated present temperature   |
| $\Theta_{n-1}$   | calculated temperature at previous time step   |
| $\Theta_{final}$ | calculated final temperature with actual current   |
| $\Delta t$       | time step between calculation of actual temperature                                      |
| $\tau$           | thermal time constant for the protected device (line or cable), set <i>Time constant</i> |

The actual temperature of the protected component (line or cable) is calculated by adding the ambient temperature to the calculated temperature, as shown above. The ambient temperature can be given a constant value or it can be measured. The calculated component temperature can be monitored as it is exported from the function as a real figure.

When the component temperature reaches the set alarm level *Alarm value*, the output signal `ALARM` is set. When the component temperature reaches the set trip level *Maximum temperature*, the `OPERATE` output is activated. The `OPERATE` signal pulse length is fixed to 100 ms

There is also a calculation of the present time to operation with the present current. This calculation is only performed if the final temperature is calculated to be above the operation temperature:

$$t_{operate} = -\tau \cdot \ln \left( \frac{\Theta_{final} - \Theta_{operate}}{\Theta_{final} - \Theta_n} \right)$$

Caused by the thermal overload protection function, there can be a lockout to reconnect the tripped circuit after operating. The lockout output `BLK_CLOSE` is activated at the same time when the `OPERATE` output is activated and is not reset until the device temperature has cooled down below the set value of the *Reclose temperature* setting. The *Maximum temperature* value must be set at least two degrees above the set value of *Reclose temperature*.

The time to lockout release is calculated, that is, the calculation of the cooling time to a set value. The calculated temperature can be reset to its initial value (the *Initial temperature* setting) via a control parameter that is located under the clear menu. This is useful during testing when secondary injected current has given a calculated false temperature level.

$$t_{lockout\_release} = -\tau \cdot \ln \left( \frac{\Theta_{final} - \Theta_{lockout\_release}}{\Theta_{final} - \Theta_n} \right)$$

Here the final temperature is equal to the set or measured ambient temperature.

In some applications, the measured current can involve a number of parallel lines. This is often used for cable lines where one bay connects several parallel cables. By setting the *Current multiplier* parameter to the number of parallel lines (cables), the actual current on one line is used in the protection algorithm. To activate this option, the ENA\_MULT input must be activated.

The ambient temperature can be measured with the RTD measurement in the bay level relay or merging unit, and sent to the protective device via GOOSE message.

The *Env temperature Set* setting is used to define the ambient temperature if the ambient temperature measurement value is not connected to the AMB\_TEMP input.

The temperature calculation is initiated from the value defined with the *Initial temperature* setting parameter. This is done in case the IED is powered up, the function is turned "Off" and back "On" or reset through the Clear menu. The temperature is also stored in the nonvolatile memory and restored in case the IED is restarted.

The thermal time constant of the protected circuit is given in seconds with the *Time constant* setting. Please see cable manufacturers manuals for further details.



T1PTTR thermal model complies with the IEC 60255-149 standard.

### 3.1.3.5

#### Application

The lines and cables in the power system are constructed for a certain maximum load current level. If the current exceeds this level, the losses will be higher than expected. As a consequence, the temperature of the conductors will increase. If the temperature of the lines and cables reaches too high values, it can cause a risk of damages by, for example, the following ways:

- The sag of overhead lines can reach an unacceptable value.
- If the temperature of conductors, for example aluminium conductors, becomes too high, the material will be destroyed.
- In cables the insulation can be damaged as a consequence of overtemperature, and therefore phase-to-phase or phase-to-earth faults can occur.

In stressed situations in the power system, the lines and cables may be required to be overloaded for a limited time. This should be done without any risk for the above-mentioned risks.

The thermal overload protection provides information that makes temporary overloading of cables and lines possible. The thermal overload protection estimates the conductor temperature continuously. This estimation is made by using a thermal model of the line/cable that is based on the current measurement.

If the temperature of the protected object reaches a set warning level, a signal is given to the operator. This enables actions in the power system to be done before dangerous temperatures are reached. If the temperature continues to increase to

the maximum allowed temperature value, the protection initiates a trip of the protected line.

### 3.1.3.6 Signals

#### T1PTTR Input signals

Table 240: T1PTTR Input signals

| Name     | Type    | Default | Description                                     |
|----------|---------|---------|---|
| I_A      | SIGNAL  | 0       | Phase A current                                 |
| I_B      | SIGNAL  | 0       | Phase B current                                 |
| I_C      | SIGNAL  | 0       | Phase C current                                 |
| ENA_MULT | BOOLEAN | 0=False | Enable Current multiplier                       |
| BLK_OPR  | BOOLEAN | 0=False | Block signal for operate outputs                |
| TEMP_AMB | FLOAT32 | 0       | The ambient temperature used in the calculation |

#### T1PTTR Output signals

Table 241: T1PTTR Output signals

| Name      | Type    | Description                                     |
|-----------|---------|---|
| OPERATE   | BOOLEAN | Operate   |
| START     | BOOLEAN | Start   |
| ALARM     | BOOLEAN | Thermal Alarm                                   |
| BLK_CLOSE | BOOLEAN | Thermal overload indicator. To inhibit reclose. |

### 3.1.3.7 Settings

#### T1PTTR Settings

Table 242: T1PTTR Group settings (Basic)

| Parameter           | Values (Range) | Unit | Step | Default | Description   |
|---------------------|----------------|------|------|---------|---|
| Env temperature Set | -50...100      | °C   | 1    | 40      | Ambient temperature used when no external temperature |

Table continues on the next page



| Parameter           | Values (Range) | Unit | Step | Default | Description   |
|---------------------|----------------|------|------|---------|---|
|                     |                |      |      |         | measurement available                                     |
| Current reference   | 0.05...4.00    | xIn  | 0.01 | 1.00    | The load current leading to Temperature raise temperature |
| Temperature rise    | 0.0...200.0    | °C   | 0.1  | 75.0    | End temperature rise above ambient                        |
| Time constant       | 60...60000     | s    | 1    | 2700    | Time constant of the line in seconds.                     |
| Maximum temperature | 20.0...200.0   | °C   | 0.1  | 90.0    | Temperature level for operate                             |
| Alarm value         | 20.0...150.0   | °C   | 0.1  | 80.0    | Temperature level for start (alarm)                       |
| Reclose temperature | 20.0...150.0   | °C   | 0.1  | 70.0    | Temperature for reset of block reclose after operate      |

Table 243: T1PTTR Group settings (Advanced)

| Parameter          | Values (Range) | Unit | Step | Default | Description   |
|--------------------|----------------|------|------|---------|---|
| Current multiplier | 1...5          |      | 1    | 1       | Current multiplier when function is used for parallel lines |

Table 244: T1PTTR Non group settings (Basic)

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

**Table 245: T1PTTR Non group settings (Advanced)**

| Parameter           | Values (Range) | Unit | Step | Default | Description  |
|---------------------|----------------|------|------|---------|--|
| Initial temperature | -50.0...100.0  | °C   | 0.1  | 0.0     | Temperature raise above ambient temperature at startup |

### 3.1.3.8

## Monitored data

### T1PTTR Monitored data

**Table 246: T1PTTR Monitored data**

| Name        | Type    | Values (Range)   | Unit | Description  |
|-------------|---------|--|------|--|
| TEMP        | FLOAT32 | -100.0...9999.9  | °C   | The calculated temperature of the protected object                               |
| TEMP_RL     | FLOAT32 | 0.00...99.99   |      | The calculated temperature of the protected object relative to the operate level |
| T_OPERATE   | INT32   | 0...60000  | s    | Estimated time to operate  |
| T_ENA_CLOSE | INT32   | 0...60000  | s    | Estimated time to deactivate BLK_CLOSE   |
| TEMP_AMB    | FLOAT32 | -99...999  | °C   | The ambient temperature used in the calculation                                  |
| T1PTTR      | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status   |

### 3.1.3.9 Technical data

Table 247: T1PTTR Technical data

| Characteristic                      | Value   |
|-------------------------------------|---|
| Operation accuracy                  | Depending on the frequency of the measured current: $f_n \pm 2$ Hz<br>Current measurement: $\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$ (at currents in the range of $0.01 \dots 4.00 \times I_n$ ) |
| Operate time accuracy <sup>27</sup> | $\pm 2.0\%$ of the theoretical value or $\pm 0.50$ s  |

### 3.1.3.10 Technical revision history

Table 248: T1PTTR Technical revision history

| Technical revision | Change  |
|--------------------|---|
| C                  | Removed the <i>Sensor available</i> setting parameter |
| D                  | Added the AMB_TEMP input                              |
| E                  | Internal improvement.                                 |
| F                  | Internal improvement.                                 |
| G                  | Modified for SSC600                                   |

## 3.1.4 Three-phase thermal overload protection, two time constants T2PTTR

### 3.1.4.1 Identification

| Function description  | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|--------------------------|--------------------------|-------------------------------|
| Three-phase thermal overload protection, two time constants | T2PTTR                   | 3Ith>T/G/C               | 49T/G/C                       |

### 3.1.4.2 Function block

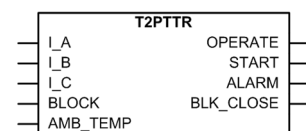


Figure 102: Function block

<sup>27</sup> Overload current  $> 1.2 \times$  Operate level temperature

### 3.1.4.3 Functionality

The three-phase thermal overload, two time constants, protection function T2PTTR protects the transformer mainly from short-time overloads. The transformer is protected from long-time overloads with the oil temperature detector included in its equipment.

The alarm signal gives an early warning to allow the operators to take action before the transformer trips. The early warning is based on the three-phase current measuring function using a thermal model with two settable time constants. If the temperature rise continues, T2PTTR operates based on the thermal model of the transformer.

After a thermal overload operation, the re-energizing of the transformer is inhibited during the transformer cooling time. The transformer cooling is estimated with a thermal model.

### 3.1.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of T2PTTR can be described using a module diagram. All the modules in the diagram are explained in the next sections.

The function uses ambient temperature which can be measured remotely. Remote measurement uses analog GOOSE to connect AMB\_TEMP input.



If the quality of remotely measured temperature is invalid or communication channel fails the function uses ambient temperature set in *Env temperature Set*.

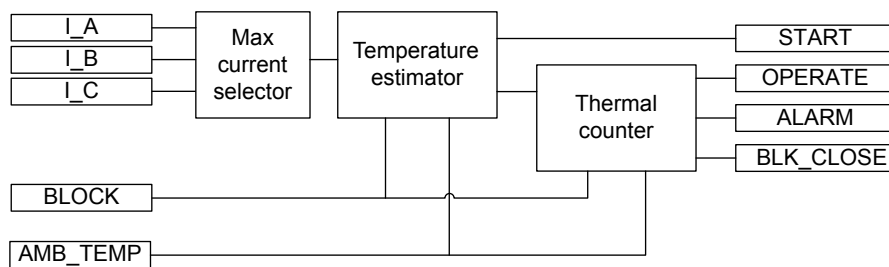


Figure 103: Functional module diagram

#### Max current selector

The max current selector of the function continuously checks the highest measured TRMS phase current value. The selector reports the highest value to the thermal counter.

#### Temperature estimator

The final temperature rise is calculated from the highest of the three-phase currents according to the expression:

$$\Theta_{final} = \left( \frac{I}{I_{ref}} \right)^2 \cdot T_{ref}$$

|                  |  |
|------------------|--|
| I                | highest measured phase current   |
| I <sub>ref</sub> | the set value of the <i>Current reference</i> setting  |
| T <sub>ref</sub> | the set value of the <i>Temperature rise</i> setting (temperature rise (°C) with the steady-state current I <sub>ref</sub> ) |

The ambient temperature value is added to the calculated final temperature rise estimation. If the total value of temperature is higher than the set operate temperature level, the *START* output is activated.

The *Current reference* setting is a steady-state current that gives the steady-state end temperature value *Temperature rise*. It gives a setting value corresponding to the rated power of the transformer.

The *Temperature rise* setting is used when the value of the reference temperature rise corresponds to the *Current reference* value. The temperature values with the corresponding transformer load currents are usually given by transformer manufacturers.

### Thermal counter

T2PTTR applies the thermal model of two time constants for temperature measurement. The temperature rise in degrees Celsius (°C) is calculated from the highest of the three-phase currents according to the expression:

$$\Delta\Theta = \left[ p \cdot \left( \frac{I}{I_{ref}} \right)^2 \cdot T_{ref} \right] \cdot \left( 1 - e^{-\frac{\Delta t}{\tau_1}} \right) + \left[ (1-p) \cdot \left( \frac{I}{I_{ref}} \right)^2 \cdot T_{ref} \right] \cdot \left( 1 - e^{-\frac{\Delta t}{\tau_2}} \right)$$

Figure 104: Thermal counter

|                |   |
|----------------|---|
| $\Delta\Theta$ | calculated temperature rise (°C) in transformer   |
| $I$            | measured phase current with the highest TRMS value  |
| $I_{ref}$      | the set value of the <i>Current reference</i> setting (rated current of the protected object)                                 |
| $T_{ref}$      | the set value of the <i>Temperature rise</i> setting (temperature rise setting (°C) with the steady-state current $I_{ref}$ ) |
| $p$            | the set value of the <i>Weighting factor p</i> setting (weighting factor for the short time constant)                         |
| $\Delta t$     | time step between the calculation of the actual temperature   |
| $\tau_1$       | the set value of the <i>Short time constant</i> setting (the short heating / cooling time constant)                           |
| $\tau_2$       | the set value of the <i>Long time constant</i> setting (the long heating / cooling time constant)                             |

The warming and cooling following the two time-constant thermal curve is a characteristic of transformers. The thermal time constants of the protected transformer are given in seconds with the *Short time constant* and *Long time constant* settings. The *Short time constant* setting describes the warming of the transformer with respect to windings. The *Long time constant* setting describes the warming of the transformer with respect to the oil. Using the two time-constant model, the IED is able to follow both fast and slow changes in the temperature of the protected object.

The *Weighting factor p* setting is the weighting factor between *Short time constant*  $\tau_1$  and *Long time constant*  $\tau_2$ . The higher the value of the *Weighting factor p* setting, the larger is the share of the steep part of the heating curve. When *Weighting factor p* = 1, only *Short-time constant* is used. When *Weighting factor p* = 0, only *Long time constant* is used.

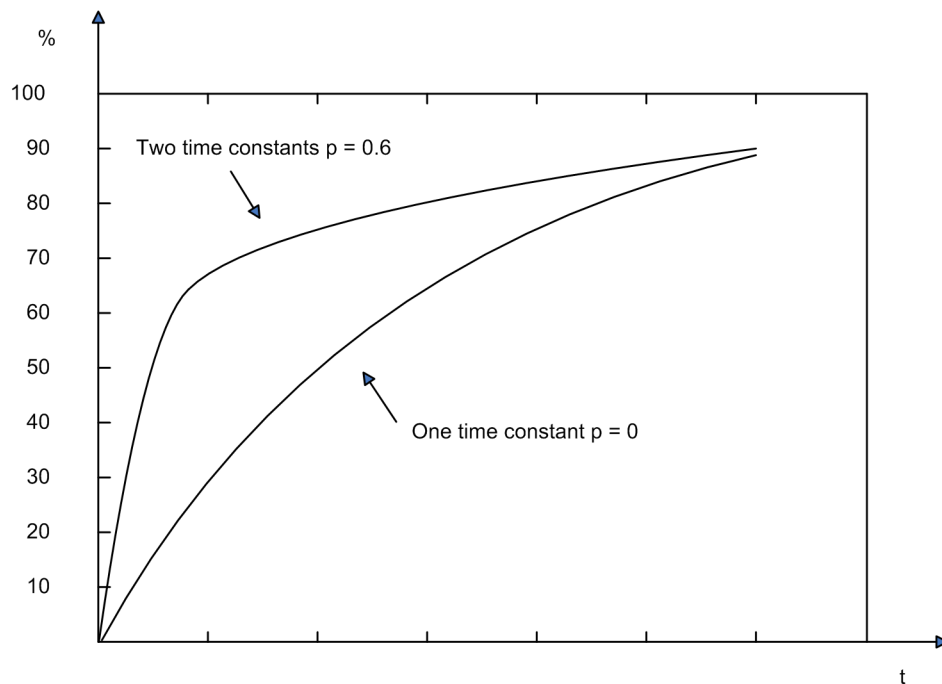


Figure 105: Effect of the Weighting factor  $p$  factor and the difference between the two time constants and one time constant models

The actual temperature of the transformer is calculated by adding the ambient temperature to the calculated temperature.

$$\Theta = \Delta\Theta + \Theta_{amb}$$

|                |   |
|----------------|---|
| $\Theta$       | temperature in transformer (°C)   |
| $\Delta\Theta$ | calculated temperature rise (°C) in transformer                                     |
| $\Theta_{amb}$ | set value of the <i>Env temperature Set</i> setting or measured ambient temperature |

The *Env temperature Set* setting is used to define the ambient temperature if the ambient temperature measurement value is not connected to the `AMB_TEMP` input.

The temperature calculation is initiated from the value defined with the *Initial temperature* and *Max temperature* setting parameters. The initial value is a percentage of *Max temperature* defined by *Initial temperature*. This is done when the IED is powered up or the function is turned off and back on or reset through the Clear menu. The temperature is stored in a nonvolatile memory and restored if the IED is restarted.

The *Max temperature* setting defines the maximum temperature of the transformer in degrees Celsius (°C). The value of the *Max temperature* setting is usually given by transformer manufacturers. The actual alarm, operating and lockout temperatures for T2PTTR are given as a percentage value of the *Max temperature* setting.

When the transformer temperature reaches the alarm level defined with the *Alarm temperature* setting, the `ALARM` output signal is set. When the transformer temperature reaches the trip level value defined with the *Operate temperature*

setting, the `OPERATE` output is activated. The `OPERATE` output is deactivated when the value of the measured current falls below 10 percent of the *Current Reference* value or the calculated temperature value falls below *Operate temperature*

There is also a calculation of the present time to operation with the present current. `T_OPERATE` is only calculated if the final temperature is calculated to be above the operation temperature. The value is available in the monitored data view.

After operating, there can be a lockout to reconnect the tripped circuit due to the thermal overload protection function. The `BLK_CLOSE` lockout output is activated when the device temperature is above the *Reclose temperature* lockout release temperature setting value. The time to lockout release `T_ENA_CLOSE` is also calculated. The value is available in the monitored data view.

### 3.1.4.5 Application

The transformers in a power system are constructed for a certain maximum load current level. If the current exceeds this level, the losses are higher than expected. This results in a rise in transformer temperature. If the temperature rise is too high, the equipment is damaged:

- Insulation within the transformer ages faster, which in turn increases the risk of internal phase-to-phase or phase-to-earth faults.
- Possible hotspots forming within the transformer degrade the quality of the transformer oil.

During stressed situations in power systems, it is required to overload the transformers for a limited time without any risks. The thermal overload protection provides information and makes temporary overloading of transformers possible.

The permissible load level of a power transformer is highly dependent on the transformer cooling system. The two main principles are:

- ONAN: The air is naturally circulated to the coolers without fans, and the oil is naturally circulated without pumps.
- OFAF: The coolers have fans to force air for cooling, and pumps to force the circulation of the transformer oil.

The protection has several parameter sets located in the setting groups, for example one for a non-forced cooling and one for a forced cooling situation. Both the permissive steady-state loading level as well as the thermal time constant are influenced by the transformer cooling system. The active setting group can be changed by a parameter, or through a binary input if the binary input is enabled for it. This feature can be used for transformers where forced cooling is taken out of operation or extra cooling is switched on. The parameters can also be changed when a fan or pump fails to operate.

The thermal overload protection continuously estimates the internal heat content, that is, the temperature of the transformer. This estimation is made by using a thermal model of the transformer which is based on the current measurement.

If the heat content of the protected transformer reaches the set alarm level, a signal is given to the operator. This enables the action that needs to be taken in the power systems before the temperature reaches a high value. If the temperature continues to rise to the trip value, the protection initiates the trip of the protected transformer.

After the trip, the transformer needs to cool down to a temperature level where the transformer can be taken into service again. `T2PTTR` continues to estimate the



heat content of the transformer during this cooling period using a set cooling time constant. The energizing of the transformer is blocked until the heat content is reduced to the set level.

The thermal curve of two time constants is typical for a transformer. The thermal time constants of the protected transformer are given in seconds with the *Short time constant* and *Long time constant* settings. If the manufacturer does not state any other value, the *Long time constant* can be set to 4920 s (82 minutes) for a distribution transformer and 7260 s (121 minutes) for a supply transformer. The corresponding *Short time constants* are 306 s (5.1 minutes) and 456 s (7.6 minutes).

If the manufacturer of the power transformer has stated only one, that is, a single time constant, it can be converted to two time constants. The single time constant is also used by itself if the p-factor *Weighting factor p* setting is set to zero and the time constant value is set to the value of the *Long time constant* setting. The thermal image corresponds to the one time constant model in that case.

**Table 249: Conversion table between one and two time constants**

| Single time constant (min) | Short time constant (min) | Long time constant (min) | Weighting factor p |
|----------------------------|---------------------------|--------------------------|--------------------|
| 10                         | 1.1                       | 17                       | 0.4                |
| 15                         | 1.6                       | 25                       | 0.4                |
| 20                         | 2.1                       | 33                       | 0.4                |
| 25                         | 2.6                       | 41                       | 0.4                |
| 30                         | 3.1                       | 49                       | 0.4                |
| 35                         | 3.6                       | 58                       | 0.4                |
| 40                         | 4.1                       | 60                       | 0.4                |
| 45                         | 4.8                       | 75                       | 0.4                |
| 50                         | 5.1                       | 82                       | 0.4                |
| 55                         | 5.6                       | 90                       | 0.4                |
| 60                         | 6.1                       | 98                       | 0.4                |
| 65                         | 6.7                       | 107                      | 0.4                |
| 70                         | 7.2                       | 115                      | 0.4                |
| 75                         | 7.8                       | 124                      | 0.4                |

The default *Max temperature* setting is 105°C. This value is chosen since even though the IEC 60076-7 standard recommends 98°C as the maximum allowable temperature in long-time loading, the standard also states that a transformer can withstand the emergency loading for weeks or even months, which may produce the winding temperature of 140°C. Therefore, 105°C is a safe maximum temperature value for a transformer if the *Max temperature* setting value is not given by the transformer manufacturer.

### 3.1.4.6 Signals

**T2PTTR Input signals****Table 250: T2PTTR Input signals**

| Name     | Type    | Default | Description                                     |
|----------|---------|---------|---|
| I_A      | SIGNAL  | 0       | Phase A current                                 |
| I_B      | SIGNAL  | 0       | Phase B current                                 |
| I_C      | SIGNAL  | 0       | Phase C current                                 |
| BLOCK    | BOOLEAN | 0=False | Block signal for activating the blocking mode   |
| TEMP_AMB | FLOAT32 | 0       | The ambient temperature used in the calculation |

**T2PTTR Output signals****Table 251: T2PTTR Output signals**

| Name      | Type    | Description                                     |
|-----------|---------|---|
| OPERATE   | BOOLEAN | Operate   |
| START     | BOOLEAN | Start   |
| ALARM     | BOOLEAN | Thermal Alarm                                   |
| BLK_CLOSE | BOOLEAN | Thermal overload indicator. To inhibit reclose. |

**3.1.4.7****Settings****T2PTTR Settings****Table 252: T2PTTR Group settings (Basic)**

| Parameter           | Values (Range) | Unit | Step | Default | Description   |
|---------------------|----------------|------|------|---------|---|
| Env temperature Set | -50...100      | °C   | 1    | 40      | Ambient temperature used when no external temperature measurement available |
| Temperature rise    | 0.0...200.0    | °C   | 0.1  | 78.0    | End temperature rise above ambient  |
| Max temperature     | 0.0...200.0    | °C   | 0.1  | 105.0   | Maximum temperature allowed for   |

*Table continues on the next page*

| Parameter           | Values (Range) | Unit | Step | Default | Description  |
|---------------------|----------------|------|------|---------|--|
|                     |                |      |      |         | the transformer                                      |
| Operate temperature | 80.0...120.0   | %    | 0.1  | 100.0   | Operate temperature, percent value                   |
| Alarm temperature   | 40.0...100.0   | %    | 0.1  | 90.0    | Alarm temperature, percent value                     |
| Reclose temperature | 40.0...100.0   | %    | 0.1  | 60.0    | Temperature for reset of block reclose after operate |
| Short time constant | 6...60000      | s    | 1    | 450     | Short time constant in seconds                       |
| Long time constant  | 60...60000     | s    | 1    | 7200    | Long time constant in seconds                        |
| Weighting factor p  | 0.00...1.00    |      | 0.01 | 0.40    | Weighting factor of the short time constant          |

Table 253: T2PTTR Group settings (Advanced)

| Parameter         | Values (Range) | Unit | Step | Default | Description   |
|-------------------|----------------|------|------|---------|---|
| Current reference | 0.05...4.00    | xIn  | 0.01 | 1.00    | The load current leading to Temperature raise temperature |

Table 254: T2PTTR Non group settings (Basic)

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

Table 255: T2PTTR Non group settings (Advanced)

| Parameter           | Values (Range) | Unit | Step | Default | Description                        |
|---------------------|----------------|------|------|---------|------------------------------------|
| Initial temperature | 0.0...100.0    | %    | 0.1  | 80.0    | Initial temperature, percent value |

### 3.1.4.8 Monitored data

#### T2PTTR Monitored data

Table 256: T2PTTR Monitored data

| Name        | Type    | Values (Range)   | Unit | Description  |
|-------------|---------|--|------|--|
| TEMP        | FLOAT32 | -100.0...9999.9  | °C   | The calculated temperature of the protected object                               |
| TEMP_RL     | FLOAT32 | 0.00...99.99   |      | The calculated temperature of the protected object relative to the operate level |
| T_OPERATE   | INT32   | 0...60000  | s    | Estimated time to operate  |
| T_ENA_CLOSE | INT32   | 0...60000  | s    | Estimated time to deactivate BLK_CLOSE in seconds                                |
| TEMP_AMB    | FLOAT32 | -99...999  | °C   | The ambient temperature used in the calculation                                  |
| T2PTTR      | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status   |

### 3.1.4.9 Technical data

Table 257: T2PTTR Technical data

| Characteristic                      | Value   |
|-------------------------------------|---|
| Operation accuracy                  | Depending on the frequency of the measured current: $f_n \pm 2$ Hz<br>Current measurement: $\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$ (at currents in the range of $0.01...4.00 \times I_n$ ) |
| Operate time accuracy <sup>28</sup> | $\pm 2.0\%$ of the theoretical value or $\pm 0.50$ s  |

<sup>28</sup> Overload current > 1.2 x Operate level temperature

### 3.1.4.10 Technical revision history

Table 258: T2PTTR Technical revision history

| Technical revision | Change                   |
|--------------------|--------------------------|
| B                  | Added the AMB_TEMP input |
| C                  | Internal improvement.    |
| D                  | Internal improvement.    |
| E                  | Modified for SSC600      |

## 3.1.5 Motor load jam protection JAMPTOC

### 3.1.5.1 Identification

| Function description      | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---------------------------|--------------------------|--------------------------|-------------------------------|
| Motor load jam protection | JAMPTOC                  | Ist>                     | 51LR                          |

### 3.1.5.2 Function block

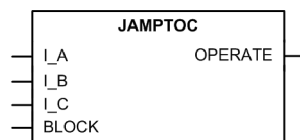


Figure 106: Function block

### 3.1.5.3 Functionality

The motor load jam protection function JAMPTOC is used for protecting the motor in stall or mechanical jam situations during the running state.

When the motor is started, a separate function is used for the startup protection, and JAMPTOC is normally blocked during the startup period. When the motor has passed the starting phase, JAMPTOC monitors the magnitude of phase currents. The function starts when the measured current exceeds the breakdown torque level, that is, above the set limit. The operation characteristic is definite time.

The function contains a blocking functionality. It is possible to block the function outputs.

### 3.1.5.4 Operational principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of JAMPTOC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

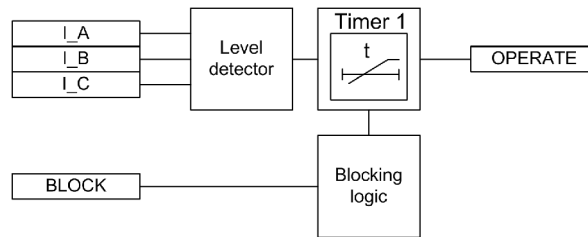


Figure 107: Functional module diagram

### Level detector

The measured phase currents are compared to the set *Start value*. The TRMS values of the phase currents are considered for the level detection. The timer module is enabled if at least two of the measured phase currents exceed the set *Start value*.

### Timer

Once activated, the internal `START` signal is activated. The value is available only through the Monitored data view. The time characteristic is according to DT. When the operation timer has reached the *Operate delay time* value, the `OPERATE` output is activated.

When the timer has elapsed but the motor stall condition still exists, the `OPERATE` output remains active until the phase currents values drop below the *Start value*, that is, until the stall condition persists. If the drop-off situation occurs while the operating time is still counting, the reset timer is activated. If the drop-off time exceeds the set *Reset delay time*, the operating timer is reset.

The timer calculates the start duration value `START_DUR`, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting **Configuration > System > Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block `OPERATE` output" mode, the function operates normally but the `OPERATE` output is not activated.

## 3.1.5.5

### Application

The motor protection during stall is primarily needed to protect the motor from excessive temperature rise, as the motor draws large currents during the stall phase. This condition causes a temperature rise in the stator windings. Due to

reduced speed, the temperature also rises in the rotor. The rotor temperature rise is more critical when the motor stops.

The physical and dielectric insulations of the system deteriorate with age and the deterioration is accelerated by the temperature increase. Insulation life is related to the time interval during which the insulation is maintained at a given temperature.

An induction motor stalls when the load torque value exceeds the breakdown torque value, causing the speed to decrease to zero or to some stable operating point well below the rated speed. This occurs, for example, when the applied shaft load is suddenly increased and is greater than the producing motor torque due to the bearing failures. This condition develops a motor current almost equal to the value of the locked-rotor current.

JAMPTOC is designed to protect the motor in stall or mechanical jam situations during the running state. To provide a good and reliable protection for motors in a stall situation, the temperature effects on the motor have to be kept within the allowed limits.

### 3.1.5.6 Signals

#### JAMPTOC Input signals

Table 259: JAMPTOC Input signals

| Name  | Type    | Default | Description                                   |
|-------|---------|---------|---|
| I_A   | SIGNAL  | 0       | Phase A current                               |
| I_B   | SIGNAL  | 0       | Phase B current                               |
| I_C   | SIGNAL  | 0       | Phase C current                               |
| BLOCK | BOOLEAN | 0=False | Block signal for activating the blocking mode |

#### JAMPTOC Output signals

Table 260: JAMPTOC Output signals

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |

### 3.1.5.7 Settings

#### JAMPTOC Settings

Table 261: JAMPTOC Non group settings (Basic)

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on           |      |      | 1=on    | Operation Off / On |

*Table continues on the next page*

| Parameter          | Values (Range) | Unit | Step | Default | Description        |
|--------------------|----------------|------|------|---------|--------------------|
|                    | 5=off          |      |      |         |                    |
| Start value        | 0.10...10.00   | xIn  | 0.01 | 2.50    | Start value        |
| Operate delay time | 100...120000   | ms   | 10   | 2000    | Operate delay time |

Table 262: JAMPTOC Non group settings (Advanced)

| Parameter        | Values (Range) | Unit | Step | Default | Description      |
|------------------|----------------|------|------|---------|------------------|
| Reset delay time | 0...60000      | ms   | 1    | 100     | Reset delay time |

### 3.1.5.8

## Monitored data

### JAMPTOC Monitored data

Table 263: JAMPTOC Monitored data

| Name      | Type    | Values (Range)   | Unit | Description                        |
|-----------|---------|--|------|------------------------------------|
| START     | BOOLEAN | 0=False<br>1=True                                      |      | Start                              |
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time |
| JAMPTOC   | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                             |

### 3.1.5.9

## Technical data

Table 264: JAMPTOC Technical data

| Characteristic                              | Value  |
|---|--|
| Operation accuracy                          | Depending on the frequency of the measured current: $f_n \pm 2$ Hz<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$ |
| Reset time                                  | Typically 40 ms  |
| Reset ratio                                 | Typically 0.96   |
| Retardation time                            | <35 ms   |
| Operate time accuracy in definite time mode | $\pm 1.0\%$ of the set value or $\pm 20$ ms  |



### 3.1.5.10 Technical revision history

Table 265: JAMPTOC Technical revision history

| Technical revision | Change                |
|--------------------|-----------------------|
| B                  | Internal improvement. |
| C                  | Internal improvement. |

## 3.1.6 Loss of load supervision LOFLPTUC

### 3.1.6.1 Identification

| Function description     | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--------------------------|--------------------------|--------------------------|-------------------------------|
| Loss of load supervision | LOFLPTUC                 | 3I<                      | 37                            |

### 3.1.6.2 Function block

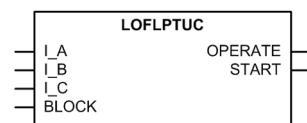


Figure 108: Function block

### 3.1.6.3 Functionality

The loss of load supervision function LOFLPTUC is used to detect a sudden load loss which is considered as a fault condition.

LOFLPTUC starts when the current is less than the set limit. It operates with the definite time (DT) characteristics, which means that the function operates after a predefined operate time and resets when the fault current disappears.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

### 3.1.6.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of LOFLPTUC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

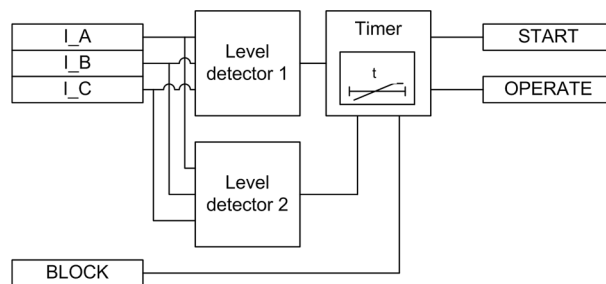


Figure 109: Functional module diagram

### Level detector 1

This module compares the phase currents (RMS value) to the set *Start value high* setting. If all the phase current values are less than the set *Start value high* value, the loss of load condition is detected and an enable signal is sent to the timer. This signal is disabled after one or several phase currents have exceeded the set *Start value high* value of the element.

### Level detector 2

This is a low-current detection module, which monitors the de-energized condition of the motor. It compares the phase currents (RMS value) to the set *Start value low* setting. If any of the phase current values is less than the set *Start value low*, a signal is sent to block the operation of the timer.

### Timer

Once activated, the timer activates the `START` output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the `OPERATE` output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the `START` output is deactivated.

The timer calculates the start duration value `START_DUR`, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

The `BLOCK` signal blocks the operation of the function and resets the timer.

## 3.1.6.5

### Application

When a motor runs with a load connected, it draws a current equal to a value between the no-load value and the rated current of the motor. The minimum load current can be determined by studying the characteristics of the connected load. When the current drawn by the motor is less than the minimum load current drawn, it can be inferred that the motor is either disconnected from the load or the coupling mechanism is faulty. If the motor is allowed to run in this condition, it may aggravate the fault in the coupling mechanism or harm the personnel handling the machine. Therefore, the motor has to be disconnected from the power supply as soon as the above condition is detected.

LOFLPTUC detects the condition by monitoring the current values and helps disconnect the motor from the power supply instantaneously or after a delay according to the requirement.

When the motor is at standstill, the current will be zero and it is not recommended to activate the trip during this time. The minimum current drawn by the motor when it is connected to the power supply is the no load current, that is, the higher start value current. If the current drawn is below the lower start value current, the motor is disconnected from the power supply. LOFLPTUC detects this condition and interprets that the motor is de-energized and disables the function to prevent unnecessary trip events.

### 3.1.6.6 Signals

#### LOFLPTUC Input signals

Table 266: LOFLPTUC Input signals

| Name  | Type    | Default | Description                                  |
|-------|---------|---------|--|
| I_A   | SIGNAL  | 0       | Phase A current                              |
| I_B   | SIGNAL  | 0       | Phase B current                              |
| I_C   | SIGNAL  | 0       | Phase C current                              |
| BLOCK | BOOLEAN | 0=False | Block all binary outputs by resetting timers |

#### LOFLPTUC Output signals

Table 267: LOFLPTUC Output signals

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

### 3.1.6.7 Settings

#### LOFLPTUC Settings

Table 268: LOFLPTUC Group settings (Basic)

| Parameter          | Values (Range) | Unit | Step | Default | Description                      |
|--------------------|----------------|------|------|---------|----------------------------------|
| Start value low    | 0.01...0.50    | xIn  | 0.01 | 0.10    | Current setting/Start value low  |
| Start value high   | 0.01...1.00    | xIn  | 0.01 | 0.50    | Current setting/Start value high |
| Operate delay time | 400...600000   | ms   | 10   | 2000    | Operate delay time               |

**Table 269: LOFLPTUC Non group settings (Basic)**

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

**Table 270: LOFLPTUC Non group settings (Advanced)**

| Parameter        | Values (Range) | Unit | Step | Default | Description      |
|------------------|----------------|------|------|---------|------------------|
| Reset delay time | 0...60000      | ms   | 1    | 20      | Reset delay time |

### 3.1.6.8

## Monitored data

### LOFLPTUC Monitored data

**Table 271: LOFLPTUC Monitored data**

| Name      | Type    | Values (Range)   | Unit | Description                        |
|-----------|---------|--|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time |
| LOFLPTUC  | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                             |

### 3.1.6.9

## Technical data

**Table 272: LOFLPTUC Technical data**

| Characteristic                              | Value  |
|---|--|
| Operation accuracy                          | Depending on the frequency of the measured current: $f_n \pm 2$ Hz<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$ |
| Start time                                  | Typically 300 ms   |
| Reset time                                  | Typically 40 ms  |
| Reset ratio                                 | Typically 1.04   |
| Retardation time                            | <35 ms   |
| Operate time accuracy in definite time mode | $\pm 1.0\%$ of the set value or $\pm 20$ ms  |

### 3.1.6.10 Technical revision history

Table 273: LOFLPTUC Technical revision history

| Technical revision | Change                |
|--------------------|-----------------------|
| B                  | Internal improvement. |
| C                  | Internal improvement. |

## 3.1.7 Thermal overload protection for motors MPTTR

### 3.1.7.1 Identification

| Function description                   | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--|--------------------------|--------------------------|-------------------------------|
| Thermal overload protection for motors | MPTTR                    | 3lth>M                   | 49M                           |

### 3.1.7.2 Function block

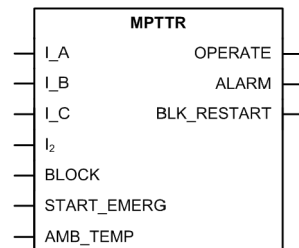


Figure 110: Function block

### 3.1.7.3 Functionality

The thermal overload protection for motors function MPTTR protects the electric motors from overheating. MPTTR models the thermal behavior of motor on the basis of the measured load current and disconnects the motor when the thermal content reaches 100 percent. The thermal overload conditions are the most often encountered abnormal conditions in industrial motor applications. The thermal overload conditions are typically the result of an abnormal rise in the motor running current, which produces an increase in the thermal dissipation of the motor and temperature or reduces cooling. MPTTR prevents an electric motor from drawing excessive current and overheating, which causes the premature insulation failures of the windings and, in worst cases, burning out of the motors.

### 3.1.7.4 Operational principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of MPTTR can be described using a module diagram. All the modules in the diagram are explained in the next sections.

The function uses ambient temperature which can be measured remotely. Remote measurement uses analog GOOSE to connect `AMB_TEMP` input.



If the quality of remotely measured temperature is invalid or communication channel fails the function uses ambient temperature set in *Env temperature Set*.

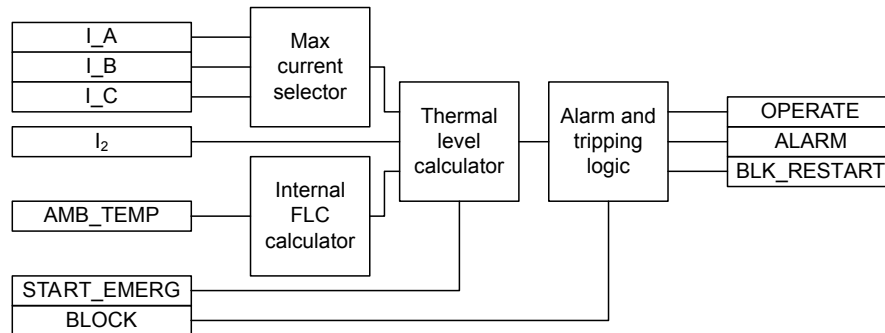


Figure 111: Functional module diagram

### Max current selector

Max current selector selects the highest measured TRMS phase current and reports it to Thermal level calculator.

### Internal FLC calculator

Full load current (FLC) of the motor is defined by the manufacturer at an ambient temperature of 40°C. Special considerations are required with an application where the ambient temperature of a motor exceeds or remains below 40°C. A motor operating at a higher temperature, even if at or below rated load, can subject the motor windings to excessive temperature similar to that resulting from overload operation at normal ambient temperature. The motor rating has to be appropriately reduced for operation in such high ambient temperatures. Similarly, when the ambient temperature is considerably lower than the nominal 40°C, the motor can be slightly overloaded. For calculating thermal level it is better that the FLC values are scaled for different temperatures. The scaled currents are known as internal FLC. An internal FLC is calculated based on the ambient temperature shown in the table. The *Env temperature mode* setting defines whether the thermal level calculations are based on FLC or internal FLC.

When the value of the *Env temperature mode* setting is set to the "FLC Only" mode, no internal FLC is calculated. Instead, the FLC given in the data sheet of the manufacturer is used. When the value of the *Env temperature mode* setting is set to "Set Amb Temp" mode, the internal FLC is calculated based on the ambient temperature taken as an input through the *Env temperature Set* setting. When the *Env temperature mode* setting is on "Use input" mode, the internal FLC is calculated from temperature data available through resistance temperature detectors (RTDs in bay level relays or merging units, sent to protective device via GOOSE message) using the `AMB_TEMP` input.

**Table 274: Modification of internal FLC**

| Ambient Temperature $T_{amb}$ | Internal FLC                        |
|-------------------------------|-------------------------------------|
| <20°C                         | FLC x 1.09                          |
| 20 to <40°C                   | FLC x (1.18 - $T_{amb}$ x 0.09/20)  |
| 40°C                          | FLC                                 |
| >40 to 65°C                   | FLC x (1 - [( $T_{amb}$ - 40)/100]) |
| >65°C                         | FLC x 0.75                          |

The ambient temperature is used for calculating thermal level and it is available in the monitored data view from the TEMP\_AMB output. The activation of the BLOCK input does not affect the TEMP\_AMB output.

The *Env temperature Set* setting is used if the ambient temperature measurement value is not connected to the AMB\_TEMP input in ACT.

#### Thermal level calculator

The module calculates the thermal load considering the TRMS and negative-sequence currents. The heating up of the motor is determined by the square value of the load current.

However, in case of unbalanced phase currents, the negative-sequence current also causes additional heating. By deploying a protection based on both current components, abnormal heating of the motor is avoided.

The thermal load is calculated based on different situations or operations and it also depends on the phase current level. The equations used for the heating calculations are:

$$\theta_B = \left[ \left( \frac{I}{k \times I_r} \right)^2 + K_2 \times \left( \frac{I_2}{k \times I_r} \right)^2 \right] \times (1 - e^{-t/\tau}) \times p\%$$

$$\theta_A = \left[ \left( \frac{I}{k \times I_r} \right)^2 + K_2 \times \left( \frac{I_2}{k \times I_r} \right)^2 \right] \times (1 - e^{-t/\tau}) \times 100\%$$

|       |  |
|-------|--|
| I     | TRMS value of the measured max of phase currents   |
| $I_r$ | set <i>Current reference</i> , FLC or internal FLC |
| $I_2$ | measured negative sequence current                 |
| k     | set value of <i>Overload factor</i>                |
| $K_2$ | set value of <i>Negative Seq factor</i>            |
| p     | set value of <i>Weighting factor</i>               |
| t     | time constant                                      |

The equation  $\theta_B$  is used when the values of all the phase currents are below the overload limit, that is,  $k \times I_r$ . The equation  $\theta_A$  is used when the value of any one of the phase currents exceeds the overload limit.

During overload condition, the thermal level calculator calculates the value of  $\theta_B$  in background, and when the overload ends the thermal level is brought linearly from  $\theta_A$  to  $\theta_B$  with a speed of 1.66 percent per second. For the motor at standstill, that is, when the current is below the value of  $0.12 \times I_r$ , the cooling is expressed as:

$$\theta = \theta_{02} \times e^{-\frac{t}{\tau}}$$

$\theta_{02}$

initial thermal level when cooling begins

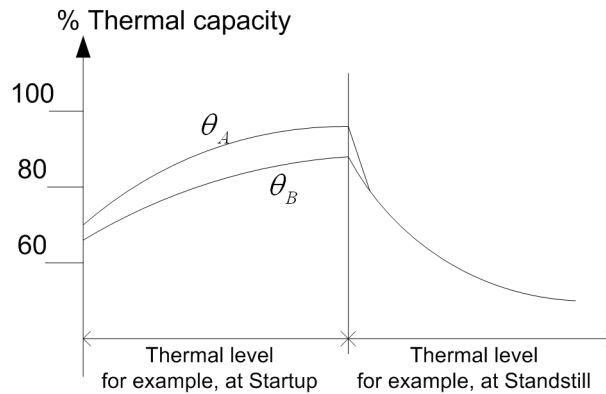


Figure 112: Thermal behavior

The required overload factor and negative sequence current heating effect factor are set by the values of the *Overload factor* and *Negative Seq factor* settings.

In order to accurately calculate the motor thermal condition, different time constants are used in the above equations. These time constants are employed based on different motor running conditions, for example starting, normal or stop, and are set through the *Time constant start*, *Time constant normal* and *Time constant stop* settings. Only one time constant is valid at a time.

Table 275: Time constant and the respective phase current values

| Time constant (tau) in use | Phase current   |
|----------------------------|---|
| Time constant start        | Any current whose value is over $2.5 \times I_r$  |
| Time constant normal       | Any current whose value is over $0.12 \times I_r$ and all currents are below $2.5 \times I_r$ |
| Time constant stop         | All the currents whose values are below $0.12 \times I_r$                                     |

The *Weighting factor p* setting determines the ratio of the thermal increase of the two curves  $\theta_A$  and  $\theta_B$ .

The thermal level at the power-up of the IED is defined by the *Initial thermal Val* setting.

The temperature calculation is initiated from the value defined in the *Initial thermal Val* setting. This is done if the IED is powered up or the function is turned off and back on or reset through the Clear menu.

The calculated temperature of the protected object relative to the operate level, the TEMP\_RL output, is available through the monitored data view. The activation of the BLOCK input does not affect the calculated temperature.



The thermal level at the beginning of the start-up condition of a motor and at the end of the start-up condition is available in the monitored data view at the `THERMLEV_ST` and `THERMLEV_END` outputs respectively. The activation of the `BLOCK` input does not have any effect on these outputs.

### Alarm and tripping logic

The module generates alarm, restart inhibit and tripping signals.

When the thermal level exceeds the set value of the *Alarm thermal value* setting, the `ALARM` output is activated. Sometimes a condition arises when it becomes necessary to inhibit the restarting of a motor, for example in case of some extreme starting condition like long starting time. If the thermal content exceeds the set value of the *Restart thermal va/setting*, the `BLK_RESTART` output is activated. The time for the next possible motor start-up is available through the monitored data view from the `T_ENARESTART` output. The `T_ENARESTART` output estimates the time for the `BLK_RESTART` deactivation considering as if the motor is stopped.

When the emergency start signal `START_EMERG` is set high, the thermal level is set to a value below the thermal restart inhibit level. This allows at least one motor start-up, even though the thermal level has exceeded the restart inhibit level.

When the thermal content reaches 100 percent, the `OPERATE` output is activated. The `OPERATE` output is deactivated when the value of the measured current falls below 12 percent of *Current reference* or the thermal content drops below 100 percent.

The activation of the `BLOCK` input blocks the `ALARM`, `BLK_RESTART` and `OPERATE` outputs.

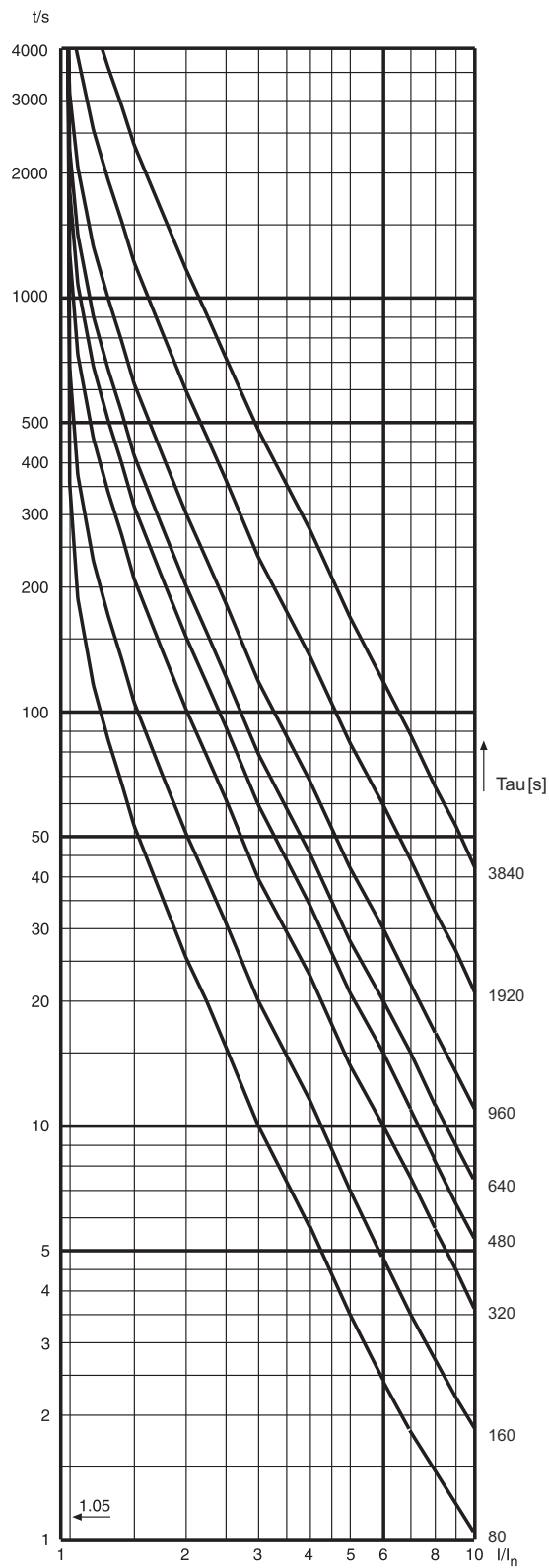


Figure 113: Trip curves when no prior load and  $p=20\dots100\%$ . Overload factor = 1.05.

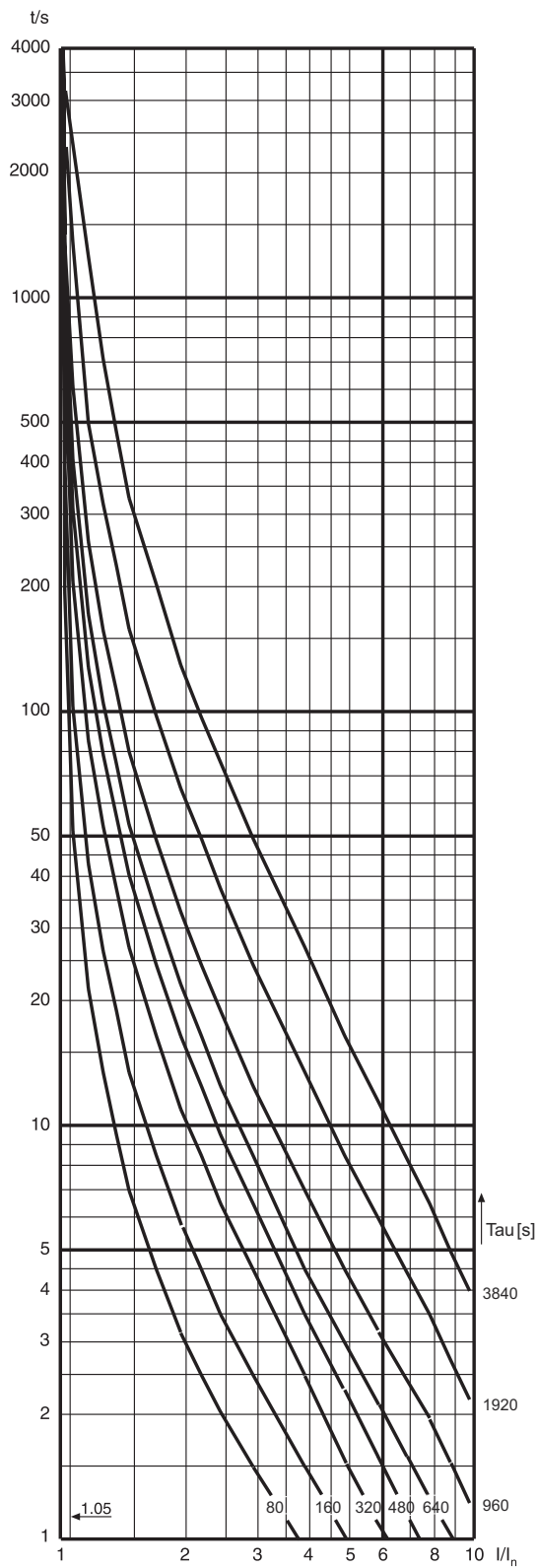


Figure 114: Trip curves at prior load 1 x FLC and  $p=100\%$ , Overload factor = 1.05.

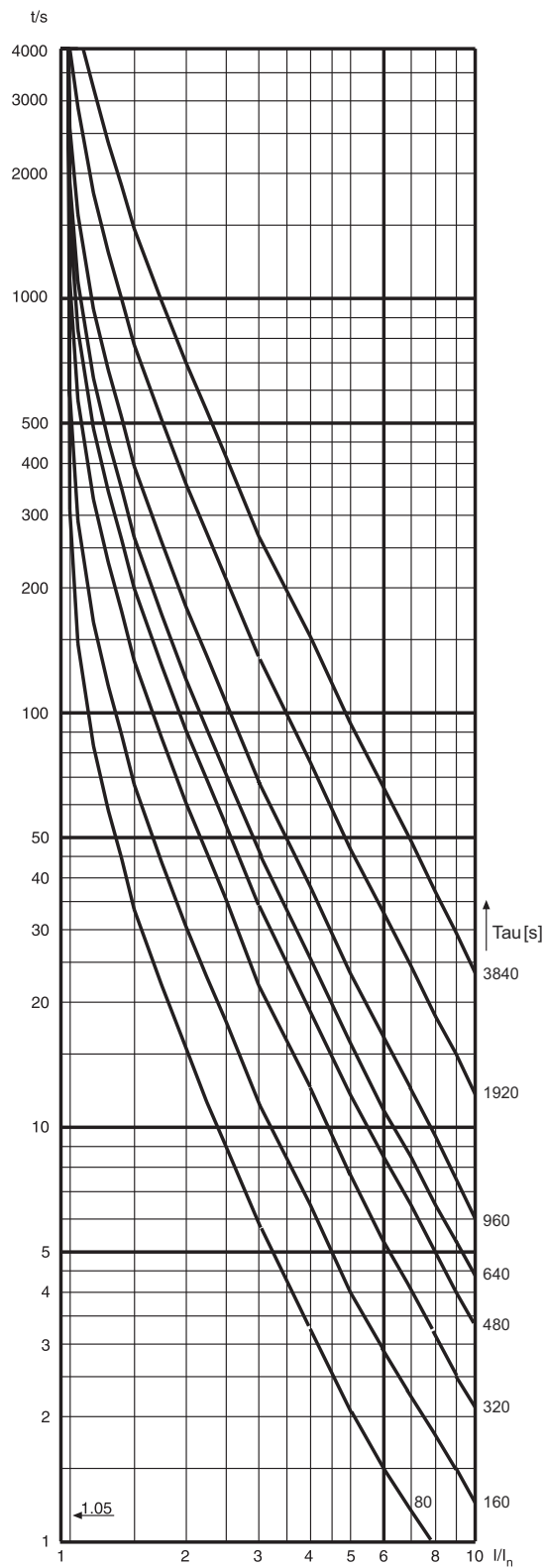


Figure 115: Trip curves at prior load  $1 \times \text{FLC}$  and  $p=50\%$ . Overload factor = 1.05.

### 3.1.7.5 Application

MPTTR is intended to limit the motor thermal level to predetermined values during the abnormal motor operating conditions. This prevents a premature motor insulation failure.

The abnormal conditions result in overheating and include overload, stalling, failure to start, high ambient temperature, restricted motor ventilation, reduced speed operation, frequent starting or jogging, high or low line voltage or frequency, mechanical failure of the driven load, improper installation and unbalanced line voltage or single phasing. The protection of insulation failure by the implementation of current sensing cannot detect some of these conditions, such as restricted ventilation. Similarly, the protection by sensing temperature alone can be inadequate in cases like frequent starting or jogging. The thermal overload protection addresses these deficiencies to a larger extent by deploying a motor thermal model based on load current.

The thermal load is calculated using the true RMS phase value and negative sequence value of the current. The heating up of the motor is determined by the square value of the load current. However, while calculating the thermal level, the rated current should be re-rated or de-rated depending on the value of the ambient temperature. Apart from current, the rate at which motor heats up or cools is governed by the time constant of the motor.

#### Setting the weighting factor

There are two thermal curves: one which characterizes the short-time loads and long-time overloads and which is also used for tripping and another which is used for monitoring the thermal condition of the motor. The value of the *Weighting factor p* setting determines the ratio of the thermal increase of the two curves.

When the *Weighting factor p* setting is 100 percent, a pure single time constant thermal unit is produced which is used for application with the cables. As presented in [Figure 116](#), the hot curve with the value of *Weighting factor p* being 100 percent only allows an operate time which is about 10 percent of that with no prior load. For example, when the set time constant is 640 seconds, the operate time with the prior load  $1 \times \text{FLC}$  (full Load Current) and overload factor 1.05 is only 2 seconds, even if the motor could withstand at least 5 to 6 seconds. To allow the use of the full capacity of the motor, a lower value of *Weighting factor p* should be used.

Normally, an approximate value of half of the thermal capacity is used when the motor is running at full load. Thus by setting *Weighting factor p* to 50 percent, the IED notifies a 45 to 50 percent thermal capacity use at full load.

For direct-on-line started motors with hot spot tendencies, the value of *Weighting factor p* is typically set to 50 percent, which will properly distinguish between short-time thermal stress and long-time thermal history. After a short period of thermal stress, for example a motor start-up, the thermal level starts to decrease quite sharply, simulating the leveling out of the hot spots. Consequently, the probability of successive allowed start-ups increases.

When protecting the objects without hot spot tendencies, for example motors started with soft starters, and cables, the value of *Weighting factor p* is set to 100 percent. With the value of *Weighting factor p* set to 100 percent, the thermal level decreases slowly after a heavy load condition. This makes the protection suitable for applications where no hot spots are expected. Only in special cases where the thermal overload protection is required to follow the characteristics of the object to be protected more closely and the thermal capacity of the object is very well known, a value between 50 and 100 percent is required.

For motor applications where, for example, two hot starts are allowed instead of three cold starts, the value of the setting *Weighting factor p* being 40 percent has proven to be useful. Setting the value of *Weighting factor p* significantly below 50 percent should be handled carefully as there is a possibility to overload the protected object as a thermal unit might allow too many hot starts or the thermal history of the motor has not been taken into account sufficiently.

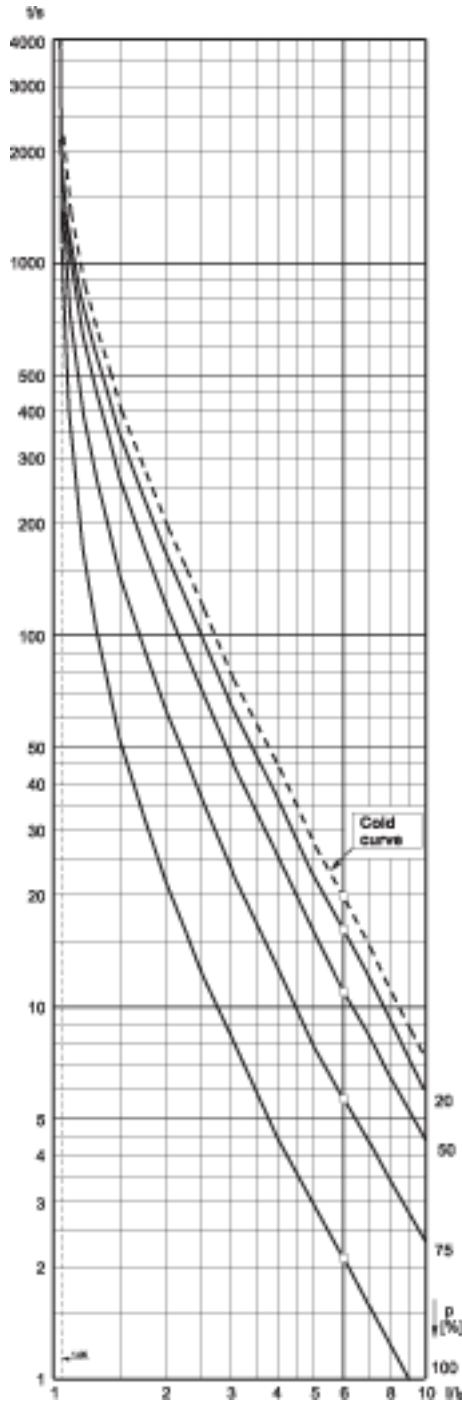


Figure 116: The influence of Weighting factor *p* at prior load 1xFLC, time constant = 640 s, and Overload factor = 1.05

### Setting the overload factor

The value of *Overload factor* defines the highest permissible continuous load. The recommended value is 1.05.

### Setting the negative sequence factor

During the unbalance condition, the symmetry of the stator currents is disturbed and a counter-rotating negative sequence component current is set up. An increased stator current causes additional heating in the stator and the negative sequence component current excessive heating in the rotor. Also mechanical problems like rotor vibration can occur.

The most common cause of unbalance for three-phase motors is the loss of phase resulting in an open fuse, connector or conductor. Often mechanical problems can be more severe than the heating effects and therefore a separate unbalance protection is used.

Unbalances in other connected loads in the same busbar can also affect the motor. A voltage unbalance typically produces 5 to 7 times higher current unbalance. Because the thermal overload protection is based on the highest TRMS value of the phase current, the additional heating in stator winding is automatically taken into account. For more accurate thermal modeling, the *Negative Seq factor* setting is used for taking account of the rotor heating effect.

$$\text{Negative Seq factor} = \frac{R_{R2}}{R_{R1}}$$

$R_{R2}$  rotor negative sequence resistance

$R_{R1}$  rotor positive sequence resistance

A conservative estimate for the setting can be calculated:

$$\text{Negative Seq factor} = \frac{175}{I_{LR}^2}$$

$I_{LR}$  locked rotor current (multiple of set *Rated current*). The same as the start-up current at the beginning of the motor start-up.

For example, if the rated current of a motor is 230 A, start-up current is  $5.7 \times I_r$ ,

$$\text{Negative Seq factor} = \frac{175}{5.7^2} = 5.4$$

### Setting the thermal restart level

The restart disable level can be calculated as follows:

$$\theta_i = 100\% - \left( \frac{\text{startup time of the motor}}{\text{operate time when no prior load}} \times 100\% + \text{margin} \right)$$

For example, the motor start-up time is 11 seconds, start-up current  $6 \times$  rated and *Time constant start* is set for 800 seconds. Using the trip curve with no prior load, the operation time at  $6 \times$  rated current is 25 seconds, one motor start-up uses  $11/25 \approx 45$  percent of the thermal capacity of the motor. Therefore, the restart disable

level must be set to below 100 percent - 45 percent = 55 percent, for example to 50 percent (100 percent - (45 percent + margin), where margin is 5 percent).

### Setting the thermal alarm level

Tripping due to high overload is avoided by reducing the load of the motor on a prior alarm.

The value of *Alarm thermal value* is set to a level which allows the use of the full thermal capacity of the motor without causing a trip due to a long overload time. Generally, the prior alarm level is set to a value of 80 to 90 percent of the trip level.

## 3.1.7.6 Signals

### MPTTR Input signals

Table 276: MPTTR Input signals

| Name           | Type    | Default | Description  |
|----------------|---------|---------|--|
| I_A            | SIGNAL  | 0       | Phase A current                                    |
| I_B            | SIGNAL  | 0       | Phase B current                                    |
| I_C            | SIGNAL  | 0       | Phase C current                                    |
| I <sub>2</sub> | SIGNAL  | 0       | Negative sequence current                          |
| BLOCK          | BOOLEAN | 0=False | Block signal for activating the blocking mode      |
| START_EMERG    | BOOLEAN | 0=False | Signal for indicating the need for emergency start |
| TEMP_AMB       | FLOAT32 | 0       | The ambient temperature used in the calculation    |

### MPTTR Output signals

Table 277: MPTTR Output signals

| Name        | Type    | Description                                    |
|-------------|---------|--|
| OPERATE     | BOOLEAN | Operate  |
| ALARM       | BOOLEAN | Thermal Alarm                                  |
| BLK_RESTART | BOOLEAN | Thermal overload indicator, to inhibit restart |

## 3.1.7.7 Settings



**MPTTR Settings****Table 278: MPTTR Group settings (Basic)**

| Parameter            | Values (Range)                              | Unit | Step | Default    | Description   |
|----------------------|---|------|------|------------|---|
| Overload factor      | 1.00...1.20                                 |      | 0.01 | 1.05       | Overload factor (k)   |
| Alarm thermal value  | 50.0...100.0                                | %    | 0.1  | 95.0       | Thermal level above which function gives an alarm                           |
| Restart thermal Val  | 20.0...80.0                                 | %    | 0.1  | 40.0       | Thermal level above which function inhibits motor restarting                |
| Negative Seq factor  | 0.0...10.0                                  |      | 0.1  | 0.0        | Heating effect factor for negative sequence current                         |
| Weighting factor p   | 20.0...100.0                                | %    | 0.1  | 50.0       | Weighting factor (p)  |
| Time constant normal | 80...4000                                   | s    | 1    | 320        | Motor time constant during the normal operation of motor                    |
| Time constant start  | 80...4000                                   | s    | 1    | 320        | Motor time constant during the start of motor                               |
| Time constant stop   | 80...60000                                  | s    | 1    | 500        | Motor time constant during the standstill condition of motor                |
| Env temperature mode | 1=FLC Only<br>2=Use input<br>3=Set Amb Temp |      |      | 1=FLC Only | Mode of measuring ambient temperature                                       |
| Env temperature Set  | -20.0...70.0                                | °C   | 0.1  | 40.0       | Ambient temperature used when no external temperature measurement available |

**Table 279: MPTTR Non group settings (Basic)**

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

**Table 280: MPTTR Non group settings (Advanced)**

| Parameter           | Values (Range) | Unit | Step | Default | Description                        |
|---------------------|----------------|------|------|---------|------------------------------------|
| Current reference   | 0.30...2.00    | xIn  | 0.01 | 1.00    | Rated current (FLC) of the motor   |
| Initial thermal Val | 0.0...100.0    | %    | 0.1  | 74.0    | Initial thermal level of the motor |

### 3.1.7.8

#### Monitored data

##### MPTTR Monitored data

**Table 281: MPTTR Monitored data**

| Name         | Type    | Values (Range)              | Unit | Description  |
|--------------|---------|-----------------------------|------|--|
| TEMP_RL      | FLOAT32 | 0.00...9.99                 |      | The calculated temperature of the protected object relative to the operate level |
| TEMP_AMB     | FLOAT32 | -99...999                   | °C   | The ambient temperature used in the calculation                                  |
| THERMLEV_ST  | FLOAT32 | 0.00...9.99                 |      | Thermal level at beginning of motor startup                                      |
| THERMLEV_END | FLOAT32 | 0.00...9.99                 |      | Thermal level at the end of motor startup situation                              |
| T_ENARESTART | INT32   | 0...99999                   | s    | Estimated time to reset of block restart   |
| MPTTR        | Enum    | 1=on<br>2=blocked<br>3=test |      | Status   |

*Table continues on the next page*

| Name      | Type    | Values (Range)          | Unit | Description   |
|-----------|---------|-------------------------|------|---|
|           |         | 4=test/blocked<br>5=off |      |   |
| Therm-Lev | FLOAT32 | 0.00...9.99             |      | Thermal level of protected object (1.00 is the operate level) |

### 3.1.7.9 Technical data

Table 282: MPTTR Technical data

| Characteristic                      | Value   |
|-------------------------------------|---|
| Operation accuracy                  | Depending on the frequency of the measured current: $f_n \pm 2$ Hz<br>Current measurement: $\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$ (at currents in the range of $0.01...4.00 \times I_n$ ) |
| Operate time accuracy <sup>29</sup> | $\pm 2.0\%$ of the theoretical value or $\pm 0.50$ s  |

### 3.1.7.10 Technical revision history

Table 283: MPTTR Technical revision history

| Technical revision | Change  |
|--------------------|---|
| B                  | Added a new input <code>AMB_TEMP</code> .<br>Added a new selection for the <i>Env temperature mode</i> setting "Use input". |
| C                  | Internal improvement.   |
| D                  | Time constant stop range maximum value changed from 8000 s to 60000 s.  |
| E                  | Internal improvement.   |
| F                  | Modified for SSC600   |

## 3.2 Earth-fault protection

### 3.2.1 Non-directional earth-fault protection EFXPTOC

<sup>29</sup> Overload current  $> 1.2 \times$  Operate level temperature

### 3.2.1.1 Identification

| Function description  | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|--------------------------|--------------------------|-------------------------------|
| Non-directional earth-fault protection, low stage           | EFLPTOC                  | Io>                      | 51N-1                         |
| Non-directional earth-fault protection, high stage          | EFHPTOC                  | Io>>                     | 51N-2                         |
| Non-directional earth-fault protection, instantaneous stage | EFIPTOC                  | Io>>>                    | 50N/51N                       |

### 3.2.1.2 Function block

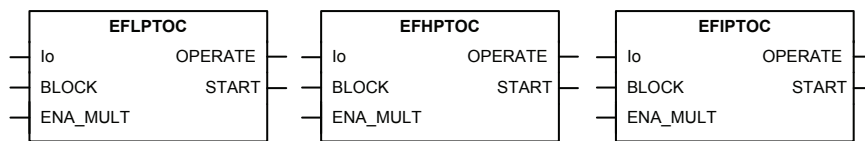


Figure 117: Function block

### 3.2.1.3 Functionality

The non-directional earth-fault protection function EFXPTOC is used as non-directional earth-fault protection for feeders.

The function starts and operates when the residual current exceeds the set limit. The operate time characteristic for low stage EFLPTOC and high stage EFHPTOC can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). The instantaneous stage EFIPTOC always operates with the DT characteristic.

In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

### 3.2.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of EFXPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

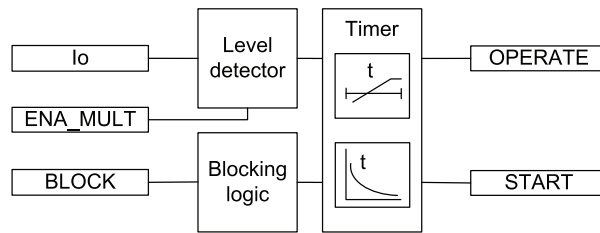


Figure 118: Functional module diagram

### Level detector

The operating quantity can be selected within the ACT configuration. The options are "Measured Io" and "Calculated Io". The operating quantity is compared to the set *Start value*. If the measured value exceeds the set *Start value*, the level detector sends an enable-signal to the timer module. If the ENA\_MULT input is active, the *Start value* setting is multiplied by the *Start value Mult* setting.



The IED does not accept the *Start value* or *Start value Mult* setting if the product of these settings exceeds the *Start value* setting range.

The start value multiplication is normally done when the inrush detection function (INRPBAR) is connected to the ENA\_MULT input.

### Timer

Once activated, the timer activates the START output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the OPERATE output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation happens, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation. The START output is deactivated when the reset timer has elapsed.



The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.



The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see [Chapter 10.2.1 IDMT curves for overcurrent protection](#) in this manual.

The timer calculates the start duration value START\_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration > System > Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

### 3.2.1.5

#### Measurement modes

The function operates on three alternative measurement modes: "RMS", "DFT" and "Peak-to-Peak". The measurement mode is selected with the *Measurement mode* setting.

**Table 284: Measurement modes supported by EFxPTOC stages**

| Measurement mode | EFLPTOC | EFHPTOC | EFIPTOC |
|------------------|---------|---------|---------|
| RMS              | x       | x       |         |
| DFT              | x       | x       |         |
| Peak-to-Peak     | x       | x       | x       |



For a detailed description of the measurement modes, see [Chapter 10.2.1 IDMT curves for overcurrent protection](#) in this manual.

### 3.2.1.6

#### Timer characteristics

EFxPTOC supports both DT and IDMT characteristics. The user can select the timer characteristics with the *Operating curve type* and *Type of reset curve* settings. When the DT characteristic is selected, it is only affected by the *Operate delay time* and *Reset delay time* settings.

The IED provides 16 IDMT characteristics curves, of which seven comply with the IEEE C37.112 and six with the IEC 60255-3 standard. Two curves follow the special characteristics of ABB praxis and are referred to as RI and RD. In addition to this, a user programmable curve can be used if none of the standard curves are applicable. The user can choose the DT characteristic by selecting the *Operating curve type*

values "ANSI Def. Time" or "IEC Def. Time". The functionality is identical in both cases.

The following characteristics, which comply with the list in the IEC 61850-7-4 specification, indicate the characteristics supported by different stages:

**Table 285: Timer characteristics supported by different stages**

| Operating curve type            | EFLPTOC | EFHPTOC |
|---------------------------------|---------|---------|
| (1) ANSI Extremely Inverse      | x       | x       |
| (2) ANSI Very Inverse           | x       |         |
| (3) ANSI Normal Inverse         | x       | x       |
| (4) ANSI Moderately Inverse     | x       |         |
| (5) ANSI Definite Time          | x       | x       |
| (6) Long Time Extremely Inverse | x       |         |
| (7) Long Time Very Inverse      | x       |         |
| (8) Long Time Inverse           | x       |         |
| (9) IEC Normal Inverse          | x       | x       |
| (10) IEC Very Inverse           | x       | x       |
| (11) IEC Inverse                | x       |         |
| (12) IEC Extremely Inverse      | x       | x       |
| (13) IEC Short Time Inverse     | x       |         |
| (14) IEC Long Time Inverse      | x       |         |
| (15) IEC Definite Time          | x       | x       |
| (17) User programmable curve    | x       | x       |
| (18) RI type                    | x       |         |
| (19) RD type                    | x       |         |



EFIPTOC supports only definite time characteristics.



For a detailed description of timers, see [Chapter 10.2 Current based inverse definite minimum time characteristics](#) in this manual.

**Table 286: Reset time characteristics supported by different stages**

| Reset curve type   | EFLPTOC | EFHPTOC | Note   |
|--------------------|---------|---------|--|
| (1) Immediate      | x       | x       | Available for all operate time curves                |
| (2) Def time reset | x       | x       | Available for all operate time curves                |
| (3) Inverse reset  | x       | x       | Available only for ANSI and user programmable curves |



The *Type of reset curve* setting does not apply to EFIPTOC or when the DT operation is selected. The reset is purely defined by the *Reset delay time* setting.

### 3.2.1.7

#### Application

EFxPTOC is designed for protection and clearance of earth faults in distribution and sub-transmission networks where the neutral point is isolated or earthed via a resonance coil or through low resistance. It also applies to solidly earthed networks and earth-fault protection of different equipment connected to the power systems, such as shunt capacitor bank or shunt reactors and for backup earth-fault protection of power transformers.

Many applications require several steps using different current start levels and time delays. EFxPTOC consists of three different protection stages.

- Low EFLPTOC
- High EFHPTOC
- Instantaneous EFIPTOC

EFLPTOC contains several types of time-delay characteristics. EFHPTOC and EFIPTOC are used for fast clearance of serious earth faults.

### 3.2.1.8

#### Signals

##### EFLPTOC Input signals

Table 287: EFLPTOC Input signals

| Name     | Type    | Default | Description                                   |
|----------|---------|---------|---|
| Io       | SIGNAL  | 0       | Residual current                              |
| BLOCK    | BOOLEAN | 0=False | Block signal for activating the blocking mode |
| ENA_MULT | BOOLEAN | 0=False | Enable signal for current multiplier          |

##### EFHPTOC Input signals

Table 288: EFHPTOC Input signals

| Name     | Type    | Default | Description                                   |
|----------|---------|---------|---|
| Io       | SIGNAL  | 0       | Residual current                              |
| BLOCK    | BOOLEAN | 0=False | Block signal for activating the blocking mode |
| ENA_MULT | BOOLEAN | 0=False | Enable signal for current multiplier          |



**EFIPTOC Input signals****Table 289: EFIPTOC Input signals**

| Name     | Type    | Default | Description                                   |
|----------|---------|---------|---|
| Io       | SIGNAL  | 0       | Residual current                              |
| BLOCK    | BOOLEAN | 0=False | Block signal for activating the blocking mode |
| ENA_MULT | BOOLEAN | 0=False | Enable signal for current multiplier          |

**EFLPTOC Output signals****Table 290: EFLPTOC Output signals**

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

**EFHPTOC Output signals****Table 291: EFHPTOC Output signals**

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

**EFIPTOC Output signals****Table 292: EFIPTOC Output signals**

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

**3.2.1.9****Settings**

**EFLPTOC Settings**

**Table 293: EFLPTOC Group settings (Basic)**

| Parameter            | Values (Range)   | Unit | Step  | Default          | Description                             |
|----------------------|--|------|-------|------------------|---|
| Start value          | 0.010...5.000  | xIn  | 0.005 | 0.010            | Start value                             |
| Start value Mult     | 0.8...10.0   |      | 0.1   | 1.0              | Multiplier for scaling the start value  |
| Time multiplier      | 0.05...15.00   |      | 0.01  | 1.00             | Time multiplier in IEC/ANSI IDMT curves |
| Operate delay time   | 40...200000  | ms   | 10    | 40               | Operate delay time                      |
| Operating curve type | 1=ANSI Ext. inv.<br>2=ANSI Very inv.<br>3=ANSI Norm. inv.<br>4=ANSI Mod. inv.<br>5=ANSI Def. Time<br>6=L.T.E. inv.<br>7=L.T.V. inv.<br>8=L.T. inv.<br>9=IEC Norm. inv.<br>10=IEC Very inv.<br>11=IEC inv.<br>12=IEC Ext. inv.<br>13=IEC S.T. inv.<br>14=IEC L.T. inv.<br>15=IEC Def. Time<br>17=Programmable<br>18=RI type<br>19=RD type |      |       | 15=IEC Def. Time | Selection of time delay curve type      |

**Table 294: EFLPTOC Group settings (Advanced)**

| Parameter           | Values (Range)                                       | Unit | Step | Default     | Description                   |
|---------------------|--|------|------|-------------|-------------------------------|
| Type of reset curve | 1=Immediate<br>2=Def time re-set<br>3=Inverse re-set |      |      | 1=Immediate | Selection of reset curve type |

**Table 295: EFLPTOC Non group settings (Basic)**

| Parameter         | Values (Range)   | Unit | Step | Default | Description                                 |
|-------------------|------------------|------|------|---------|---|
| Operation         | 1=on<br>5=off    |      |      | 1=on    | Operation Off / On                          |
| Curve parameter A | 0.0086...120.000 |      | 1    | 28.2000 | Parameter A for customer programmable curve |
| Curve parameter B | 0.0000...0.7120  |      | 1    | 0.1217  | Parameter B for customer programmable curve |
| Curve parameter C | 0.02...2.00      |      | 1    | 2.00    | Parameter C for customer programmable curve |
| Curve parameter D | 0.46...30.00     |      | 1    | 29.10   | Parameter D for customer programmable curve |
| Curve parameter E | 0.0...1.0        |      | 1    | 1.0     | Parameter E for customer programmable curve |

**Table 296: EFLPTOC Non group settings (Advanced)**

| Parameter            | Values (Range) | Unit | Step | Default | Description                          |
|----------------------|----------------|------|------|---------|--------------------------------------|
| Minimum operate time | 20...60000     | ms   | 1    | 20      | Minimum operate time for IDMT curves |
| Reset delay time     | 0...60000      | ms   | 1    | 20      | Reset delay time                     |
| Measurement mode     | 1=RMS<br>2=DFT |      |      | 2=DFT   | Selects used measurement mode        |

| Parameter | Values (Range) | Unit | Step | Default | Description |
|-----------|----------------|------|------|---------|-------------|
|           | 3=Peak-to-Peak |      |      |         |             |

**EFHPTOC Settings**

**Table 297: EFHPTOC Group settings (Basic)**

| Parameter            | Values (Range)   | Unit | Step | Default          | Description                             |
|----------------------|--|------|------|------------------|---|
| Start value          | 0.10...40.00   | xIn  | 0.01 | 0.10             | Start value                             |
| Start value Mult     | 0.8...10.0   |      | 0.1  | 1.0              | Multiplier for scaling the start value  |
| Time multiplier      | 0.05...15.00   |      | 0.01 | 1.00             | Time multiplier in IEC/ANSI IDMT curves |
| Operate delay time   | 40...200000  | ms   | 10   | 40               | Operate delay time                      |
| Operating curve type | 1=ANSI Ext. inv.<br>3=ANSI Norm. inv.<br>5=ANSI Def. Time<br>9=IEC Norm. inv.<br>10=IEC Very inv.<br>12=IEC Ext. inv.<br>15=IEC Def. Time<br>17=Programmable |      |      | 15=IEC Def. Time | Selection of time delay curve type      |

**Table 298: EFHPTOC Group settings (Advanced)**

| Parameter           | Values (Range)                  | Unit | Step | Default     | Description                   |
|---------------------|---------------------------------|------|------|-------------|-------------------------------|
| Type of reset curve | 1=Immediate<br>2=Def time reset |      |      | 1=Immediate | Selection of reset curve type |

| Parameter | Values (Range)   | Unit | Step | Default | Description |
|-----------|------------------|------|------|---------|-------------|
|           | 3=Inverse re-set |      |      |         |             |

**Table 299: EFHPTOC Non group settings (Basic)**

| Parameter         | Values (Range)    | Unit | Step | Default | Description                                 |
|-------------------|-------------------|------|------|---------|---|
| Operation         | 1=on<br>5=off     |      |      | 1=on    | Operation Off / On                          |
| Curve parameter A | 0.0086...120.0000 |      | 1    | 28.2000 | Parameter A for customer programmable curve |
| Curve parameter B | 0.0000...0.7120   |      | 1    | 0.1217  | Parameter B for customer programmable curve |
| Curve parameter C | 0.02...2.00       |      | 1    | 2.00    | Parameter C for customer programmable curve |
| Curve parameter D | 0.46...30.00      |      | 1    | 29.10   | Parameter D for customer programmable curve |
| Curve parameter E | 0.0...1.0         |      | 1    | 1.0     | Parameter E for customer programmable curve |

**Table 300: EFHPTOC Non group settings (Advanced)**

| Parameter            | Values (Range)                   | Unit | Step | Default | Description                          |
|----------------------|----------------------------------|------|------|---------|--------------------------------------|
| Minimum operate time | 20...60000                       | ms   | 1    | 20      | Minimum operate time for IDMT curves |
| Reset delay time     | 0...60000                        | ms   | 1    | 20      | Reset delay time                     |
| Measurement mode     | 1=RMS<br>2=DFT<br>3=Peak-to-Peak |      |      | 2=DFT   | Selects used measurement mode        |

**EFIPTOC Settings****Table 301: EFIPTOC Group settings (Basic)**

| Parameter          | Values (Range) | Unit | Step | Default | Description                            |
|--------------------|----------------|------|------|---------|--|
| Start value        | 1.00...40.00   | xIn  | 0.01 | 1.00    | Start value                            |
| Start value Mult   | 0.8...10.0     |      | 0.1  | 1.0     | Multiplier for scaling the start value |
| Operate delay time | 20...200000    | ms   | 10   | 20      | Operate delay time                     |

**Table 302: EFIPTOC Non group settings (Basic)**

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

**Table 303: EFIPTOC Non group settings (Advanced)**

| Parameter        | Values (Range) | Unit | Step | Default | Description      |
|------------------|----------------|------|------|---------|------------------|
| Reset delay time | 0...60000      | ms   | 1    | 20      | Reset delay time |

**3.2.1.10****Monitored data****EFLPTOC Monitored data****Table 304: EFLPTOC Monitored data**

| Name      | Type    | Values (Range)   | Unit | Description                        |
|-----------|---------|--|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time |
| EFLPTOC   | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                             |

**EFHPTOC Monitored data****Table 305: EFHPTOC Monitored data**

| Name      | Type    | Values (Range)   | Unit | Description                        |
|-----------|---------|--|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time |
| EFHPTOC   | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                             |

**EFIPTOC Monitored data****Table 306: EFIPTOC Monitored data**

| Name      | Type    | Values (Range)   | Unit | Description                        |
|-----------|---------|--|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time |
| EFIPTOC   | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                             |

**3.2.1.11****Technical data****Table 307: EFXPTOC Technical data**

| Characteristic           |                     | Value   |         |         |
|--------------------------|---------------------|---|---------|---------|
| Operation accuracy       |                     | Depending on the frequency of the measured current: $f_n \pm 2$ Hz  |         |         |
|                          | EFLPTOC             | $\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$  |         |         |
|                          | EFHPTOC and EFIPTOC | $\pm 1.5\%$ of set value or $\pm 0.002 \times I_n$<br>(at currents in the range of $0.1 \dots 10 \times I_n$ )<br>$\pm 5.0\%$ of the set value<br>(at currents in the range of $10 \dots 40 \times I_n$ ) |         |         |
| Start time <sup>31</sup> |                     | Minimum   | Typical | Maximum |
|                          | EFIPTOC:            | 16 ms   | 19 ms   | 23 ms   |

*Table continues on the next page*

| Characteristic                              |   | Value  |       |       |
|---|---|--|-------|-------|
|   | $I_{\text{Fault}} = 2 \times \text{set } \textit{Start value}$                          | 11 ms  | 12 ms | 14 ms |
|   | $I_{\text{Fault}} = 10 \times \text{set } \textit{Start value}$                         |  |       |       |
|   | EFHPTOC and EFLP-TOC:<br>$I_{\text{Fault}} = 2 \times \text{set } \textit{Start value}$ | 23 ms  | 26 ms | 29 ms |
| Reset time                                  |   | Typically 40 ms  |       |       |
| Reset ratio                                 |   | Typically 0.96   |       |       |
| Retardation time                            |   | <30 ms   |       |       |
| Operate time accuracy in definite time mode |   | $\pm 1.0\%$ of the set value or $\pm 20$ ms  |       |       |
| Operate time accuracy in inverse time mode  |   | $\pm 5.0\%$ of the theoretical value or $\pm 20$ ms  |       |       |
| Suppression of harmonics                    |   | RMS: No suppression<br>DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$<br>Peak-to-Peak: No suppression |       |       |

## 3.2.1.12

## Technical revision history

| Technical revision | Change  |
|--------------------|---|
| B                  | The minimum and default values changed to 40 ms for the <i>Operate delay time</i> setting   |
| C                  | Minimum and default values changed to 20 ms for the <i>Operate delay time</i> setting<br>Minimum value changed to $1.00 \times I_n$ for the <i>Start value</i> setting. |
| D                  | Added a setting parameter for the "Measured Io" or "Calculated Io" selection  |
| E                  | Internal improvement.   |
| F                  | Internal improvement.   |

<sup>30</sup> *Measurement mode* = default (depends on stage), current before fault =  $0.0 \times I_n$ ,  $f_n = 50$  Hz, earth-fault current with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements

<sup>31</sup> Includes the delay of the signal output contact

<sup>32</sup> Maximum *Start value* =  $2.5 \times I_n$ , *Start value* multiples in range of 1.5...20



**Table 308: EFHPTOC Technical revision history**

| Technical revision | Change  |
|--------------------|---|
| B                  | Minimum and default values changed to 40 ms for the <i>Operate delay time</i> setting |
| C                  | Added a setting parameter for the "Measured Io" or "Calculated Io" selection          |
| D                  | Step value changed from 0.05 to 0.01 for the <i>Time multiplier</i> setting.          |
| E                  | Internal improvement.   |
| F                  | Internal improvement.   |

**Table 309: EFLPTOC Technical revision history**

| Technical revision | Change  |
|--------------------|---|
| B                  | The minimum and default values changed to 40 ms for the <i>Operate delay time</i> setting |
| C                  | <i>Start value</i> step changed to 0.005  |
| D                  | Added a setting parameter for the "Measured Io" or "Calculated Io" selection              |
| E                  | Step value changed from 0.05 to 0.01 for the <i>Time multiplier</i> setting.              |
| F                  | Internal improvement.   |
| G                  | Internal improvement.   |

## 3.2.2 Directional earth-fault protection DEFxPDEF

### 3.2.2.1 Identification

| Function description                           | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--|--------------------------|--------------------------|-------------------------------|
| Directional earth-fault protection, low stage  | DEFLPDEF                 | Io> ->                   | 67N-1                         |
| Directional earth-fault protection, high stage | DEFHPDEF                 | Io>> ->                  | 67N-2                         |

### 3.2.2.2 Function block

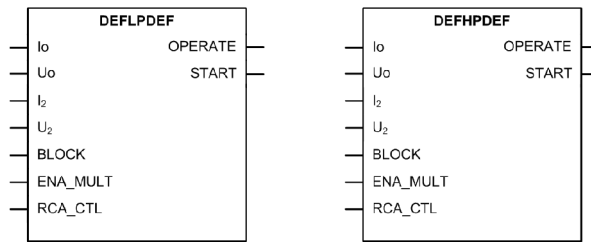


Figure 119: Function block

### 3.2.2.3 Functionality

The directional earth-fault protection function DEFxPDEF is used as directional earth-fault protection for feeders.

The function starts and operates when the operating quantity (current) and polarizing quantity (voltage) exceed the set limits and the angle between them is inside the set operating sector. The operate time characteristic for low stage (DEFLPDEF) and high stage (DEFHPDEF) can be selected to be either definite time (DT) or inverse definite minimum time (IDMT).

In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

### 3.2.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of DEFxPDEF can be described using a module diagram. All the modules in the diagram are explained in the next sections.

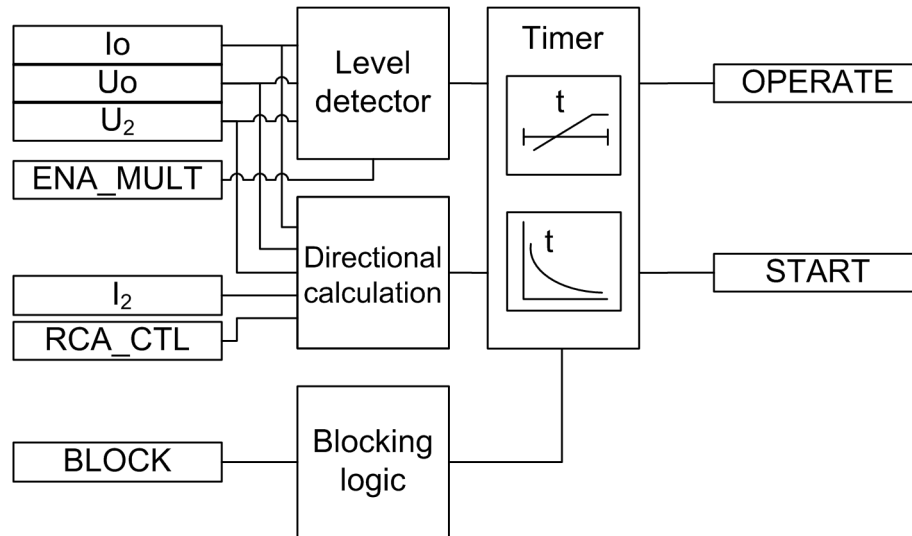


Figure 120: Functional module diagram

### Level detector

The magnitude of the operating quantity is compared to the set *Start value* and the magnitude of the polarizing quantity is compared to the set *Voltage start value*. If both the limits are exceeded, the level detector sends an enabling signal to the timer module. When the *Enable voltage limit* setting is set to "False", *Voltage start value* has no effect and the level detection is purely based on the operating quantity. If the `ENA_MULT` input is active, the *Start value* setting is multiplied by the *Start value Mult* setting.

The operating quantity (residual current) can be selected within the ACT configuration. The options are "Measured  $I_0$ " and "Calculated  $I_0$ ". Measured  $I_0$  is selected when `IRES` input of the corresponding SMVRECEIVE function is connected to `I0` input of the function. Similarly Calculated  $I_0$  is selected, when `IRES_CALC` input is connected. CT ratios need to be defined in the parameters of the SMVRECEIVE function.

The operating quantity (residual voltage) can be selected within the ACT configuration. The options are "Measured  $U_0$ " and "Calculated  $U_0$ ". Measured  $U_0$  is selected when `URES` input of the corresponding SMVRECEIVE function is connected to `U0` input of the function. Similarly Calculated  $U_0$  is selected, when `URES_CALC` input is connected. VT ratios need to be defined in the parameters of the SMVRECEIVE function.

**Example 1:**  $I_0$  is measured with cable core CT (100/1 A) and  $U_0$  is measured from open-delta connected VTs (20/sqrt(3) kV : 100/sqrt(3) V : 100/3 V). In this case, "Measured  $I_0$ " and "Measured  $U_0$ " are selected. The nominal values for residual current and residual voltage are obtained from CT and VT ratios entered in Residual current  $I_0$ : SMVRECEIVE function settings: 100 A : 1 A. The Residual voltage  $U_0$ : SMVRECEIVE function settings: 11.547 kV : 100 V. The *Start value* of  $1.0 \times I_n$  corresponds to  $1.0 \times 100 \text{ A} = 100 \text{ A}$  in the primary. The *Voltage start value* of  $1.0 \times U_n$  corresponds to  $1.0 \times 11.547 \text{ kV} = 11.547 \text{ kV}$  in the primary.

**Example 2:** Both  $I_0$  and  $U_0$  are calculated from the phase quantities. Phase CT-ratio is 100 : 1 A and phase VT-ratio is 20/sqrt(3) kV : 100/sqrt(3) V. In this case, "Calculated  $I_0$ " and "Calculated  $U_0$ " are selected. The nominal values for residual current and residual voltage are obtained from CT and VT ratios entered in Residual

current  $I_0$ : SMVRECEIVE function settings: 100 A : 1 A. The residual voltage  $U_0$ : SMVRECEIVE function settings: 20.000 kV : 100 V. The *Start value* of  $1.0 \times I_n$  corresponds to  $1.0 \times 100 \text{ A} = 100 \text{ A}$  in the primary. The *Voltage start value* of  $1.0 \times U_n$  corresponds to  $1.0 \times 20.000 \text{ kV} = 20.000 \text{ kV}$  in the primary.



If "Calculated  $U_0$ " is selected, the residual voltage nominal value is always phase-to-phase voltage. Thus, the valid maximum setting for residual Voltage start value is  $0.577 \times U_n$ . The calculated  $U_0$  requires that all the three phase-to-earth voltages are connected to the IED.  $U_0$  cannot be calculated from the phase-to-phase voltages.



If the *Enable voltage limit* setting is set to "True", the magnitude of the polarizing quantity is checked even if the *Directional mode* was set to "Non-directional" or *Allow Non Dir* to "True". The IED does not accept the *Start value* or *Start value Mult* setting if the product of these settings exceeds the *Start value* setting range.

Typically, the  $ENA\_MULT$  input is connected to the inrush detection function INRHPAR. In case of inrush, INRHPAR activates the  $ENA\_MULT$  input, which multiplies *Start value* by the *Start value Mult* setting.

**Directional calculation**

The directional calculation module monitors the angle between the polarizing quantity and operating quantity. Depending on the *Pol quantity* setting, the polarizing quantity can be the residual voltage (measured or calculated) or the negative sequence voltage. When the angle is in the operation sector, the module sends the enabling signal to the timer module.

The minimum signal level which allows the directional operation can be set with the *Min operate current* and *Min operate voltage* settings.

If *Pol quantity* is set to "Zero. seq. volt", the residual current and residual voltage are used for directional calculation.

If *Pol quantity* is set to "Neg. seq. volt", the negative sequence current and negative sequence voltage are used for directional calculation.

In the phasor diagrams representing the operation of DEFxPDEF, the polarity of the polarizing quantity ( $U_0$  or  $U_2$ ) is reversed, that is, the polarizing quantity in the phasor diagrams is either  $-U_0$  or  $-U_2$ . Reversing is done by switching the polarity of the residual current measuring channel (see the connection diagram in the application manual). Similarly the polarity of the calculated  $I_0$  and  $I_2$  is also switched.

For defining the operation sector, there are five modes available through the *Operation mode* setting.

**Table 310: Operation modes**

| Operation mode | Description   |
|----------------|---|
| Phase angle    | The operating sectors for forward and reverse are defined with the settings <i>Min for-</i> |

*Table continues on the next page*

| Operation mode | Description   |
|----------------|---|
|                | <i>ward angle, Max forward angle, Min reverse angle and Max reverse angle.</i>  |
| IoSin          | The operating sectors are defined as "forward" when $ I_o  \times \sin(\text{ANGLE})$ has a positive value and "reverse" when the value is negative. ANGLE is the angle difference between $-U_o$ and $I_o$ . |
| IoCos          | As "IoSin" mode. Only cosine is used for calculating the operation current.   |
| Phase angle 80 | The sector maximum values are frozen to 80 degrees respectively. Only <i>Min forward angle</i> and <i>Min reverse angle</i> are settable.   |
| Phase angle 88 | The sector maximum values are frozen to 88 degrees. Otherwise as "Phase angle 80" mode.   |



Polarizing quantity selection "Neg. seq. volt." is available only in the "Phase angle" operation mode.

The directional operation can be selected with the *Directional mode* setting. The alternatives are "Non-directional", "Forward" and "Reverse" operation. The operation criterion is selected with the *Operation mode* setting. By setting *Allow Non Dir* to "True", non-directional operation is allowed when the directional information is invalid, that is, when the magnitude of the polarizing quantity is less than the value of the *Min operate voltage* setting.

Typically, the network rotating direction is counter-clockwise and defined as "ABC". If the network rotating direction is reversed, meaning clockwise, that is, "ACB", the equation for calculating the negative sequence voltage component need to be changed. The network rotating direction is defined with a system parameter *Phase rotation*. The calculation of the component is affected but the angle difference calculation remains the same. When the residual voltage is used as the polarizing method, the network rotating direction change has no effect on the direction calculation.



The network rotating direction is set in the IED using the parameter in the WHMI menu: **Configuration > System > Phase rotation**.

The default parameter value is "ABC".



If the *Enable voltage limit* setting is set to "True", the magnitude of the polarizing quantity is checked even if *Directional mode* is set to "Non-directional" or *Allow Non Dir* to "True".

The *Characteristic angle* setting is used in the "Phase angle" mode to adjust the operation according to the method of neutral point earthing so that in an isolated network the *Characteristic angle* ( $\phi_{RCA}$ ) =  $-90^\circ$  and in a compensated network  $\phi_{RCA}$  =  $0^\circ$ . In addition, the characteristic angle can be changed via the control signal RCA\_CTL. RCA\_CTL affects the *Characteristic angle* setting.

The *Correction angle* setting can be used to improve selectivity due the inaccuracies in the measurement transformers. The setting decreases the operation sector. The correction can only be used with the "IoCos" or "IoSin" modes.

The polarity of the polarizing quantity can be reversed by setting the *Pol reversal* to "True", which turns the polarizing quantity by 180 degrees.



For definitions of different directional earth-fault characteristics, see [Chapter 3.2.2.5 Directional earth-fault principles](#) in this manual.



For definitions of different directional earth-fault characteristics, refer to general function block features information.

The directional calculation module calculates several values which are presented in the monitored data.

**Table 311: Monitored data values**

| Monitored data values | Description   |
|-----------------------|---|
| FAULT_DIR             | The detected direction of fault during fault situations, that is, when START output is active.  |
| DIRECTION             | The momentary operating direction indication output.  |
| ANGLE                 | Also called operating angle, shows the angle difference between the polarizing quantity ( $U_0, U_2$ ) and operating quantity ( $I_0, I_2$ ).   |
| ANGLE_RCA             | The angle difference between the operating angle and <i>Characteristic angle</i> , that is, $ANGLE\_RCA = ANGLE - \textit{Characteristic angle}$ .  |
| I_OPER                | The current that is used for fault detection. If the <i>Operation mode</i> setting is "Phase angle", "Phase angle 80" or "Phase angle 88", I_OPER is the measured or calculated residual current. If the <i>Operation mode</i> setting is "IoSin", I_OPER is calculated as follows $I\_OPER = I_0 \times \sin(ANGLE)$ . If the <i>Operation mode</i> setting is "IoCos", I_OPER is calculated as follows $I\_OPER = I_0 \times \cos(ANGLE)$ . |

Monitored data values are accessible on the WHMI or through tools via communications.

### Timer

Once activated, the timer activates the START output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the OPERATE output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset*

*curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation. The *START* output is deactivated when the reset timer has elapsed.



The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.



The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see [Chapter 10.2.1 IDMT curves for overcurrent protection](#) in this manual.

The timer calculates the start duration value *START\_DUR*, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the *BLOCK* input and the global setting in **Configuration > System > Blocking mode** which selects the blocking mode. The *BLOCK* input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED's program. The influence of the *BLOCK* signal activation is preselected with the global setting *Blocking mode*

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the *OPERATE* output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block *OPERATE* output" mode, the function operates normally but the *OPERATE* output is not activated.

## 3.2.2.5

### Directional earth-fault principles

In many cases it is difficult to achieve selective earth-fault protection based on the magnitude of residual current only. To obtain a selective earth-fault protection scheme, it is necessary to take the phase angle of *I<sub>o</sub>* into account. This is done by comparing the phase angle of the operating and polarizing quantity.

#### Relay characteristic angle

The *Characteristic angle* setting, also known as Relay Characteristic Angle (RCA), Relay Base Angle or Maximum Torque Angle (MTA), is used in the "Phase angle" mode to turn the directional characteristic if the expected fault current angle does not coincide with the polarizing quantity to produce the maximum torque. That is,

RCA is the angle between the maximum torque line and polarizing quantity. If the polarizing quantity is in phase with the maximum torque line, RCA is 0 degrees. The angle is positive if the operating current lags the polarizing quantity and negative if it leads the polarizing quantity.

**Example 1**

The "Phase angle" mode is selected, compensated network ( $\phi_{RCA} = 0 \text{ deg}$ )

=> *Characteristic angle = 0 deg*

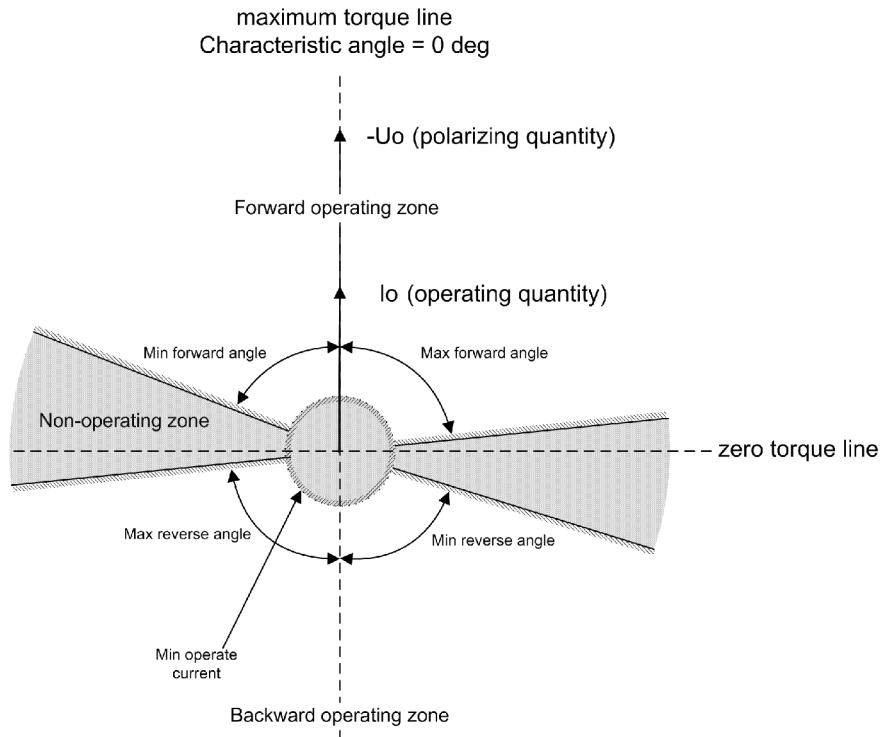


Figure 121: Definition of the relay characteristic angle,  $RCA=0 \text{ degrees}$  in a compensated network

**Example 2**

The "Phase angle" mode is selected, solidly earthed network ( $\phi_{RCA} = +60 \text{ deg}$ )

=> *Characteristic angle = +60 deg*



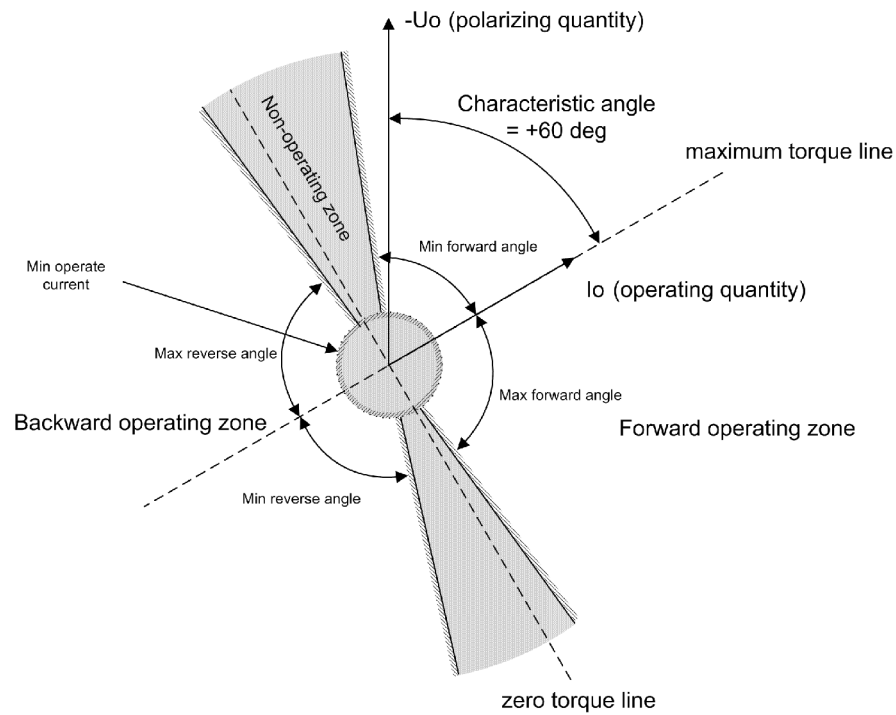


Figure 122: Definition of the relay characteristic angle,  $RCA = +60$  degrees in a solidly earthed network

### Example 3

The "Phase angle" mode is selected, isolated network ( $\phi RCA = -90^\circ$ )

=> Characteristic angle =  $-90^\circ$

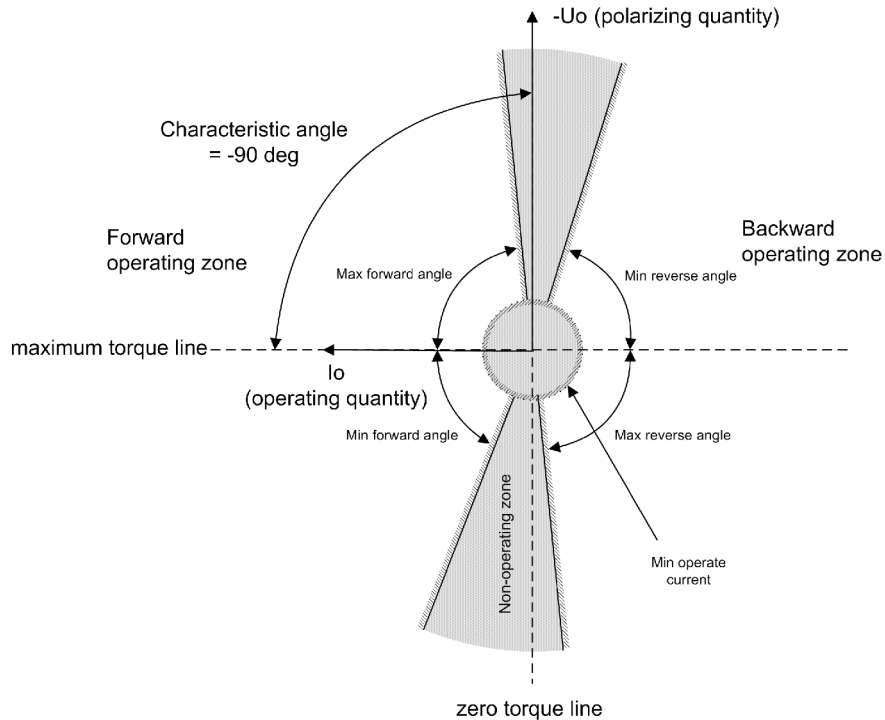


Figure 123: Definition of the relay characteristic angle,  $RCA = -90$  degrees in an isolated network

**Directional earth-fault protection in an isolated neutral network**

In isolated networks, there is no intentional connection between the system neutral point and earth. The only connection is through the phase-to-earth capacitances ( $C_0$ ) of phases and leakage resistances ( $R_0$ ). This means that the residual current is mainly capacitive and has a phase shift of  $-90$  degrees compared to the polarizing voltage. Consequently, the relay characteristic angle (RCA) should be set to  $-90$  degrees and the operation criteria to " $I_0 \sin$ " or "Phase angle". The width of the operating sector in the phase angle criteria can be selected with the settings *Min forward angle*, *Max forward angle*, *Min reverse angle* or *Max reverse angle*. [Figure 124](#) illustrates a simplified equivalent circuit for an unearthed network with an earth fault in phase C.



For definitions of different directional earth-fault characteristics, see [Chapter 3.2.2.8 Directional earth-fault characteristics](#).

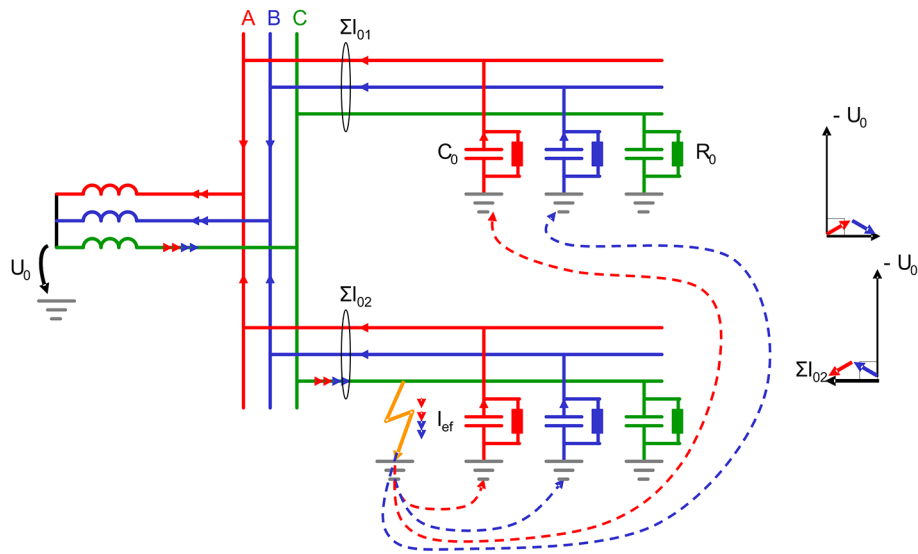


Figure 124: Earth-fault situation in an isolated network

**Directional earth-fault protection in a compensated network**

In compensated networks, the capacitive fault current and the inductive resonance coil current compensate each other. The protection cannot be based on the reactive current measurement, since the current of the compensation coil would disturb the operation of the IEDs. In this case, the selectivity is based on the measurement of the active current component. The magnitude of this component is often small and must be increased by means of a parallel resistor in the compensation equipment. When measuring the resistive part of the residual current, the relay characteristic angle (RCA) should be set to 0 degrees and the operation criteria to "IoCos" or "Phase angle". Figure 125 illustrates a simplified equivalent circuit for a compensated network with an earth fault in phase C.

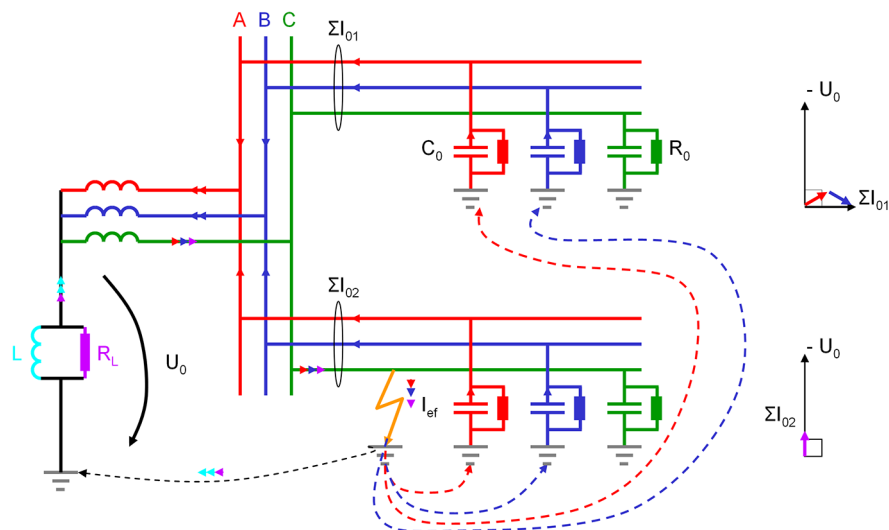


Figure 125: Earth-fault situation in a compensated network

The Petersen coil or the earthing resistor may be temporarily out of operation. To keep the protection scheme selective, it is necessary to update the characteristic angle setting accordingly. This can be done with an auxiliary input in the relay which

receives a signal from an auxiliary switch of the disconnector of the Petersen coil in compensated networks. As a result the characteristic angle is set automatically to suit the earthing method used. The RCA\_CTL input can be used to change the operation criteria as described in [Table 312](#) and [Table 312](#).

**Table 312: Relay characteristic angle control in losin( $\phi$ ) and locos( $\phi$ ) operation criteria**

| <i>Operation mode setting:</i> | RCA_CTL = FALSE              | RCA_CTL = TRUE               |
|--------------------------------|------------------------------|------------------------------|
| losin                          | Actual operation mode: losin | Actual operation mode: locos |
| locos                          | Actual operation mode: locos | Actual operation mode: losin |

**Table 313: Characteristic angle control in phase angle operation mode**

| <i>Characteristic angle setting</i> | RCA_CTL = FALSE          | RCA_CTL = TRUE           |
|-------------------------------------|--------------------------|--------------------------|
| -90°                                | $\phi_{RCA} = -90^\circ$ | $\phi_{RCA} = 0^\circ$   |
| 0°                                  | $\phi_{RCA} = 0^\circ$   | $\phi_{RCA} = -90^\circ$ |

#### Use of the extended phase angle characteristic

The traditional method of adapting the directional earth-fault protection function to the prevailing neutral earthing conditions is done with the *Characteristic angle* setting. In an unearthed network, *Characteristic angle* is set to -90 degrees and in a compensated network *Characteristic angle* is set to 0 degrees. In case the earthing method of the network is temporarily changed from compensated to unearthed due to the disconnection of the arc suppression coil, the *Characteristic angle* setting should be modified correspondingly. This can be done using the setting groups or the RCA\_CTL input. Alternatively, the operating sector of the directional earth-fault protection function can be extended to cover the operating sectors of both neutral earthing principles. Such characteristic is valid for both unearthed and compensated network and does not require any modification in case the neutral earthing changes temporarily from the unearthed to compensated network or vice versa.

The extended phase angle characteristic is created by entering a value of over 90 degrees for the *Min forward angle* setting; a typical value is 170 degrees (*Min reverse angle* in case *Directional mode* is set to "Reverse"). The *Max forward angle* setting should be set to cover the possible measurement inaccuracies of current and voltage transformers; a typical value is 80 degrees (*Max reverse angle* in case *Directional mode* is set to "Reverse").

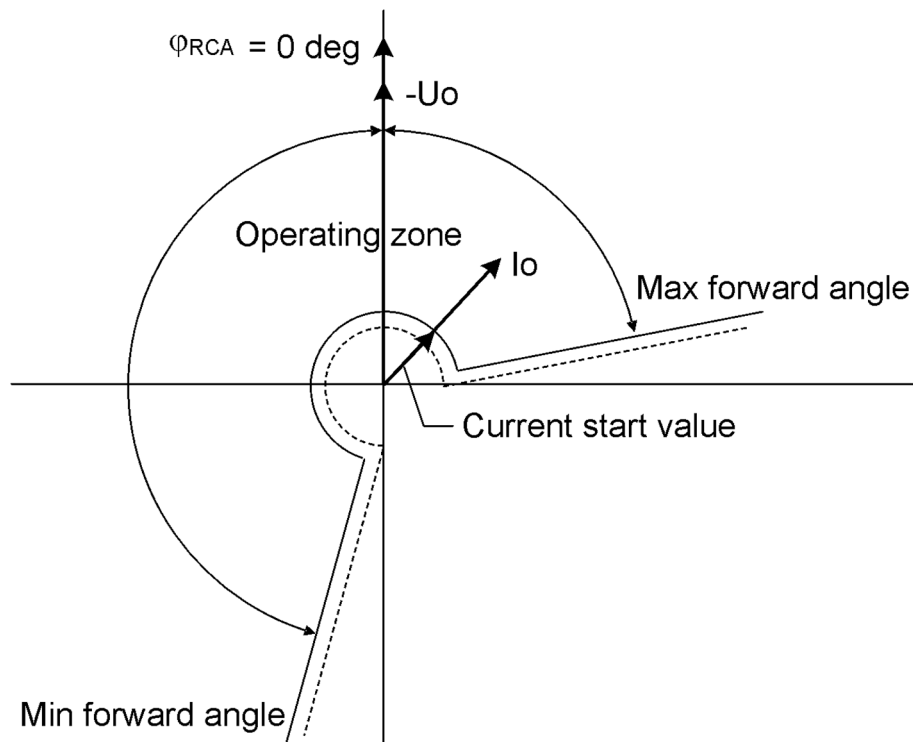


Figure 126: Extended operation area in directional earth-fault protection

### 3.2.2.6 Measurement modes

The function operates on three alternative measurement modes: "RMS", "DFT" and "Peak-to-Peak". The measurement mode is selected with the *Measurement mode* setting.

Table 314: Measurement modes supported by DEFxPDEF stages

| Measurement mode | DEFLPDEF | DEFHPDEF |
|------------------|----------|----------|
| RMS              | x        | x        |
| DFT              | x        | x        |
| Peak-to-Peak     | x        | x        |



For a detailed description of the measurement modes, see [Chapter 10.5 Measurement modes](#) in this manual.

### 3.2.2.7 Timer characteristics

DEFxPDEF supports both DT and IDMT characteristics. The user can select the timer characteristics with the *Operating curve type* setting.

The IED provides 16 IDMT characteristics curves, of which seven comply with the IEEE C37.112 and six with the IEC 60255-3 standard. Two curves follow the special characteristics of ABB praxis and are referred to as RI and RD. In addition to this, a user programmable curve can be used if none of the standard curves are applicable.

The user can choose the DT characteristic by selecting the *Operating curve type* values "ANSI Def. Time" or "IEC Def. Time". The functionality is identical in both cases.

The following characteristics, which comply with the list in the IEC 61850-7-4 specification, indicate the characteristics supported by different stages.

**Table 315: Timer characteristics supported by different stages**

| Operating curve type            | DEFLPDEF | DEFHPDEF |
|---------------------------------|----------|----------|
| (1) ANSI Extremely Inverse      | x        | x        |
| (2) ANSI Very Inverse           | x        |          |
| (3) ANSI Normal Inverse         | x        | x        |
| (4) ANSI Moderately Inverse     | x        |          |
| (5) ANSI Definite Time          | x        | x        |
| (6) Long Time Extremely Inverse | x        |          |
| (7) Long Time Very Inverse      | x        |          |
| (8) Long Time Inverse           | x        |          |
| (9) IEC Normal Inverse          | x        |          |
| (10) IEC Very Inverse           | x        |          |
| (11) IEC Inverse                | x        |          |
| (12) IEC Extremely Inverse      | x        |          |
| (13) IEC Short Time Inverse     | x        |          |
| (14) IEC Long Time Inverse      | x        |          |
| (15) IEC Definite Time          | x        | x        |
| (17) User programmable curve    | x        | x        |
| (18) RI type                    | x        |          |
| (19) RD type                    | x        |          |



For a detailed description of the timers, see [Chapter 10 General function block features](#) in this manual.

**Table 316: Reset time characteristics supported by different stages**

| Reset curve type   | DEFLPDEF | DEFHPDEF | Note   |
|--------------------|----------|----------|--|
| (1) Immediate      | x        | x        | Available for all operate time curves                |
| (2) Def time reset | x        | x        | Available for all operate time curves                |
| (3) Inverse reset  | x        | x        | Available only for ANSI and user programmable curves |

### 3.2.2.8

## Directional earth-fault characteristics

### Phase angle characteristic

The operation criterion phase angle is selected with the *Operation mode* setting using the value "Phase angle".

When the phase angle criterion is used, the function indicates with the `DIRECTION` output whether the operating quantity is within the forward or reverse operation sector or within the non-directional sector.

The forward and reverse sectors are defined separately. The forward operation area is limited with the *Min forward angle* and *Max forward angle* settings. The reverse operation area is limited with the *Min reverse angle* and *Max reverse angle* settings.



The sector limits are always given as positive degree values.

In the forward operation area, the *Max forward angle* setting gives the clockwise sector and the *Min forward angle* setting correspondingly the counterclockwise sector, measured from the *Characteristic angle* setting.

In the reverse operation area, the *Max reverse angle* setting gives the clockwise sector and the *Min reverse angle* setting correspondingly the counterclockwise sector, measured from the complement of the *Characteristic angle* setting (180 degrees phase shift).

The relay characteristic angle (RCA) is set to positive if the operating current lags the polarizing quantity. It is set to negative if it leads the polarizing quantity.

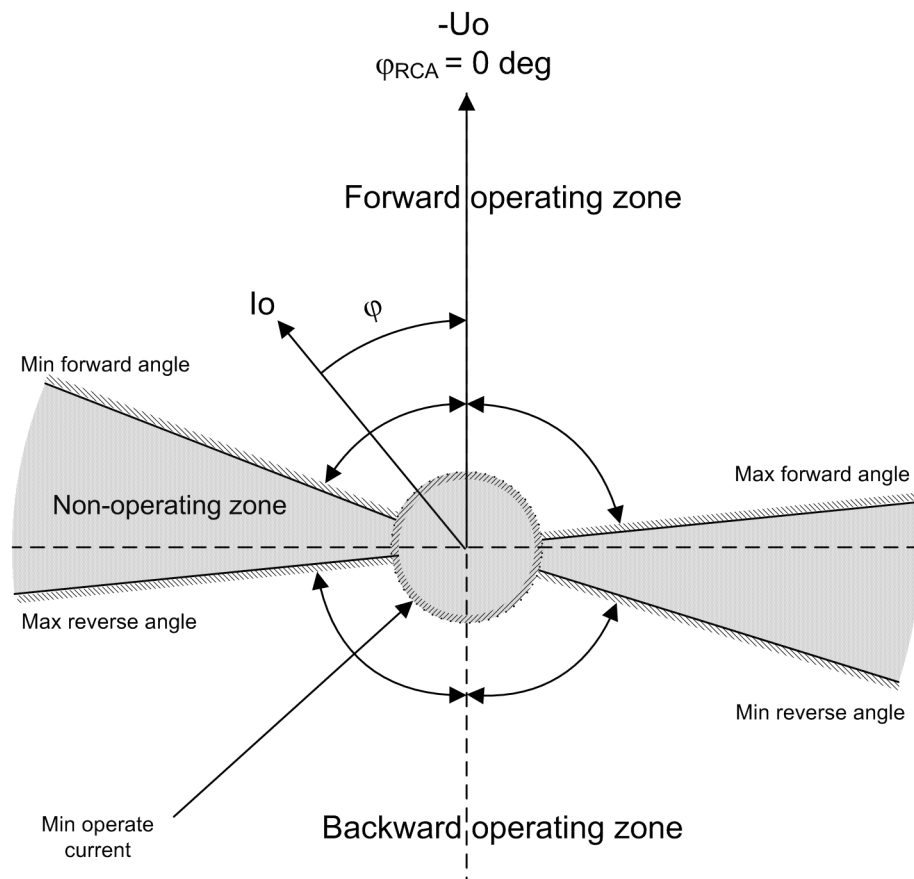


Figure 127: Configurable operating sectors in phase angle characteristic

**Table 317: Momentary operating direction**

| Fault direction   | The value for DIRECTION |
|---|-------------------------|
| Angle between the polarizing and operating quantity is not in any of the defined sectors.   | 0 = unknown             |
| Angle between the polarizing and operating quantity is in the forward sector.   | 1= forward              |
| Angle between the polarizing and operating quantity is in the reverse sector.   | 2 = backward            |
| Angle between the polarizing and operating quantity is in both the forward and the reverse sectors, that is, the sectors are overlapping. | 3 = both                |

If the *Allow Non Dir* setting is "False", the directional operation (forward, reverse) is not allowed when the measured polarizing or operating quantities are invalid, that is, their magnitude is below the set minimum values. The minimum values can be defined with the settings *Min operate current* and *Min operate voltage*. In case of low magnitudes, the `FAULT_DIR` and `DIRECTION` outputs are set to 0 = unknown, except when the *Allow non dir* setting is "True". In that case, the function is allowed to operate in the directional mode as non-directional, since the directional information is invalid.

#### losin( $\phi$ ) and locos( $\phi$ ) criteria

A more modern approach to directional protection is the active or reactive current measurement. The operating characteristic of the directional operation depends on the earthing principle of the network. The losin( $\phi$ ) characteristics is used in an isolated network, measuring the reactive component of the fault current caused by the earth capacitance. The locos( $\phi$ ) characteristics is used in a compensated network, measuring the active component of the fault current.

The operation criteria losin( $\phi$ ) and locos( $\phi$ ) are selected with the *Operation mode* setting using the values "IoSin" or "IoCos" respectively.

The angle correction setting can be used to improve selectivity. The setting decreases the operation sector. The correction can only be used with the losin( $\phi$ ) or locos( $\phi$ ) criterion. The `RCA_CTL` input is used to change the Io characteristic:

**Table 318: Relay characteristic angle control in the IoSin and IoCos operation criteria**

| Operation mode: | RCA_CTL = "False"                           | RCA_CTL = "True"                            |
|-----------------|---|---|
| IoSin           | Actual operation criterion: losin( $\phi$ ) | Actual operation criterion: locos( $\phi$ ) |
| IoCos           | Actual operation criterion: locos( $\phi$ ) | Actual operation criterion: losin( $\phi$ ) |

When the losin( $\phi$ ) or locos( $\phi$ ) criterion is used, the component indicates a forward- or reverse-type fault through the `FAULT_DIR` and `DIRECTION` outputs, in which 1 equals a forward fault and 2 equals a reverse fault. Directional operation is not allowed (the *Allow non dir* setting is "False") when the measured polarizing or operating quantities are not valid, that is, when their magnitude is below the set minimum values. The minimum values can be defined with the *Min operate current*



and *Min operate voltage* settings. In case of low magnitude, the `FAULT_DIR` and `DIRECTION` outputs are set to 0 = unknown, except when the *Allow non dir* setting is "True". In that case, the function is allowed to operate in the directional mode as non-directional, since the directional information is invalid.

The calculated  $I_{\sin(\phi)}$  or  $I_{\cos(\phi)}$  current used in direction determination can be read through the `I_OPER` monitored data. The value can be passed directly to a decisive element, which provides the final start and operate signals.



The `I_OPER` monitored data gives an absolute value of the calculated current.

The following examples show the characteristics of the different operation criteria:

#### Example 1.

$I_{\sin(\phi)}$  criterion selected, forward-type fault

=> `FAULT_DIR` = 1

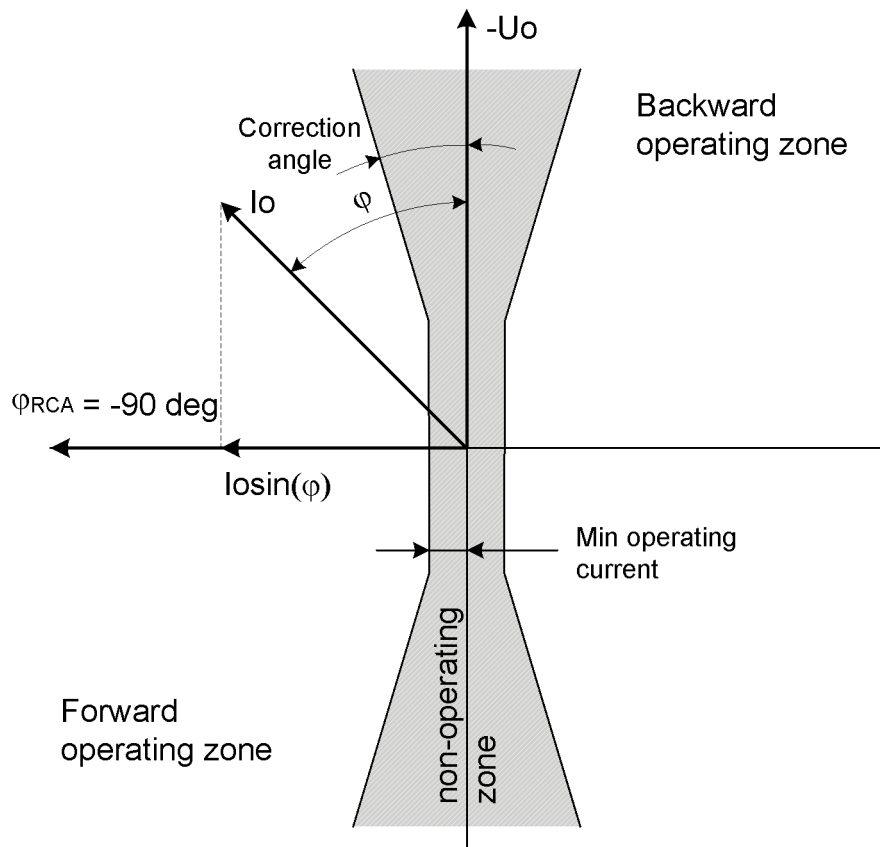


Figure 128: Operating characteristic  $I_{\sin(\phi)}$  in forward fault

The operating sector is limited by angle correction, that is, the operating sector is 180 degrees - 2\*(angle correction).

#### Example 2.

$I_{\sin(\phi)}$  criterion selected, reverse-type fault

=> `FAULT_DIR` = 2

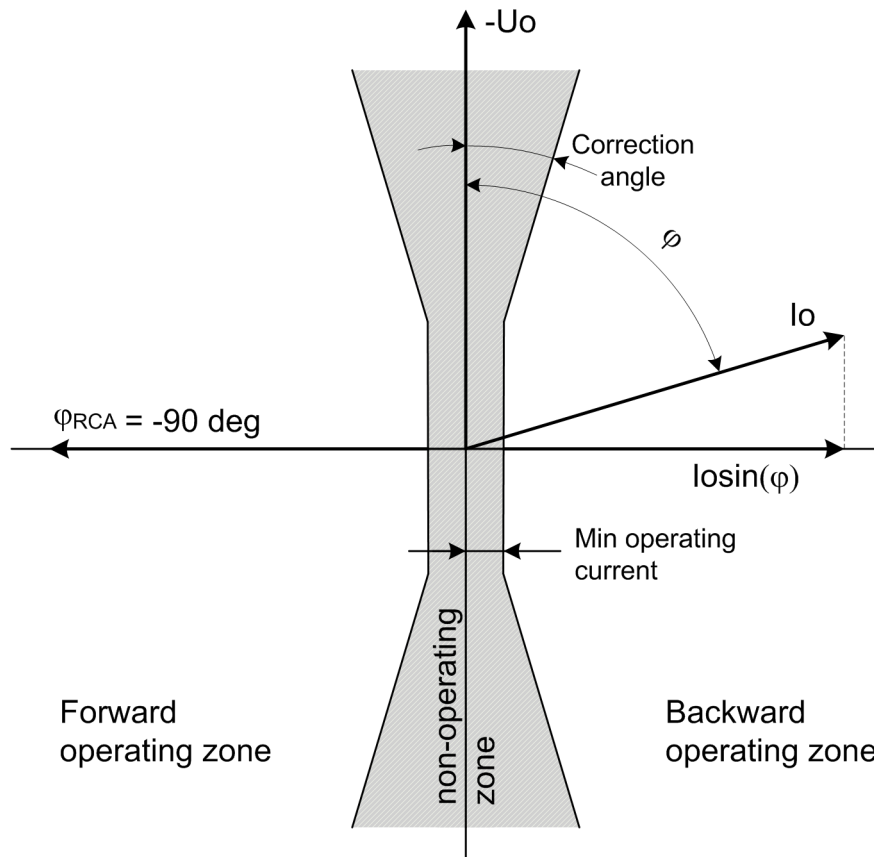


Figure 129: Operating characteristic  $I_{osin(\phi)}$  in reverse fault

**Example 3.**

$I_{oc}(\phi)$  criterion selected, forward-type fault

=> `FAULT_DIR = 1`

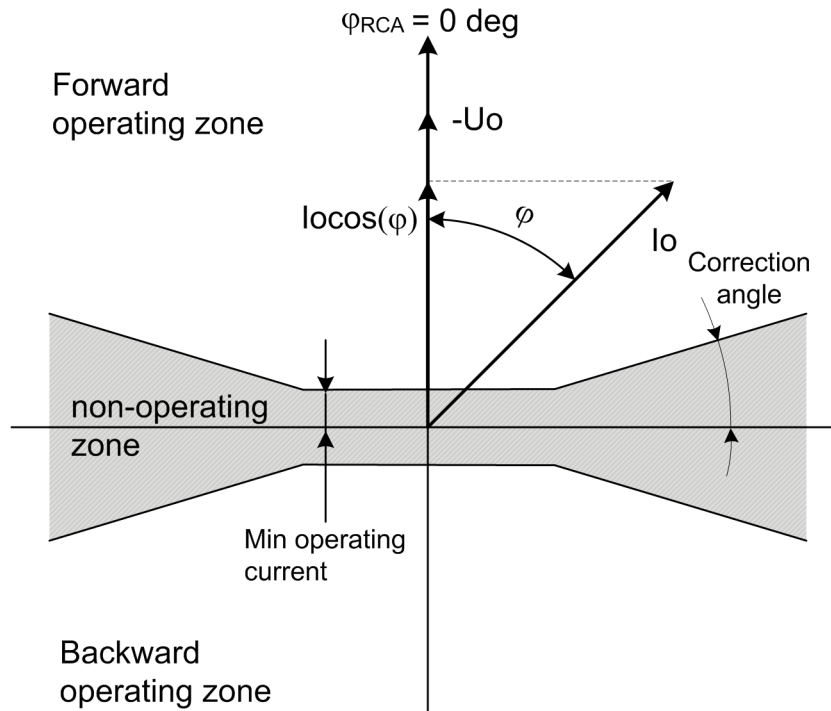


Figure 130: Operating characteristic  $\text{locos}(\varphi)$  in forward fault

**Example 4.**

$\text{locos}(\varphi)$  criterion selected, reverse-type fault

=> `FAULT_DIR = 2`

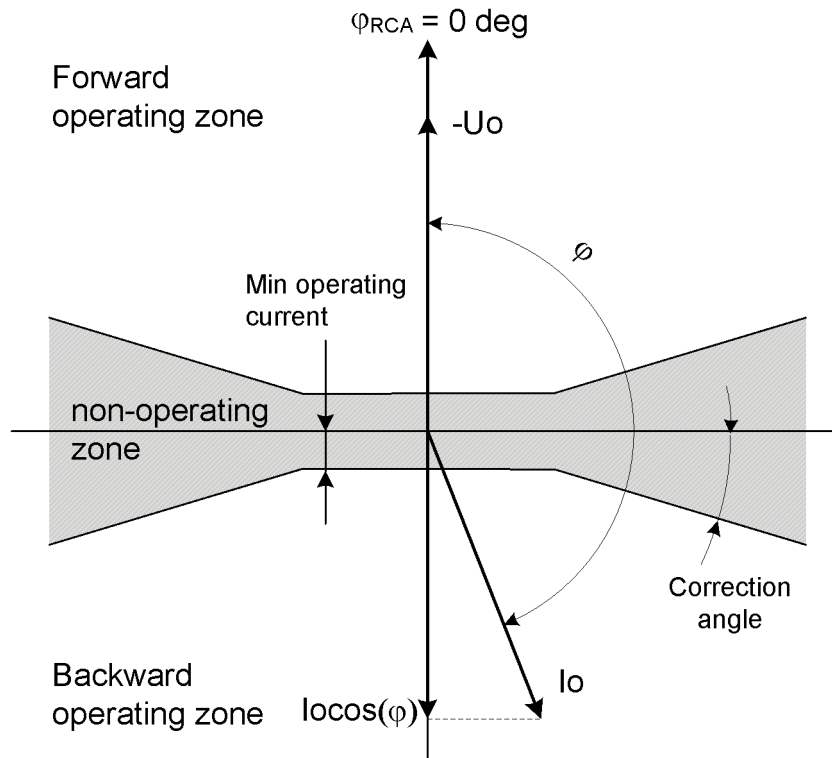


Figure 131: Operating characteristic  $locos(\phi)$  in reverse fault

**Phase angle 80**

The operation criterion phase angle 80 is selected with the *Operation mode* setting by using the value "Phase angle 80".

Phase angle 80 implements the same functionality as the phase angle but with the following differences:

- The *Max forward angle* and *Max reverse angle* settings cannot be set but they have a fixed value of 80 degrees
- The sector limits of the fixed sectors are rounded.

The sector rounding is used for cancelling the CT measurement errors at low current amplitudes. When the current amplitude falls below three percent of the nominal current, the sector is reduced to 70 degrees at the fixed sector side. This makes the protection more selective, which means that the phase angle measurement errors do not cause faulty operation.



There is no sector rounding on the other side of the sector.

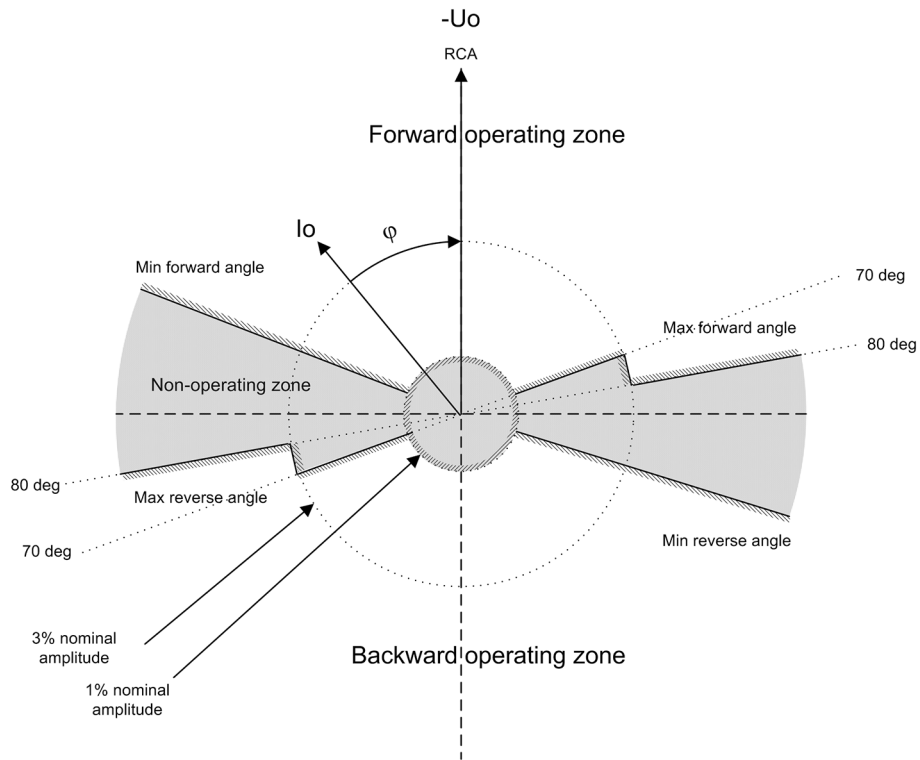


Figure 132: Operating characteristic for phase angle 80

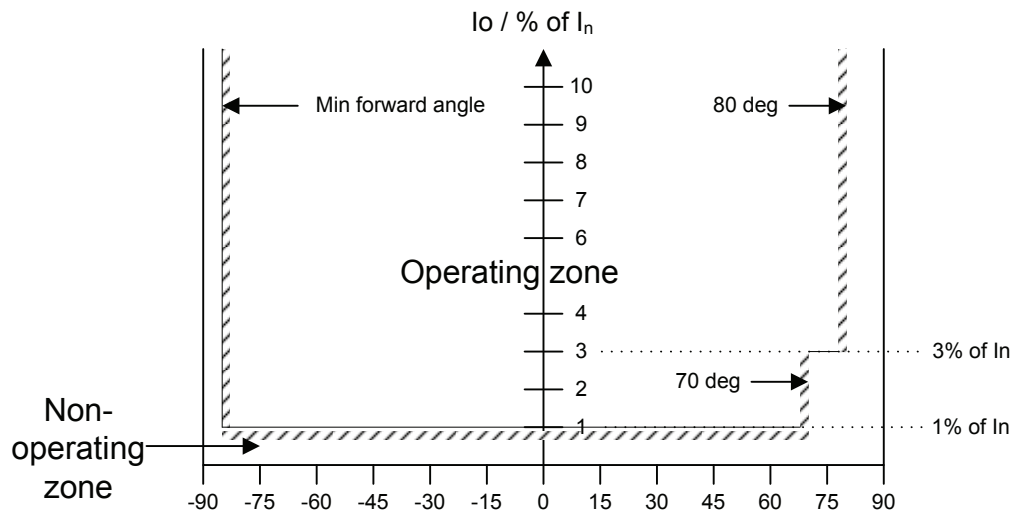


Figure 133: Phase angle 80 amplitude (Directional mode = Forward)

**Phase angle 88**

The operation criterion phase angle 88 is selected with the *Operation mode* setting using the value "Phase angle 88".

Phase angle 88 implements the same functionality as the phase angle but with the following differences:

- The *Max forward angle* and *Max reverse angle* settings cannot be set but they have a fixed value of 88 degrees

- The sector limits of the fixed sectors are rounded.

Sector rounding in the phase angle 88 consists of three parts:

- If the current amplitude is between 1...20 percent of the nominal current, the sector limit increases linearly from 73 degrees to 85 degrees
- If the current amplitude is between 20...100 percent of the nominal current, the sector limit increases linearly from 85 degrees to 88 degrees
- If the current amplitude is more than 100 percent of the nominal current, the sector limit is 88 degrees.



There is no sector rounding on the other side of the sector.

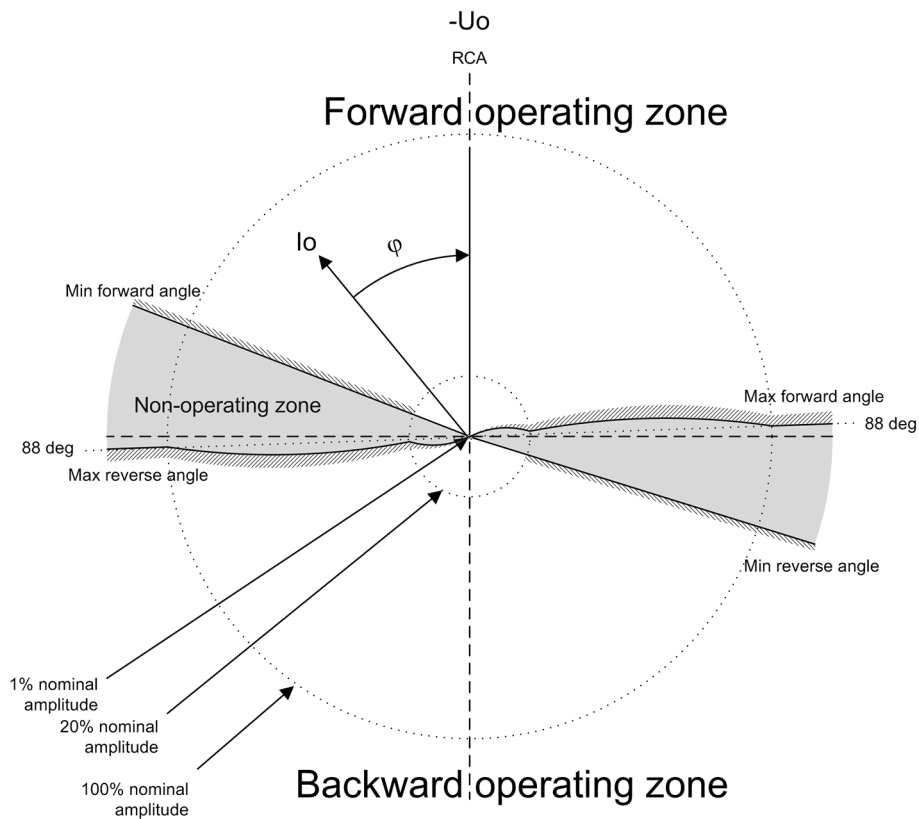


Figure 134: Operating characteristic for phase angle 88

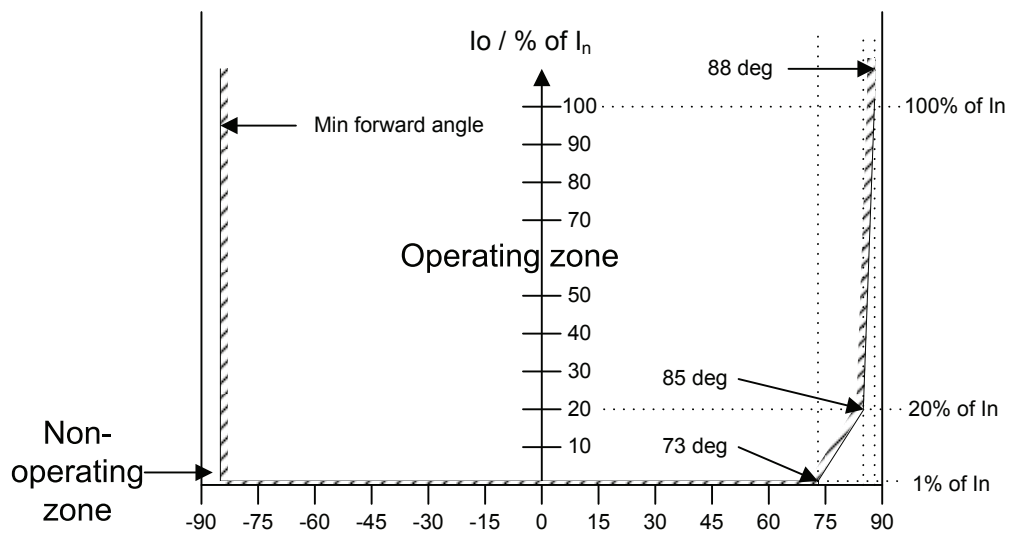


Figure 135: Phase angle 88 amplitude (Directional mode = Forward)

### 3.2.2.9

#### Application

The directional earth-fault protection DEFxPDEF is designed for protection and clearance of earth faults and for earth-fault protection of different equipment connected to the power systems, such as shunt capacitor banks or shunt reactors, and for backup earth-fault protection of power transformers.

Many applications require several steps using different current start levels and time delays. DEFxPDEF consists of two different stages.

- Low DEFLPDEF
- High DEFHPDEF

DEFLPDEF contains several types of time delay characteristics. DEFHPDEF is used for fast clearance of serious earth faults.

The protection can be based on the phase angle criterion with extended operating sector. It can also be based on measuring either the reactive part  $I_{\text{osin}}(\phi)$  or the active part  $I_{\text{ocos}}(\phi)$  of the residual current. In isolated networks or in networks with high impedance earthing, the phase-to-earth fault current is significantly smaller than the short-circuit currents. In addition, the magnitude of the fault current is almost independent of the fault location in the network.

The function uses the residual current components  $I_{\text{ocos}}(\phi)$  or  $I_{\text{osin}}(\phi)$  according to the earthing method, where  $\phi$  is the angle between the residual current and the reference residual voltage ( $-U_0$ ). In compensated networks, the phase angle criterion with extended operating sector can also be used. When the relay characteristic angle RCA is 0 degrees, the negative quadrant of the operation sector can be extended with the *Min forward angle* setting. The operation sector can be set between 0 and -180 degrees, so that the total operation sector is from +90 to -180 degrees. In other words, the sector can be up to 270 degrees wide. This allows the protection settings to stay the same when the resonance coil is disconnected from between the neutral point and earth.

System neutral earthing is meant to protect personnel and equipment and to reduce interference for example in telecommunication systems. The neutral earthing sets challenges for protection systems, especially for earth-fault protection.

In isolated networks, there is no intentional connection between the system neutral point and earth. The only connection is through the line-to-earth capacitances ( $C_0$ ) of phases and leakage resistances ( $R_0$ ). This means that the residual current is mainly capacitive and has  $-90$  degrees phase shift compared to the residual voltage ( $-U_0$ ). The characteristic angle is  $-90$  degrees.

In resonance-earthed networks, the capacitive fault current and the inductive resonance coil current compensate each other. The protection cannot be based on the reactive current measurement, since the current of the compensation coil would disturb the operation of the relays. In this case, the selectivity is based on the measurement of the active current component. This means that the residual current is mainly resistive and has zero phase shift compared to the residual voltage ( $-U_0$ ) and the characteristic angle is  $0$  degrees. Often the magnitude of this component is small, and must be increased by means of a parallel resistor in the compensation equipment.

In networks where the neutral point is earthed through low resistance, the characteristic angle is also  $0$  degrees (for phase angle). Alternatively,  $\text{locos}(\phi)$  operation can be used.

In solidly earthed networks, the *Characteristic angle* is typically set to  $+60$  degrees for the phase angle. Alternatively,  $\text{losin}(\phi)$  operation can be used with a reversal polarizing quantity. The polarizing quantity can be rotated  $180$  degrees by setting the *Pol reversal* parameter to "True" or by switching the polarity of the residual voltage measurement wires. Although the  $\text{losin}(\phi)$  operation can be used in solidly earthed networks, the phase angle is recommended.

#### **Connection of measuring transformers in directional earth fault applications**

The residual current  $I_0$  can be measured with a core balance current transformer or the residual connection of the phase current signals. If the neutral of the network is either isolated or earthed with high impedance, a core balance current transformer is recommended to be used in earth-fault protection. To ensure sufficient accuracy of residual current measurements and consequently the selectivity of the scheme, the core balance current transformers should have a transformation ratio of at least 70:1. Lower transformation ratios such as 50:1 or 50:5 are not recommended.

Attention should be paid to make sure the measuring transformers are connected correctly so that DEFxPDEF is able to detect the fault current direction without failure. As directional earth fault uses residual current and residual voltage ( $-U_0$ ), the poles of the measuring transformers must match each other and also the fault current direction. Also the earthing of the cable sheath must be taken into notice when using core balance current transformers. The following figure describes how measuring transformers can be connected to the IED.



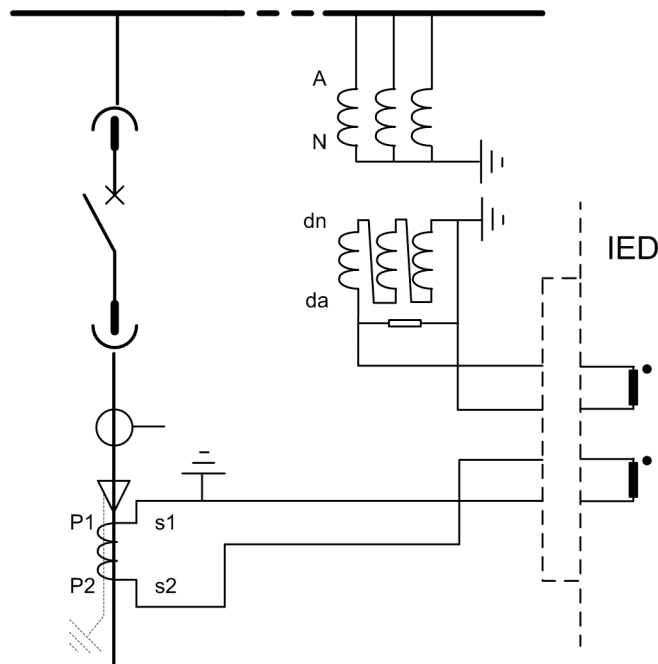


Figure 136: Connection of measuring transformers

### 3.2.2.10

## Signals

### DEFLPDEF Input signals

Table 319: DEFLPDEF Input signals

| Name     | Type    | Default | Description                                   |
|----------|---------|---------|---|
| Io       | SIGNAL  | 0       | Residual current                              |
| Uo       | SIGNAL  | 0       | Residual voltage                              |
| BLOCK    | BOOLEAN | 0=False | Block signal for activating the blocking mode |
| ENA_MULT | BOOLEAN | 0=False | Enable signal for current multiplier          |
| RCA_CTL  | BOOLEAN | 0=False | Relay characteristic angle control            |

### DEFHPDEF Input signals

Table 320: DEFHPDEF Input signals

| Name | Type   | Default | Description      |
|------|--------|---------|------------------|
| Io   | SIGNAL | 0       | Residual current |
| Uo   | SIGNAL | 0       | Residual voltage |

Table continues on the next page

| Name     | Type    | Default | Description                                   |
|----------|---------|---------|---|
| BLOCK    | BOOLEAN | 0=False | Block signal for activating the blocking mode |
| ENA_MULT | BOOLEAN | 0=False | Enable signal for current multiplier          |
| RCA_CTL  | BOOLEAN | 0=False | Relay characteristic angle control            |

### DEFLPDEF Output signals

Table 321: DEFLPDEF Output signals

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

### DEFHPDEF Output signals

Table 322: DEFHPDEF Output signals

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

## 3.2.2.11

### Settings

#### DEFLPDEF Settings

Table 323: DEFLPDEF Group settings (Basic)

| Parameter        | Values (Range)                              | Unit | Step  | Default   | Description                             |
|------------------|---|------|-------|-----------|---|
| Start value      | 0.010...5.000                               | xIn  | 0.005 | 0.010     | Start value                             |
| Start value Mult | 0.8...10.0                                  |      | 0.1   | 1.0       | Multiplier for scaling the start value  |
| Directional mode | 1=Non-directional<br>2=Forward<br>3=Reverse |      |       | 2=Forward | Directional mode                        |
| Time multiplier  | 0.05...15.00                                |      | 0.01  | 1.00      | Time multiplier in IEC/ANSI IDMT curves |

Table continues on the next page

| Parameter            | Values (Range)  | Unit | Step | Default          | Description                              |
|----------------------|---|------|------|------------------|--|
| Operating curve type | 1=ANSI Ext. inv.<br>2=ANSI Very inv.<br>3=ANSI Norm. inv.<br>4=ANSI Mod. inv.<br>5=ANSI Def. Time<br>6=L.T.E. inv.<br>7=L.T.V. inv.<br>8=L.T. inv.<br>9=IEC Norm. inv.<br>10=IEC Very inv.<br>11=IEC inv.<br>12=IEC Ext. inv.<br>13=IEC S.T. inv.<br>14=IEC L.T. inv.<br>15=IEC Def. Time<br>17=Program-mable<br>18=RI type<br>19=RD type |      |      | 15=IEC Def. Time | Selection of time delay curve type       |
| Operate delay time   | 50...200000   | ms   | 10   | 50               | Operate delay time                       |
| Characteristic angle | -179...180  | deg  | 1    | -90              | Characteristic angle                     |
| Max forward angle    | 0...180   | deg  | 1    | 80               | Maximum phase angle in forward direction |
| Max reverse angle    | 0...180   | deg  | 1    | 80               | Maximum phase angle in reverse direction |

*Table continues on the next page*

| Parameter           | Values (Range) | Unit | Step  | Default | Description                              |
|---------------------|----------------|------|-------|---------|--|
| Min forward angle   | 0...180        | deg  | 1     | 80      | Minimum phase angle in forward direction |
| Min reverse angle   | 0...180        | deg  | 1     | 80      | Minimum phase angle in reverse direction |
| Voltage start value | 0.010...1.000  | xUn  | 0.001 | 0.010   | Voltage start value                      |

Table 324: DEFLPDEF Group settings (Advanced)

| Parameter            | Values (Range)  | Unit | Step | Default       | Description                   |
|----------------------|---|------|------|---------------|-------------------------------|
| Type of reset curve  | 1=Immediate<br>2=Def time reset<br>3=Inverse reset                          |      |      | 1=Immediate   | Selection of reset curve type |
| Operation mode       | 1=Phase angle<br>2=IoSin<br>3=IoCos<br>4=Phase angle 80<br>5=Phase angle 88 |      |      | 1=Phase angle | Operation criteria            |
| Enable voltage limit | 0=False<br>1=True   |      |      | 1=True        | Enable voltage limit          |

Table 325: DEFLPDEF Non group settings (Basic)

| Parameter         | Values (Range)   | Unit | Step | Default | Description                                 |
|-------------------|------------------|------|------|---------|---|
| Operation         | 1=on<br>5=off    |      |      | 1=on    | Operation Off / On                          |
| Curve parameter A | 0.0086...120.000 |      | 1    | 28.2000 | Parameter A for customer programmable curve |
| Curve parameter B | 0.0000...0.7120  |      | 1    | 0.1217  | Parameter B for customer                    |

*Table continues on the next page*

| Parameter         | Values (Range) | Unit | Step | Default | Description                                 |
|-------------------|----------------|------|------|---------|---|
|                   |                |      |      |         | programmable curve                          |
| Curve parameter C | 0.02...2.00    |      | 1    | 2.00    | Parameter C for customer programmable curve |
| Curve parameter D | 0.46...30.00   |      | 1    | 29.10   | Parameter D for customer programmable curve |
| Curve parameter E | 0.0...1.0      |      | 1    | 1.0     | Parameter E for customer programmable curve |

**Table 326: DEFLPDEF Non group settings (Advanced)**

| Parameter            | Values (Range)                   | Unit | Step  | Default           | Description  |
|----------------------|----------------------------------|------|-------|-------------------|--|
| Reset delay time     | 0...60000                        | ms   | 1     | 20                | Reset delay time   |
| Minimum operate time | 50...60000                       | ms   | 1     | 50                | Minimum operate time for IDMT curves                       |
| Allow Non Dir        | 0=False<br>1=True                |      |       | 0=False           | Allows prot activation as non-dir when dir info is invalid |
| Measurement mode     | 1=RMS<br>2=DFT<br>3=Peak-to-Peak |      |       | 2=DFT             | Selects used measurement mode                              |
| Min operate current  | 0.005...1.000                    | xIn  | 0.001 | 0.005             | Minimum operating current                                  |
| Min operate voltage  | 0.01...1.00                      | xUn  | 0.01  | 0.01              | Minimum operating voltage                                  |
| Correction angle     | 0.0...10.0                       | deg  | 0.1   | 0.0               | Angle correction   |
| Pol reversal         | 0=False<br>1=True                |      |       | 0=False           | Rotate polarizing quantity                                 |
| Pol quantity         | 3=Zero seq. volt.                |      |       | 3=Zero seq. volt. | Reference quantity used                                    |

| Parameter | Values (Range)    | Unit | Step | Default | Description                  |
|-----------|-------------------|------|------|---------|------------------------------|
|           | 4=Neg. seq. volt. |      |      |         | to determine fault direction |

### DEFHPDEF Settings

Table 327: DEFHPDEF Group settings (Basic)

| Parameter            | Values (Range)   | Unit | Step | Default          | Description                              |
|----------------------|--|------|------|------------------|--|
| Start value          | 0.10...40.00   | xIn  | 0.01 | 0.10             | Start value                              |
| Start value Mult     | 0.8...10.0   |      | 0.1  | 1.0              | Multiplier for scaling the start value   |
| Directional mode     | 1=Non-directional<br>2=Forward<br>3=Reverse  |      |      | 2=Forward        | Directional mode                         |
| Time multiplier      | 0.05...15.00   |      | 0.01 | 1.00             | Time multiplier in IEC/ANSI IDMT curves  |
| Operating curve type | 1=ANSI Ext. inv.<br>3=ANSI Norm. inv.<br>5=ANSI Def. Time<br>15=IEC Def. Time<br>17=Programmable |      |      | 15=IEC Def. Time | Selection of time delay curve type       |
| Operate delay time   | 40...200000  | ms   | 10   | 40               | Operate delay time                       |
| Characteristic angle | -179...180   | deg  | 1    | -90              | Characteristic angle                     |
| Max forward angle    | 0...180  | deg  | 1    | 80               | Maximum phase angle in forward direction |
| Max reverse angle    | 0...180  | deg  | 1    | 80               | Maximum phase angle in reverse direction |

Table continues on the next page

| Parameter           | Values (Range) | Unit | Step  | Default | Description                              |
|---------------------|----------------|------|-------|---------|--|
| Min forward angle   | 0...180        | deg  | 1     | 80      | Minimum phase angle in forward direction |
| Min reverse angle   | 0...180        | deg  | 1     | 80      | Minimum phase angle in reverse direction |
| Voltage start value | 0.010...1.000  | xUn  | 0.001 | 0.010   | Voltage start value                      |

**Table 328: DEFHPDEF Group settings (Advanced)**

| Parameter            | Values (Range)  | Unit | Step | Default       | Description                   |
|----------------------|---|------|------|---------------|-------------------------------|
| Type of reset curve  | 1=Immediate<br>2=Def time reset<br>3=Inverse reset                          |      |      | 1=Immediate   | Selection of reset curve type |
| Operation mode       | 1=Phase angle<br>2=IoSin<br>3=IoCos<br>4=Phase angle 80<br>5=Phase angle 88 |      |      | 1=Phase angle | Operation criteria            |
| Enable voltage limit | 0=False<br>1=True   |      |      | 1=True        | Enable voltage limit          |

**Table 329: DEFHPDEF Non group settings (Basic)**

| Parameter         | Values (Range)   | Unit | Step | Default | Description                                 |
|-------------------|------------------|------|------|---------|---|
| Operation         | 1=on<br>5=off    |      |      | 1=on    | Operation Off / On                          |
| Curve parameter A | 0.0086...120.000 |      | 1    | 28.2000 | Parameter A for customer programmable curve |
| Curve parameter B | 0.0000...0.7120  |      | 1    | 0.1217  | Parameter B for customer                    |

*Table continues on the next page*

| Parameter         | Values (Range) | Unit | Step | Default | Description                                 |
|-------------------|----------------|------|------|---------|---|
|                   |                |      |      |         | programmable curve                          |
| Curve parameter C | 0.02...2.00    |      | 1    | 2.00    | Parameter C for customer programmable curve |
| Curve parameter D | 0.46...30.00   |      | 1    | 29.10   | Parameter D for customer programmable curve |
| Curve parameter E | 0.0...1.0      |      | 1    | 1.0     | Parameter E for customer programmable curve |

Table 330: DEFHPDEF Non group settings (Advanced)

| Parameter            | Values (Range)                   | Unit | Step  | Default           | Description  |
|----------------------|----------------------------------|------|-------|-------------------|--|
| Reset delay time     | 0...60000                        | ms   | 1     | 20                | Reset delay time   |
| Minimum operate time | 40...60000                       | ms   | 1     | 40                | Minimum operate time for IDMT curves                       |
| Allow Non Dir        | 0=False<br>1=True                |      |       | 0=False           | Allows prot activation as non-dir when dir info is invalid |
| Measurement mode     | 1=RMS<br>2=DFT<br>3=Peak-to-Peak |      |       | 2=DFT             | Selects used measurement mode                              |
| Min operate current  | 0.005...1.000                    | xIn  | 0.001 | 0.005             | Minimum operating current                                  |
| Min operate voltage  | 0.01...1.00                      | xUn  | 0.01  | 0.01              | Minimum operating voltage                                  |
| Correction angle     | 0.0...10.0                       | deg  | 0.1   | 0.0               | Angle correction   |
| Pol reversal         | 0=False<br>1=True                |      |       | 0=False           | Rotate polarizing quantity                                 |
| Pol quantity         | 3=Zero seq. volt.                |      |       | 3=Zero seq. volt. | Reference quantity used                                    |



| Parameter | Values (Range)    | Unit | Step | Default | Description                  |
|-----------|-------------------|------|------|---------|------------------------------|
|           | 4=Neg. seq. volt. |      |      |         | to determine fault direction |

### 3.2.2.12

## Monitored data

### DEFLPDEF Monitored data

Table 331: DEFLPDEF Monitored data

| Name      | Type    | Values (Range)   | Unit | Description  |
|-----------|---------|--|------|--|
| FAULT_DIR | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both         |      | Detected fault direction                               |
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time                     |
| DIRECTION | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both         |      | Direction information                                  |
| ANGLE_RCA | FLOAT32 | -180.00...180.00                                       | deg  | Angle between operating angle and characteristic angle |
| ANGLE     | FLOAT32 | -180.00...180.00                                       | deg  | Angle between polarizing and operating quantity        |
| I_OPER    | FLOAT32 | 0.00...40.00   | xIn  | Calculated operating current                           |
| DEFLPDEF  | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status   |

**DEFHPDEF Monitored data****Table 332: DEFHPDEF Monitored data**

| Name      | Type    | Values (Range)   | Unit            | Description  |
|-----------|---------|--|-----------------|--|
| FAULT_DIR | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both         |                 | Detected fault direction                               |
| START_DUR | FLOAT32 | 0.00...100.00  | %               | Ratio of start time / operate time                     |
| DIRECTION | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both         |                 | Direction information                                  |
| ANGLE_RCA | FLOAT32 | -180.00...180.00                                       | deg             | Angle between operating angle and characteristic angle |
| ANGLE     | FLOAT32 | -180.00...180.00                                       | deg             | Angle between polarizing and operating quantity        |
| I_OPER    | FLOAT32 | 0.00...40.00   | xI <sub>n</sub> | Calculated operating current                           |
| DEFHPDEF  | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |                 | Status   |

**3.2.2.13****Technical data****Table 333: DEFxPDEF Technical data**

| Characteristic     |          | Value   |
|--------------------|----------|---|
| Operation accuracy |          | Depending on the frequency of the measured current: $f_n \pm 2$ Hz            |
|                    | DEFLPDEF | Current:<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$<br>Voltage |

*Table continues on the next page*

| Characteristic                              |  | Value  |         |         |
|---|--|--|---------|---------|
|   |  | $\pm 1.5\%$ of the set value or $\pm 0.002 \times U_n$<br>Phase angle:<br>$\pm 2^\circ$  |         |         |
|   | DEFHPDEF   | Current:<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$<br>(at currents in the range of $0.1 \dots 10 \times I_n$ )<br>$\pm 5.0\%$ of the set value<br>(at currents in the range of $10 \dots 40 \times I_n$ )<br>Voltage:<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times U_n$<br>Phase angle:<br>$\pm 2^\circ$ |         |         |
| Start time <sup>3334</sup>                  |  | Minimum  | Typical | Maximum |
|   | DEFHPDEF<br>$I_{\text{Fault}} = 2 \times \text{set Start value}$ | 42 ms  | 46 ms   | 49 ms   |
|   | DEFLPDEF<br>$I_{\text{Fault}} = 2 \times \text{set Start value}$ | 58 ms  | 62 ms   | 66 ms   |
| Reset time                                  |  | Typically 40 ms  |         |         |
| Reset ratio                                 |  | Typically 0.96   |         |         |
| Retardation time                            |  | <30 ms   |         |         |
| Operate time accuracy in definite time mode |  | $\pm 1.0\%$ of the set value or $\pm 20$ ms  |         |         |
| Operate time accuracy in inverse time mode  |  | $\pm 5.0\%$ of the theoretical value or $\pm 20$ ms  |         |         |
| Suppression of harmonics                    |  | RMS: No suppression<br>DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$<br>Peak-to-Peak: No suppression   |         |         |

<sup>33</sup> *Measurement mode* = default (depends on stage), current before fault =  $0.0 \times I_n$ ,  $f_n = 50$  Hz, earth-fault current with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements

<sup>34</sup> Includes the delay of the signal output contact

<sup>35</sup> Maximum *Start value* =  $2.5 \times I_n$ , *Start value* multiples in range of 1.5...20

### 3.2.2.14 Technical revision history

**Table 334: DEFHPDEF Technical revision history**

| Technical revision | Change   |
|--------------------|--|
| B                  | Maximum value changed to 180 deg for the <i>Max forward angle</i> setting  |
| C                  | Added a setting parameter for the "Measured Io" or "Calculated Io" selection and setting parameter for the "Measured Uo", "Calculated Uo" or "Neg. seq. volt." selection for polarization. <i>Operate delay time</i> and <i>Minimum operate time</i> changed from 60 ms to 40 ms. The sector default setting values are changed from 88 degrees to 80 degrees. |
| D                  | Step value changed from 0.05 to 0.01 for the <i>Time multiplier</i> setting.   |
| E                  | Unit added to calculated operating current output (I_OPER).  |
| F                  | Added setting <i>Pol quantity</i> .  |
| G                  | Modified for SSC600  |

**Table 335: DEFLPDEF Technical revision history**

| Technical revision | Change  |
|--------------------|---|
| B                  | Maximum value changed to 180 deg for the <i>Max forward angle</i> setting.<br><i>Start value</i> step changed to 0.005  |
| C                  | Added a setting parameter for the "Measured Io" or "Calculated Io" selection and setting parameter for the "Measured Uo", "Calculated Uo" or "Neg. seq. volt." selection for polarization. The sector default setting values are changed from 88 degrees to 80 degrees. |
| D                  | Step value changed from 0.05 to 0.01 for the <i>Time multiplier</i> setting.  |
| E                  | Unit added to calculated operating current output (I_OPER).   |
| F                  | Added setting <i>Pol quantity</i> . Minimum value for <i>Operate delay time</i> and <i>Minimum operate time</i> changed from "60 ms" to "50 ms". Default value for <i>Operate delay time</i> and <i>Minimum operate time</i> changed from "60 ms" to "50 ms".           |
| G                  | Modified for SSC600   |

### 3.2.3 Transient-intermittent earth-fault protection INTRPTEF

#### 3.2.3.1 Identification

| Function description                          | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|--------------------------|--------------------------|-------------------------------|
| Transient/intermittent earth-fault protection | INTRPTEF                 | Io> -> IEF               | 67NIEF                        |

#### 3.2.3.2 Function block

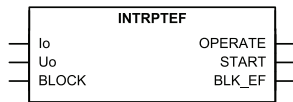


Figure 137: Function block

#### 3.2.3.3 Functionality

The transient/intermittent earth-fault protection function INTRPTEF is a function designed for the protection and clearance of permanent and intermittent earth faults in distribution and sub-transmission networks. Fault detection is done from the residual current and residual voltage signals by monitoring the transients.

The operating time characteristics are according to definite time (DT).

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

#### 3.2.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of INTRPTEF can be described with a module diagram. All the modules in the diagram are explained in the next sections.

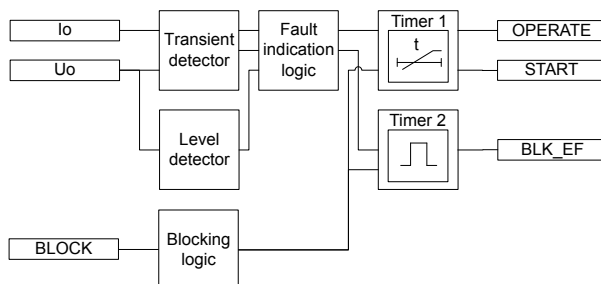


Figure 138: Functional module diagram

### Level detector

The operating quantity (residual voltage) can be selected within the ACT configuration. The options are "Measured U<sub>o</sub>" and "Calculated U<sub>o</sub>". Measured U<sub>o</sub> is selected when U<sub>RES</sub> input of the corresponding SMVRECEIVE function is connected to U<sub>o</sub> input of the function. Similarly Calculated U<sub>o</sub> is selected, when U<sub>RES\_CALC</sub> input is connected. VT ratios need to be defined in the parameters of the SMVRECEIVE function. If "Measured U<sub>o</sub>" is selected, the voltage ratio for U<sub>o</sub>-channel is given in the SMVRECEIVE function settings. If "Calculated U<sub>o</sub>" is selected, the voltage ratio is obtained from phase-voltage channels given in the SMVRECEIVE function settings.

**Example 1:** U<sub>o</sub> is measured from open-delta connected VTs (20/sqrt(3) kV : 100/sqrt(3) V : 100/3 V). In this case, "Measured U<sub>o</sub>" is selected. The nominal values for residual voltage is obtained from VT ratios entered in Residual voltage U<sub>o</sub>: SMVRECEIVE function settings: 11.547 kV :100 V. The residual voltage start value of  $1.0 \times U_n$  corresponds to  $1.0 \times 11.547 \text{ kV} = 11.547 \text{ kV}$  in the primary.

**Example 2:** U<sub>o</sub> is calculated from phase quantities. The phase VT-ratio is 20/sqrt(3) kV : 100/sqrt(3) V. In this case, "Calculated U<sub>o</sub>" is selected. The nominal values for residual current and residual voltage are obtained from VT ratios entered in Residual voltage U<sub>o</sub>: SMVRECEIVE function settings: 20.000 kV : 100 V. The residual voltage start value of  $1.0 \times U_n$  corresponds to  $1.0 \times 20.000 \text{ kV} = 20.000 \text{ kV}$  in the primary.



If "Calculated U<sub>o</sub>" is selected, the residual voltage nominal value is always phase-to-phase voltage. Thus, the valid maximum setting for residual voltage start value is  $0.577 \times U_n$ . Calculated U<sub>o</sub> requires that all three phase-to-earth voltages are connected to the IED. U<sub>o</sub> cannot be calculated from the phase-to-phase voltages.

### Transient detector

The Transient detector module is used for detecting transients in the residual current and residual voltage signals.

The transient detection is supervised with a settable current threshold. With a special filtering technique, the setting *Min operate current* is based on the fundamental frequency current. This setting should be set based on the value of the parallel resistor of the coil, with security margin. For example, if the resistive current of the parallel resistor is 10 A, then a value of  $0.7 \times 10 \text{ A} = 7 \text{ A}$  could be used. The same setting is also applicable in case the coil is disconnected and the network becomes unearthed. Generally, a smaller value should be used and it must never exceed the value of the parallel resistor in order to allow operation of the faulted feeder.

### Fault indication logic

Depending on the set *Operation mode*, INTRPTEF has two independent modes for detecting earth faults. The "Transient EF" mode is intended to detect all kinds of earth faults. The "Intermittent EF" mode is dedicated for detecting intermittent earth faults in cable networks.



To satisfy the sensitivity requirements, basic earth fault protection (based on fundamental frequency phasors) should always be used in parallel with the INTRPTEF function.

The Fault indication logic module determines the direction of the fault. The fault direction determination is secured by multi-frequency neutral admittance measurement and special filtering techniques. This enables fault direction

determination which is not sensitive to disturbances in measured  $I_o$  and  $U_o$  signals, for example, switching transients.

When *Directional mode* setting "Forward" is used, the protection operates when the fault is in the protected feeder. When *Directional mode* setting "Reverse" is used, the protection operates when the fault is outside the protected feeder (in the background network). If the direction has no importance, the value "Non-directional" can be selected. The detected fault direction (FAULT\_DIR) is available in the monitored data view.

In the "Transient EF" mode, when the start transient of the fault is detected and the  $U_o$  level exceeds the set *Voltage start value*, Timer 1 is activated. Timer 1 is kept activated until the  $U_o$  level exceeds the set value or in case of a drop-off, the drop-off duration is shorter than the set *Reset delay time*.

In the "Intermittent EF" mode, when the start transient of the fault is detected and the  $U_o$  level exceeds the set *Voltage start value*, the Timer 1 is activated. When a required number of intermittent earth-fault transients set with the *Peak counter limit* setting are detected without the function being reset (depends on the drop-off time set with the *Reset delay time* setting), the START output is activated. The Timer 1 is kept activated as long as transients are occurring during the drop-off time defined by setting *Reset delay time*.

### Timer 1

The time characteristic is according to DT.

In the "Transient EF" mode, the OPERATE output is activated after *Operate delay time* if the residual voltage exceeds the set *Voltage start value*. The *Reset delay time* starts to elapse when residual voltage falls below *Voltage start value*. If there is no OPERATE activation, for example, the fault disappears momentarily, START stays activated until the *Reset delay time* elapses. After OPERATE activation, START and OPERATE signals are reset as soon as  $U_o$  falls below *Voltage start value*.

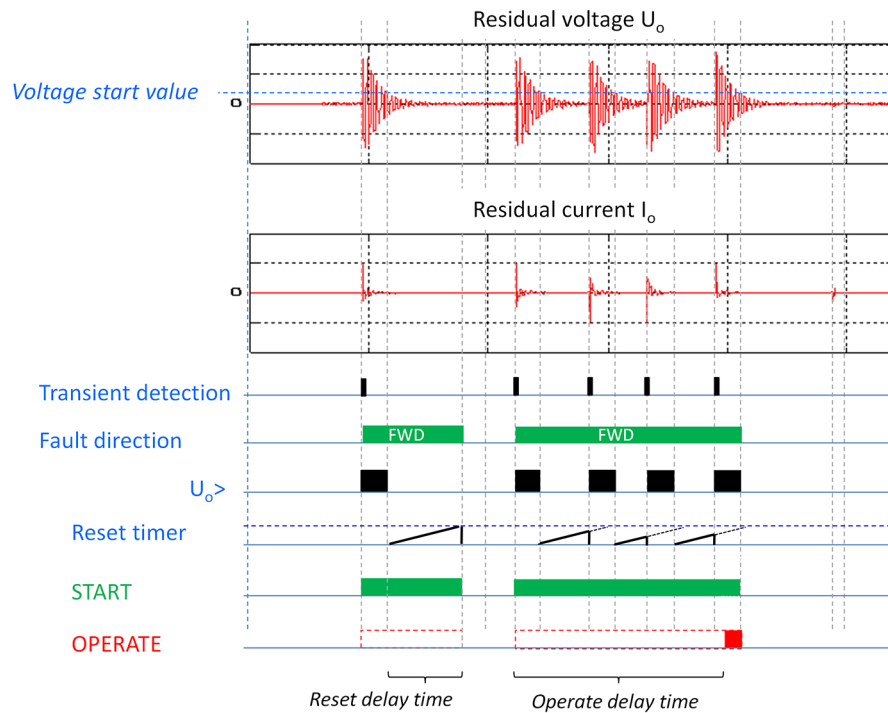


Figure 139: Example of INTRPTEF operation in "Transient EF" mode in the faulty feeder

In the "Intermittent EF" mode the OPERATE output is activated when the following conditions are fulfilled:

- the number of transients that have been detected exceeds the *Peak counter limit* setting
- the timer has reached the time set with the *Operate delay time*
- and one additional transient is detected during the drop-off cycle

The *Reset delay time* starts to elapse from each detected transient (peak). In case there is no OPERATE activation, for example, the fault disappears momentarily START stays activated until the *Reset delay time* elapses, that is, reset takes place if time between transients is more than *Reset delay time*. After OPERATE activation, a fixed pulse length of 100 ms for OPERATE is given, whereas START is reset after *Reset delay time* elapses



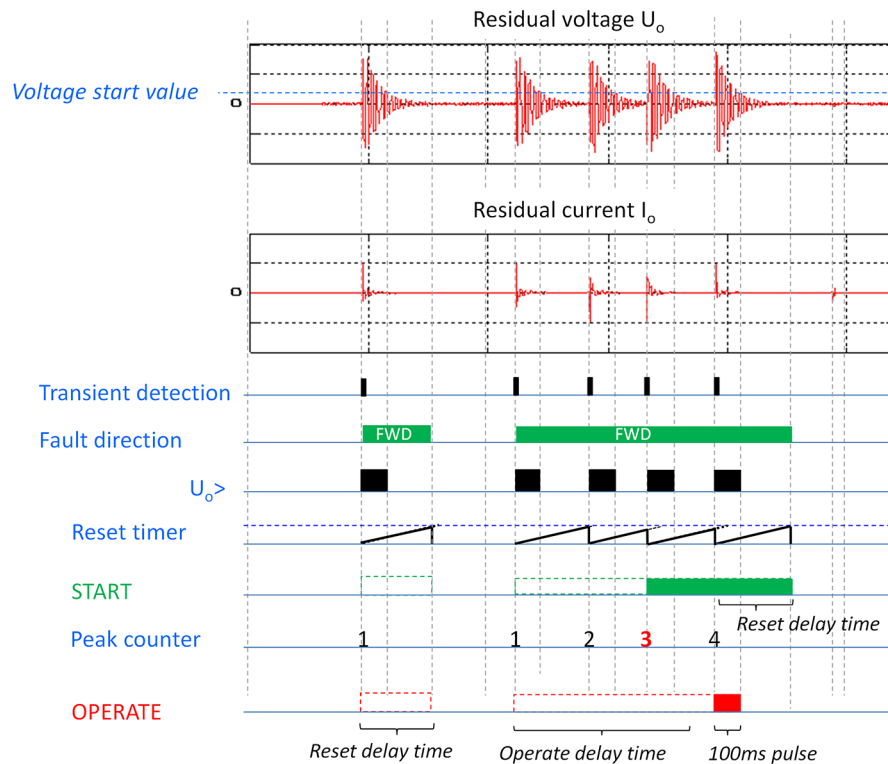


Figure 140: Example of INTRPTEF operation in "Intermittent EF" mode in the faulty feeder, Peak counter limit=3

The timer calculates the start duration value START\_DUR which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

### Timer 2

If the function is used in the directional mode and an opposite direction transient is detected, the `BLK_EF` output is activated for the fixed delay time of 25 ms. If the `START` output is activated when the `BLK_EF` output is active, the `BLK_EF` output is deactivated.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting **Configuration > System > Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the `OPERATE` output is not activated.

### 3.2.3.5 Application

INTRPTEF is an earth-fault function dedicated to operate in intermittent and permanent earth faults occurring in distribution and sub-transmission networks. Fault detection is done from the residual current and residual voltage signals by monitoring the transients with predefined criteria. As the function has a dedicated purpose for the fault types, fast detection and clearance of the faults can be achieved.

#### Intermittent earth fault

Intermittent earth fault is a special type of fault that is encountered especially in compensated networks with underground cables. A typical reason for this type of fault is the deterioration of cable insulation either due to mechanical stress or due to insulation material aging process where water or moisture gradually penetrates the cable insulation. This eventually reduces the voltage withstand of the insulation, leading to a series of cable insulation breakdowns. The fault is initiated as the phase-to-earth voltage exceeds the reduced insulation level of the fault point and mostly extinguishes itself as the fault current drops to zero for the first time, as shown in *Figure 141*. As a result, very short transients, that is, rapid changes in the form of spikes in residual current ( $I_o$ ) and in residual voltage ( $U_o$ ), can be repeatedly measured. Typically, the fault resistance in case of an intermittent earth fault is only a few ohms.

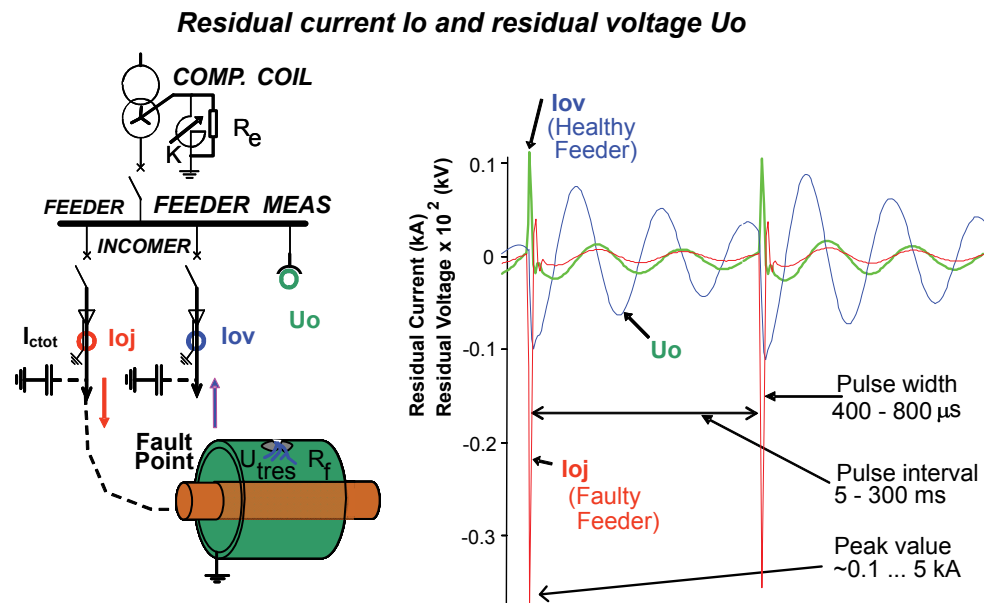


Figure 141: Typical intermittent earth-fault characteristics

#### Earth-fault transients

In general, earth faults generate transients in currents and voltages. There are several factors that affect the magnitude and frequency of these transients, such as the fault moment on the voltage wave, fault location, fault resistance and the parameters of the feeders and the supplying transformers. In the fault initiation, the voltage of the faulty phase decreases and the corresponding capacitance is discharged to earth (→ discharge transients). At the same time, the voltages of

the healthy phases increase and the related capacitances are charged (→ charge transient).

If the fault is permanent (non-transient) in nature, only the initial fault transient in current and voltage can be measured, whereas the intermittent fault creates repetitive transients.

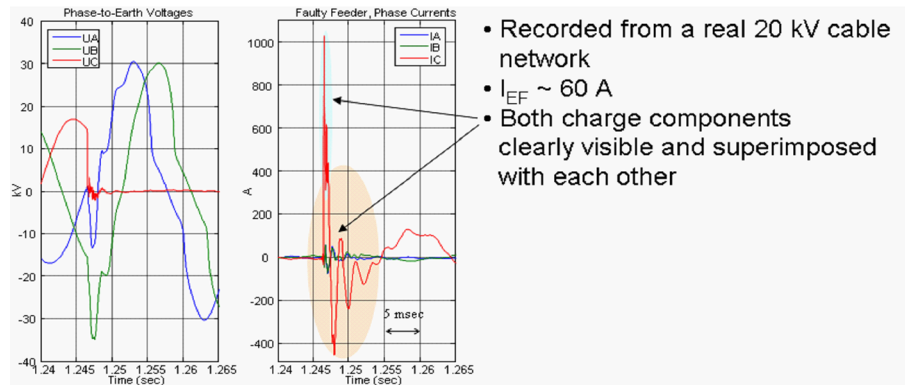


Figure 142: Example of earth-fault transients, including discharge and charge transient components, when a permanent fault occurs in a 20 kV network in phase C

### 3.2.3.6 Signals

#### INTRPTEF Input signals

Table 336: INTRPTEF Input signals

| Name  | Type    | Default | Description                                   |
|-------|---------|---------|---|
| Io    | SIGNAL  | 0       | Residual current                              |
| Uo    | SIGNAL  | 0       | Residual voltage                              |
| BLOCK | BOOLEAN | 0=False | Block signal for activating the blocking mode |

#### INTRPTEF Output signals

Table 337: INTRPTEF Output signals

| Name    | Type    | Description  |
|---------|---------|--|
| OPERATE | BOOLEAN | Operate  |
| START   | BOOLEAN | Start  |
| BLK_EF  | BOOLEAN | Block signal for EF to indicate opposite direction peaks |

### 3.2.3.7 Settings

**INTRPTEF Settings****Table 338: INTRPTEF Group settings (Basic)**

| Parameter           | Values (Range)                              | Unit | Step | Default   | Description         |
|---------------------|---|------|------|-----------|---------------------|
| Directional mode    | 1=Non-directional<br>2=Forward<br>3=Reverse |      |      | 2=Forward | Directional mode    |
| Operate delay time  | 40...1200000                                | ms   | 10   | 500       | Operate delay time  |
| Voltage start value | 0.05...0.50                                 | xUn  | 0.01 | 0.20      | Voltage start value |

**Table 339: INTRPTEF Non group settings (Basic)**

| Parameter      | Values (Range)                      | Unit | Step | Default           | Description        |
|----------------|-------------------------------------|------|------|-------------------|--------------------|
| Operation      | 1=on<br>5=off                       |      |      | 1=on              | Operation Off / On |
| Operation mode | 1=Intermittent EF<br>2=Transient EF |      |      | 1=Intermittent EF | Operation criteria |

**Table 340: INTRPTEF Non group settings (Advanced)**

| Parameter           | Values (Range) | Unit | Step | Default | Description   |
|---------------------|----------------|------|------|---------|---|
| Reset delay time    | 40...60000     | ms   | 1    | 500     | Reset delay time  |
| Peak counter limit  | 2...20         |      | 1    | 2       | Min requirement for peak counter before start in IEF mode |
| Min operate current | 0.01...1.00    | xIn  | 0.01 | 0.01    | Minimum operating current for transient detector          |

**3.2.3.8****Monitored data**

**INTRPTEF Monitored data****Table 341: INTRPTEF Monitored data**

| Name      | Type    | Values (Range)   | Unit | Description                        |
|-----------|---------|--|------|------------------------------------|
| FAULT_DIR | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both         |      | Detected fault direction           |
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time |
| INTRPTEF  | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                             |

**3.2.3.9****Technical data****Table 342: INTRPTEF Technical data**

| Characteristic   | Value  |
|--|--|
| Operation accuracy (U <sub>o</sub> criteria with transient protection) | Depending on the frequency of the measured current: $f_n \pm 2$ Hz<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times U_o$ |
| Operate time accuracy  | $\pm 1.0\%$ of the set value or $\pm 20$ ms  |
| Suppression of harmonics   | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5$   |

**3.2.3.10****Technical revision history****Table 343: INTRPTEF Technical revision history**

| Technical revision | Change  |
|--------------------|---|
| B                  | Minimum and default values changed to 40 ms for the <i>Operate delay time</i> setting   |
| C                  | The <i>Minimum operate current</i> setting is added. Correction in IEC61850 mapping: DO BlkEF renamed to InhEF. Minimum value changed from 0.01 to 0.10 (default changed from 0.01 to 0.20) for the <i>Voltage start value</i> setting. Minimum value changed from 0 ms to 40 ms for the <i>Reset delay time</i> setting. |

*Table continues on the next page*

| Technical revision | Change  |
|--------------------|---|
| D                  | Voltage start value description changed from "Voltage start value for transient EF" to "Voltage start value" since the start value is effective in both operation modes. Added support for calculated Uo. Uo source (measured/calculated) can be selected with "Uo signal Sel". <i>Voltage start value</i> setting minimum changed from 0.10 to 0.05. |
| E                  | <i>Min operate current</i> setting scaling corrected to RMS level from peak level.  |
| F                  | Modified for SSC600   |

### 3.2.4 Admittance-based earth-fault protection EFPADM

#### 3.2.4.1 Identification

| Function description                    | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|--------------------------|--------------------------|-------------------------------|
| Admittance-based earth-fault protection | EFPADM                   | Yo> ->                   | 21YN                          |

#### 3.2.4.2 Function block

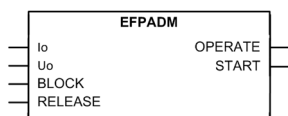


Figure 143: Function block

#### 3.2.4.3 Functionality

The admittance-based earth-fault protection function EFPADM provides a selective earth-fault protection function for high-resistance earthed, unearthed and compensated networks. It can be applied for the protection of overhead lines as well as with underground cables. It can be used as an alternative solution to traditional residual current-based earth-fault protection functions, such as the IoCos mode in DEFxPDEF. Main advantages of EFPADM include a versatile applicability, good sensitivity and easy setting principles.

EFPADM is based on evaluating the neutral admittance of the network, that is, the quotient:

$$Y_o = I_o / -U_o$$

The measured admittance is compared to the admittance characteristic boundaries in the admittance plane. The supported characteristics include overadmittance, oversusceptance, overconductance or any combination of the three. The directionality of the oversusceptance and overconductance criteria can be defined as forward, reverse or non-directional, and the boundary lines can be tilted if

required by the application. This allows the optimization of the shape of the admittance characteristics for any given application.

EFPADM supports two calculation algorithms for admittance. The admittance calculation can be set to include or exclude the prefault zero-sequence values of  $I_0$  and  $U_0$ . Furthermore, the calculated admittance is recorded at the time of the trip and it can be monitored for post-fault analysis purposes.

To ensure the security of the protection, the admittance calculation is supervised by a residual overvoltage condition which releases the admittance protection during a fault condition. Alternatively, the release signal can be provided by an external binary signal.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

### 3.2.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of EFPADM can be described using a module diagram. All the modules in the diagram are explained in the next sections.

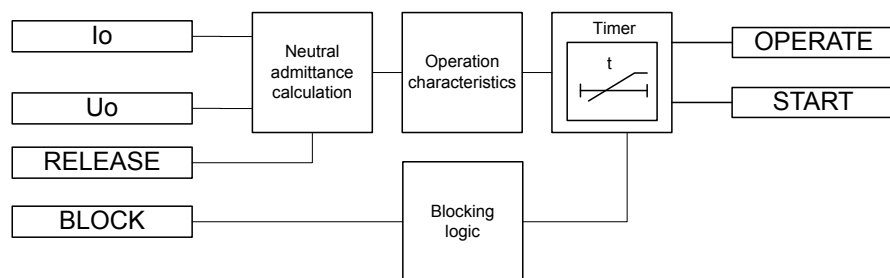


Figure 144: Functional module diagram

#### Neutral admittance calculation

The operating quantity (residual current) can be selected within the ACT configuration. The options are "Measured  $I_0$ " and "Calculated  $I_0$ ". Measured  $I_0$  is selected when  $I_{RES}$  input of the corresponding SMVRECEIVE function is connected to  $I_0$  input of the function. Similarly Calculated  $I_0$  is selected, when  $I_{RES\_CALC}$  input is connected. CT ratios need to be defined in the parameters of the SMVRECEIVE function. If "Measured  $I_0$ " is selected, the current ratio for  $I_0$ -channel is given in SMVRECEIVE function settings. If "Calculated  $I_0$ " is selected, the current ratio is obtained from phase-current channels given in SMVRECEIVE function settings.

Respectively, the residual voltage can be selected within the ACT configuration. The options are "Measured  $U_0$ " and "Calculated  $U_0$ ". If "Measured  $U_0$ " is selected, the voltage ratio for  $U_0$ -channel is given in SMVRECEIVE function settings. If "Calculated  $U_0$ " is selected, the voltage ratio is obtained from phase-voltage channels given in SMVRECEIVE function settings.

**Example 1:**  $U_0$  is measured from open-delta connected VTs ( $20/\sqrt{3}$  kV :  $100/\sqrt{3}$  V:100/3 V). In this case, "Measured  $U_0$ " is selected. The nominal values for residual voltage is obtained from the VT ratios entered in *Residual voltage  $U_0$*  :

SMVRECEIVE function settings: 11.547 kV : 100 V. The residual voltage start value of  $1.0 \times U_n$  corresponds to  $1.0 \times 11.547 \text{ kV} = 11.547 \text{ kV}$  in the primary.

**Example 2:**  $U_o$  is calculated from phase quantities. The phase VT-ratio is  $20/\sqrt{3}$  kV : 100/ $\sqrt{3}$  V. In this case, "Calculated  $U_o$ " is selected. The nominal value for residual voltage is obtained from the VT ratios entered in Residual voltage  $U_o$  : SMVRECEIVE function settings : 20.000kV : 100V. The residual voltage start value of  $1.0 \times U_n$  corresponds to  $1.0 \times 20.000 \text{ kV} = 20.000 \text{ kV}$  in the primary.



In case, if "Calculated  $U_o$ " is selected, the residual voltage nominal value is always phase-to-phase voltage. Thus, the valid maximum setting for residual voltage start value is  $0.577 \times U_n$ . The calculated  $U_o$  requires that all three phase-to-earth voltages are connected to the IED.  $U_o$  cannot be calculated from the phase-to-phase voltages.

When the residual voltage exceeds the set threshold *Voltage start value*, an earth fault is detected and the neutral admittance calculation is released.

To ensure a sufficient accuracy for the  $I_o$  and  $U_o$  measurements, it is required that the residual voltage exceeds the value set by *Min operate voltage*. If the admittance calculation mode is "Delta", the minimum change in the residual voltage due to a fault must be  $0.01 \times U_n$  to enable the operation. Similarly, the residual current must exceed the value set by *Min operate current*.



The polarity of the polarizing quantity  $U_o$  can be changed, that is, rotated by 180 degrees, by setting the *Pol reversal* parameter to "True" or by switching the polarity of the residual voltage measurement wires.

As an alternative for the internal residual overvoltage-based start condition, the neutral admittance protection can also be externally released by utilizing the `RELEASE` input.

When *Admittance Clc mode* is set to "Delta", the external logic used must be able to give `RELEASE` in less than 0.1 s from fault initiation. Otherwise the collected pre-fault values are overwritten with fault time values. If it is slower, *Admittance Clc mode* must be set to "Normal".

Neutral admittance is calculated as the quotient between the residual current and residual voltage (polarity reversed) fundamental frequency phasors. The *Admittance Clc mode* setting defines the calculation mode.

*Admittance Clc mode* = "Normal"

$$\underline{Y}_o = \frac{\underline{I}_o \text{ fault}}{-\underline{U}_o \text{ fault}}$$

(Equation 2)

*Admittance Clc mode* = "Delta"



$$\underline{Y}_O = \frac{\underline{I}_O_{fault} - \underline{I}_O_{prefault}}{-(\underline{U}_O_{fault} - \underline{U}_O_{prefault})} = \frac{\Delta \underline{I}_O}{-\Delta \underline{U}_O}$$

(Equation 3)

|                              |   |
|------------------------------|---|
| $\underline{Y}_O$            | Calculated neutral admittance [Siemens]               |
| $\underline{I}_O_{fault}$    | Residual current during the fault [Amperes]           |
| $\underline{U}_O_{fault}$    | Residual voltage during the fault [Volts]             |
| $\underline{I}_O_{prefault}$ | Prefault residual current [Amperes]                   |
| $\underline{U}_O_{prefault}$ | Prefault residual voltage [Volts]                     |
| $\Delta \underline{I}_O$     | Change in the residual current due to fault [Amperes] |
| $\Delta \underline{U}_O$     | Change in the residual voltage due to fault [Volts]   |

Traditionally, admittance calculation is done with the calculation mode "Normal", that is, with the current and voltage values directly measured during the fault. As an alternative, by selecting the calculation mode "Delta", the prefault zero-sequence asymmetry of the network can be removed from the admittance calculation. Theoretically, this makes the admittance calculation totally immune to fault resistance, that is, the estimated admittance value is not affected by fault resistance. Utilization of the change in  $U_o$  and  $I_o$  due to a fault in the admittance calculation also mitigates the effects of the VT and CT measurement errors, thus improving the measuring accuracy, the sensitivity and the selectivity of the protection.



Calculation mode "Delta" is recommended in case a high sensitivity of the protection is required, if the network has a high degree of asymmetry during the healthy state or if the residual current measurement is based on sum connection, that is, the Holmgren connection.

Neutral admittance calculation produces certain values during forward and reverse faults.

Fault in reverse direction, that is, outside the protected feeder.

$$\underline{Y}_O = -\underline{Y}_{Ftot}$$

(Equation 4)

$$\approx -j \cdot \frac{I_{eFd}}{U_{ph}}$$

(Equation 5)

|                         |   |
|-------------------------|---|
| $\underline{Y}_{Fdtot}$ | Sum of the phase-to-earth admittances ( $\underline{Y}_{FdA}$ , $\underline{Y}_{FdB}$ , $\underline{Y}_{FdC}$ ) of the protected feeder |
| $I_{eFd}$               | Magnitude of the earth-fault current of the protected feeder when the fault resistance is zero ohm                                      |
| $U_{ph}$                | Magnitude of the nominal phase-to-earth voltage of the system   |

*Equation 4* shows that in case of outside faults, the measured admittance equals the admittance of the protected feeder with a negative sign. The measured admittance is dominantly reactive; the small resistive part of the measured admittance is due to the leakage losses of the feeder. Theoretically, the measured admittance is located in the third quadrant in the admittance plane close to the  $\text{im}(\underline{Y}_0)$  axis, see *Figure 145*.



The result of *Equation 5* is valid regardless of the neutral earthing method. In compensated networks the compensation degree does not affect the result. This enables a straightforward setting principle for the neutral admittance protection: admittance characteristic is set to cover the value  $\underline{Y}_0 = -\underline{Y}_{Fdtot}$  with a suitable margin.



Due to inaccuracies in voltage and current measurement, the small real part of the calculated neutral admittance may appear as positive, which brings the measured admittance in the fourth quadrant in the admittance plane. This should be considered when setting the admittance characteristic.

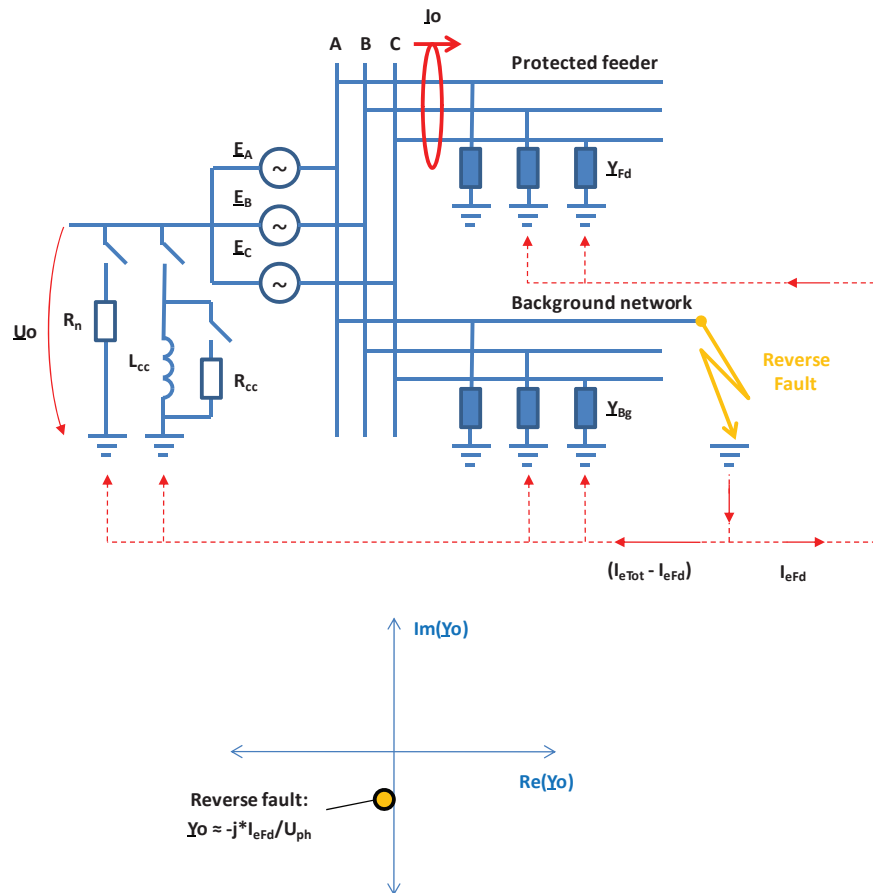


Figure 145: Admittance calculation during a reverse fault

- $R_{CC}$  Resistance of the parallel resistor
- $L_{CC}$  Inductance of the compensation coil
- $R_n$  Resistance of the neutral earthing resistor
- $Y_{Fd}$  Phase-to-earth admittance of the protected feeder
- $Y_{Bg}$  Phase-to-earth admittance of the background network

For example, in a 15 kV compensated network with the magnitude of the earth-fault current in the protected feeder being 10 A ( $R_f = 0 \Omega$ ), the theoretical value for the measured admittance during an earth fault in the reverse direction, that is, outside the protected feeder, can be calculated.

$$Y_O \approx -j \cdot \frac{I_{eFd}}{U_{ph}} = -j \cdot \frac{10A}{15/\sqrt{3}kV} = -j \cdot 1.15 \text{ milliSiemens}$$

(Equation 6)

The result is valid regardless of the neutral earthing method.

In this case, the resistive part of the measured admittance is due to leakage losses of the protected feeder. As they are typically very small, the resistive part is close to zero. Due to inaccuracies in the voltage and current measurement, the small

real part of the apparent neutral admittance may appear positive. This should be considered in the setting of the admittance characteristic.

Fault in the forward direction, that is, inside the protected feeder.

Unearthed network.

$$\underline{Y}_O = \underline{Y}_{Bgtot}$$

(Equation 7)

$$\approx j \cdot \left( \frac{I_{eTot} - I_{eFd}}{U_{ph}} \right)$$

(Equation 8)

Compensated network:

$$\underline{Y}_O = \underline{Y}_{Bgtot} + \underline{Y}_{CC}$$

(Equation 9)

$$\approx \frac{I_{Rcc} + j \cdot (I_{eTot} \cdot (1 - K) - I_{eFd})}{U_{ph}}$$

(Equation 10)

High-resistance earthed network:

$$\underline{Y}_O = \underline{Y}_{Bgtot} + \underline{Y}_{Rn}$$

(Equation 11)

$$\approx \frac{I_{Rn} + j \cdot (I_{eTot} - I_{eFd})}{U_{ph}}$$

(Equation 12)

|                         |   |
|-------------------------|---|
| $\underline{Y}_{Bgtot}$ | Sum of the phase-to-earth admittances ( $\underline{Y}_{BgA}$ , $\underline{Y}_{BgB}$ , $\underline{Y}_{BgC}$ ) of the background network |
| $\underline{Y}_{CC}$    | Admittance of the earthing arrangement (compensation coil and parallel resistor)  |
| $I_{Rcc}$               | Rated current of the parallel resistor  |
| $I_{eFd}$               | Magnitude of the earth-fault current of the protected feeder when the fault resistance is zero ohm  |
| $I_{eTot}$              | Magnitude of the uncompensated earth-fault current of the network when $R_f$ is zero ohm  |
| K                       | Compensation degree, $K = 1$ full resonance, $K < 1$ undercompensated, $K > 1$ overcompensated  |
| $I_{Rn}$                | Rated current of the neutral earthing resistor  |

[Equation 8](#) shows that in case of a fault inside the protected feeder in unearthed networks, the measured admittance equals the admittance of the background network. The admittance is dominantly reactive; the small resistive part of the measured admittance is due to the leakage losses of the background network. Theoretically, the measured admittance is located in the first quadrant in the admittance plane, close to the  $\text{im}(Y_o)$  axis, see [Figure 146](#).

[Equation 10](#) shows that in case of a fault inside the protected feeder in compensated networks, the measured admittance equals the admittance of the background network and the coil including the parallel resistor. Basically, the compensation degree determines the imaginary part of the measured admittance and the resistive part is due to the parallel resistor of the coil and the leakage losses of the background network and the losses of the coil. Theoretically, the measured admittance is located in the first or fourth quadrant in the admittance plane, depending on the compensation degree, see [Figure 146](#).



Before the parallel resistor is connected, the resistive part of the measured admittance is due to the leakage losses of the background network and the losses of the coil. As they are typically small, the resistive part may not be sufficiently large to secure the discrimination of the fault and its direction based on the measured conductance. This and the rating and the operation logic of the parallel resistor should be considered when setting the admittance characteristic in compensated networks.

[Equation 12](#) shows that in case of a fault inside the protected feeder in high-resistance earthed systems, the measured admittance equals the admittance of the background network and the neutral earthing resistor. Basically, the imaginary part of the measured admittance is due to the phase-to-earth capacitances of the background network, and the resistive part is due to the neutral earthing resistor

and the leakage losses of the background network. Theoretically, the measured admittance is located in the first quadrant in the admittance plane, see *Figure 146*.

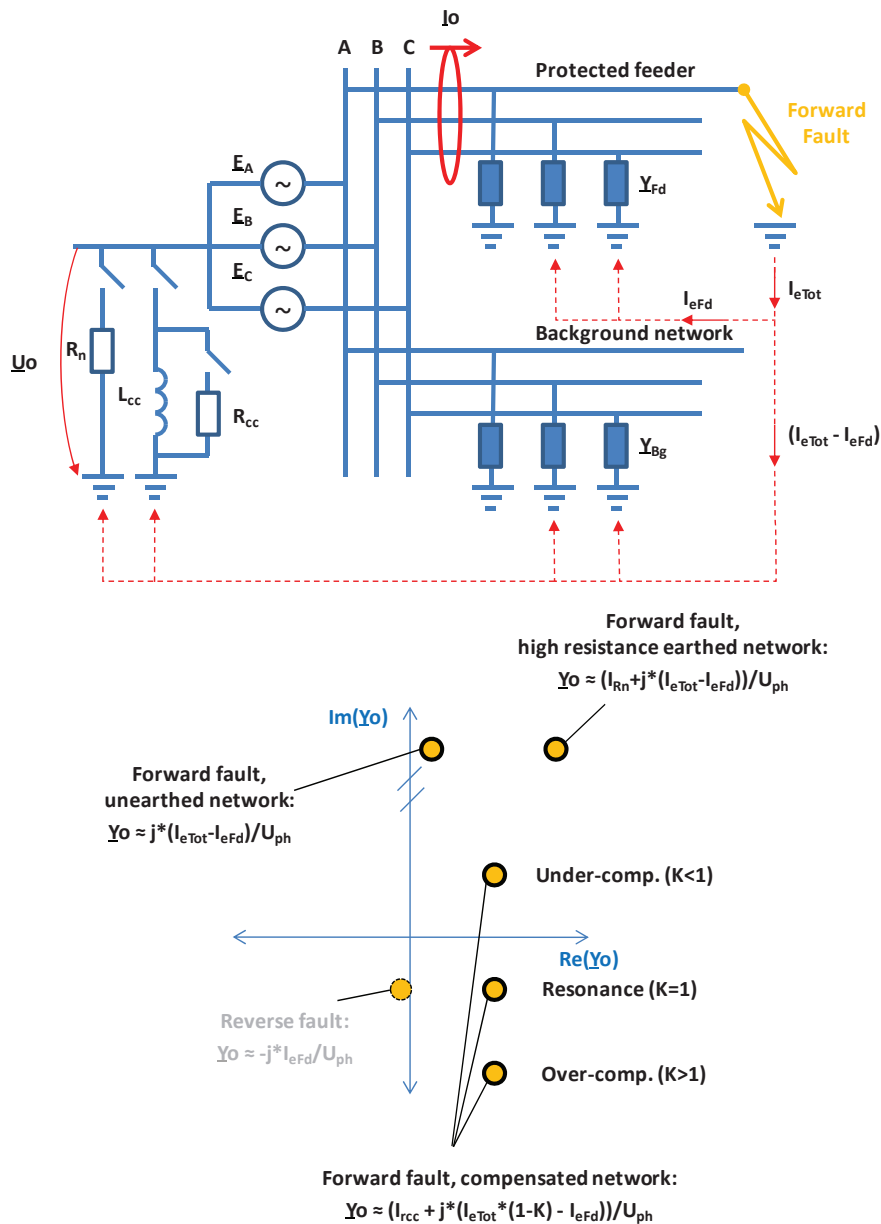


Figure 146: Admittance calculation during a forward fault



When the network is fully compensated in compensated networks, theoretically during a forward fault, the imaginary part of the measured admittance equals the susceptance of the protected feeder with a negative sign. The discrimination between a forward and reverse fault must therefore be based on the real part of the measured admittance, that is, conductance. Thus, the best selectivity is achieved when the compensated network is operated either in the undercompensated or overcompensated mode.

For example, in a 15 kV compensated network, the magnitude of the earth fault current of the protected feeder is 10 A ( $R_f = 0 \Omega$ ) and the magnitude of the network is 100 A ( $R_f = 0 \Omega$ ). During an earth fault, a 15 A resistor is connected in parallel to the coil after a 1.0 second delay. Compensation degree is overcompensated,  $K = 1.1$ .

During an earth fault in the forward direction, that is, inside the protected feeder, the theoretical value for the measured admittance after the connection of the parallel resistor can be calculated.

$$\begin{aligned} \underline{Y}_O &\approx \frac{I_{Rcc} + j \cdot (I_{eTot} \cdot (1 - K) - I_{eFd})}{U_{ph}} \\ &= \frac{15A + j \cdot (100A \cdot (1 - 1.1) - 10A)}{15kV/\sqrt{3}} \approx (1.73 - j \cdot 2.31) \text{ milliSiemens} \end{aligned}$$

(Equation 13)

Before the parallel resistor is connected, the resistive part of the measured admittance is due to the leakage losses of the background network and the losses of the coil. As they are typically small, the resistive part may not be sufficiently large to secure the discrimination of the fault and its direction based on the measured conductance. This and the rating and the operation logic of the parallel resistor should be considered when setting the admittance characteristic.



When a high sensitivity of the protection is required, the residual current should be measured with a cable/ring core CT, that is, the Ferranti CT. Also the use of the sensitive  $I_O$  input should be considered. The residual voltage measurement should be done with an open delta connection of the three single pole-insulated voltage transformers.



The sign of the admittance characteristic settings should be considered based on the location of characteristic boundary in the admittance plane. All forward-settings are given with positive sign and reverse-settings with negative sign.

### Operation characteristic

After the admittance calculation is released, the calculated neutral admittance is compared to the admittance characteristic boundaries in the admittance plane. If the calculated neutral admittance  $\underline{Y}_O$  moves outside the characteristic, the enabling signal is sent to the timer.

EFPADM supports a wide range of different characteristics to achieve the maximum flexibility and sensitivity in different applications. The basic characteristic shape is selected with the *Operation mode* and *Directional mode* settings. *Operation mode* defines which operation criterion or criteria are enabled and *Directional mode* defines if the forward, reverse or non-directional boundary lines for that particular operation mode are activated.

**Table 344: Operation criteria**

| Operation mode | Description           |
|----------------|-----------------------|
| Yo             | Admittance criterion  |
| Bo             | Susceptance criterion |
| Go             | Conductance criterion |

*Table continues on the next page*

| Operation mode | Description  |
|----------------|--|
| Yo, Go         | Admittance criterion combined with the conductance criterion                 |
| Yo, Bo         | Admittance criterion combined with the susceptance criterion                 |
| Go, Bo         | Conductance criterion combined with the susceptance criterion                |
| Yo, Go, Bo     | Admittance criterion combined with the conductance and susceptance criterion |

The options for the *Directional mode* setting are "Non-directional", "Forward" and "Reverse".

[Figure 147](#), [Figure 148](#) and [Figure 149](#) illustrate the admittance characteristics supported by EFPADM and the settings relevant to that particular characteristic. The most typical characteristics are highlighted and explained in details in [Chapter 3.2.4.5 Neutral admittance characteristics](#). Operation is achieved when the calculated neutral admittance  $Y_o$  moves outside the characteristic (the operation area is marked with gray).



The settings defining the admittance characteristics are given in primary milliSiemens (mS). The conversion equation for the admittance from secondary to primary is:

$$Y_{pri} = Y_{sec} \cdot \frac{n_{iCT}}{n_{uVT}}$$

(Equation 14)

$n_{iCT}$

CT ratio for the residual current  $I_o$

$n_{uVT}$

VT ratio for the residual voltage  $U_o$

Example: Admittance setting in the secondary is 5.00 milliSiemens. The CT ratio is 100/1 A and the VT ratio is 11547/100 V. The admittance setting in the primary can be calculated.

$$Y_{pri} = 5.00 \text{ milliSiemens} \cdot \frac{100/1A}{11547/100V} = 4.33 \text{ milliSiemens}$$

(Equation 15)



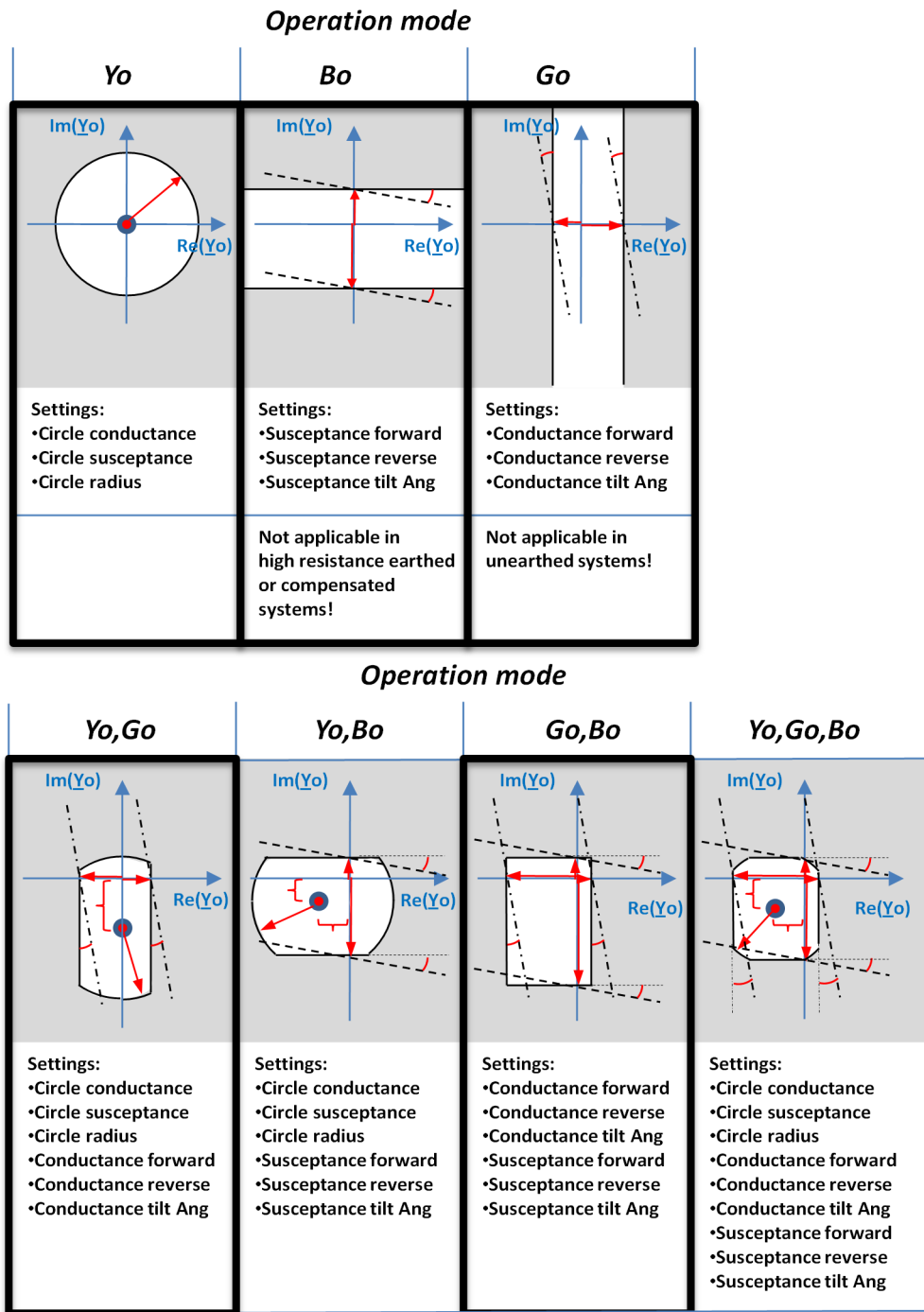


Figure 147: Admittance characteristic with different operation modes when Directional mode = "Non-directional"

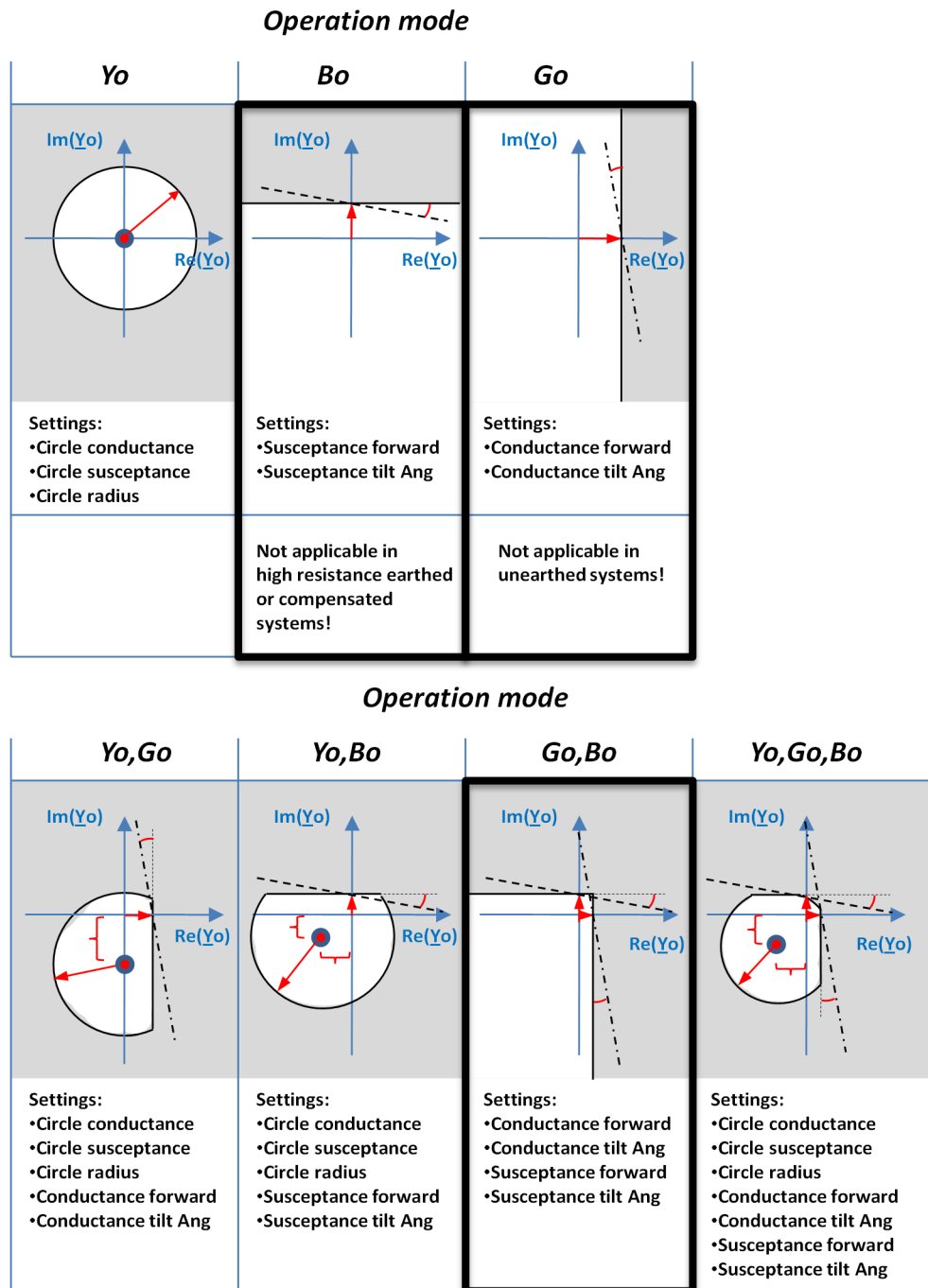


Figure 148: Admittance characteristic with different operation modes when Directional mode = "Forward"

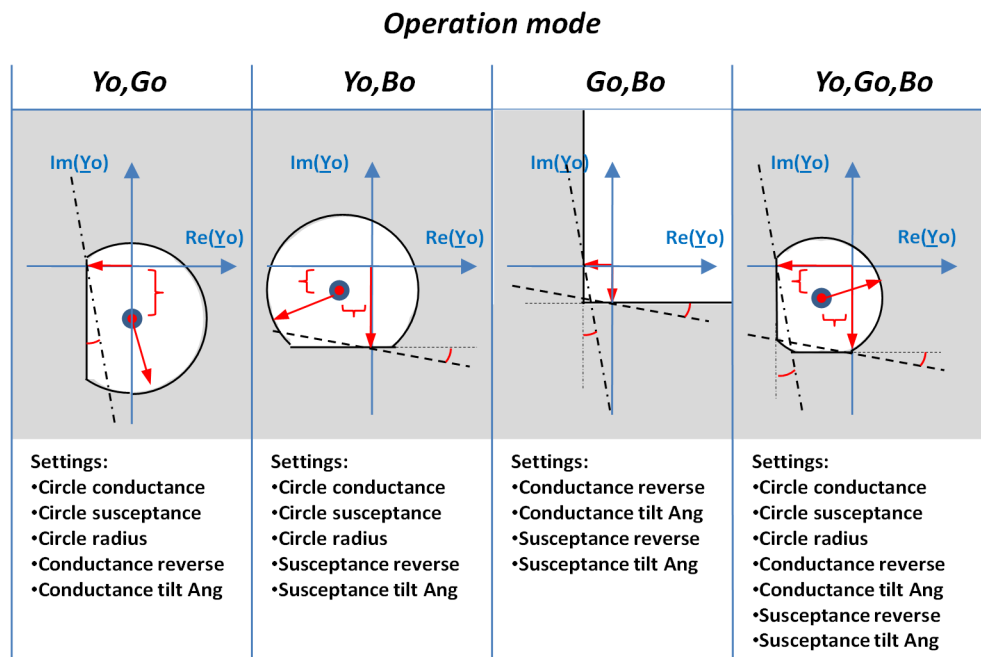
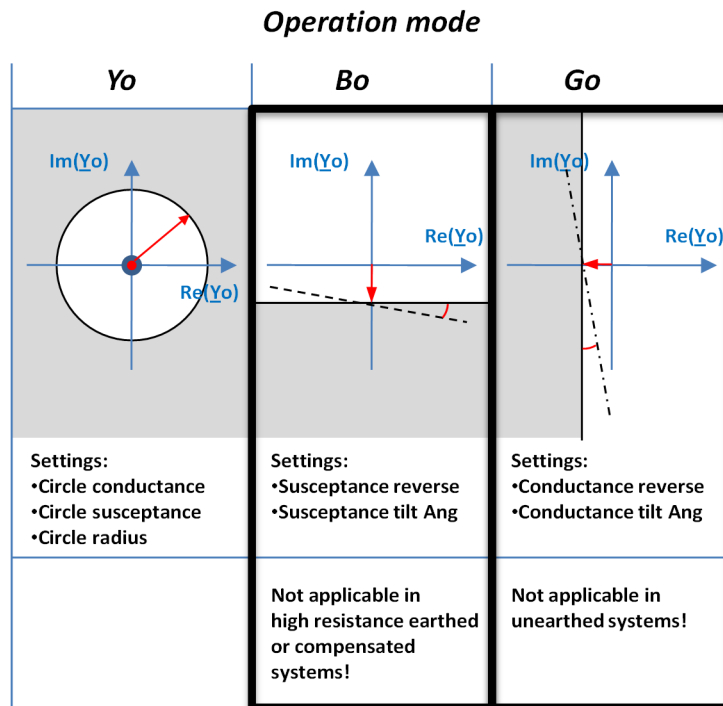


Figure 149: Admittance characteristic with different operation modes when Directional mode = "Reverse"

**Timer**

Once activated, the timer activates the START output. The time characteristic is according to DT. When the operation timer has reached the value set with the Operate delay time setting, the OPERATE output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set with the Reset delay time setting, the operation timer resets and

the START output is deactivated. The timer calculates the start duration value START\_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration > System > Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

## 3.2.4.5

### Neutral admittance characteristics

The applied characteristic should always be set to cover the total admittance of the protected feeder with a suitable margin. However, more detailed setting value selection principles depend on the characteristic in question.



The settings defining the admittance characteristics are given in primary milliSiemens.

The forward and reverse boundary settings should be set so that the forward setting is always larger than the reverse setting and that there is space between them.

### Overadmittance characteristic

The overadmittance criterion is enabled with the setting *Operation mode* set to "Yo". The characteristic is a circle with the radius defined with the *Circle radius* setting. For the sake of application flexibility, the midpoint of the circle can be moved away from the origin with the *Circle conductance* and *Circle susceptance* settings. Default values for *Circle conductance* and *Circle susceptance* are 0.0 mS, that is, the characteristic is an origin-centered circle.

Operation is achieved when the measured admittance moves outside the circle.

The overadmittance criterion is typically applied in unearthed networks, but it can also be used in compensated networks, especially if the circle is set off from the origin.

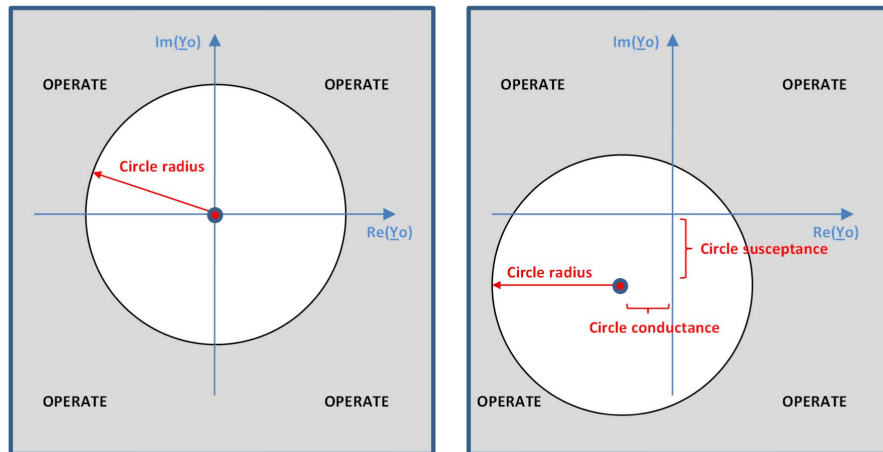


Figure 150: Overadmittance characteristic. Left figure: classical origin-centered admittance circle. Right figure: admittance circle is set off from the origin.

**Non-directional overconductance characteristic**

The non-directional overconductance criterion is enabled with the *Operation mode* setting set to "Go" and *Directional mode* to "Non-directional". The characteristic is defined with two overconductance boundary lines with the *Conductance forward* and *Conductance reverse* settings. For the sake of application flexibility, the boundary lines can be tilted by the angle defined with the *Conductance tilt Ang* setting. By default, the tilt angle is zero degrees, that is, the boundary line is a vertical line in the admittance plane. A positive tilt value rotates the boundary line counterclockwise from the vertical axis.

In case of non-directional conductance criterion, the *Conductance reverse* setting must be set to a smaller value than *Conductance forward*.

Operation is achieved when the measured admittance moves over either of the boundary lines.



The non-directional overconductance criterion is applicable in high-resistance earthed and compensated networks. It must not be applied in unearthed networks.

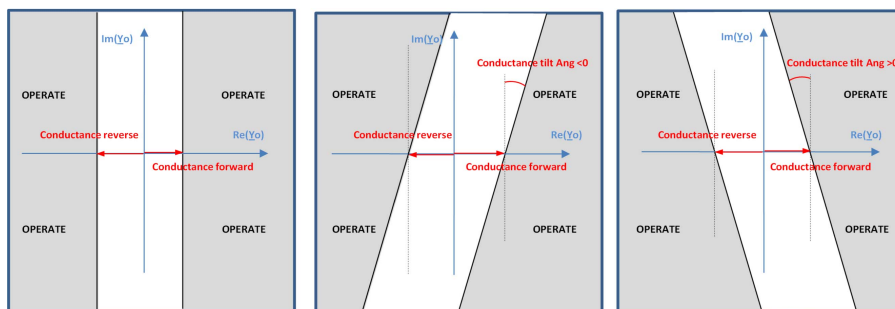


Figure 151: Non-directional overconductance characteristic. Left figure: classical non-directional overconductance criterion. Middle figure: characteristic is tilted with negative tilt angle. Right figure: characteristic is tilted with positive tilt angle.

**Forward directional overconductance characteristic**

The forward directional overconductance criterion is enabled with the *Operation mode* setting set to "Go" and *Directional mode* set to "Forward". The characteristic is defined by one overconductance boundary line with the *Conductance forward* setting. For the sake of application flexibility, the boundary line can be tilted with the angle defined with the *Conductance tilt Ang* setting. By default, the tilt angle is zero degrees, that is, the boundary line is a vertical line in the admittance plane. A positive tilt value rotates the boundary line counterclockwise from the vertical axis.

Operation is achieved when the measured admittance moves over the boundary line.



The forward directional overconductance criterion is applicable in high-resistance earthed and compensated networks. It must not be applied in unearthed networks.

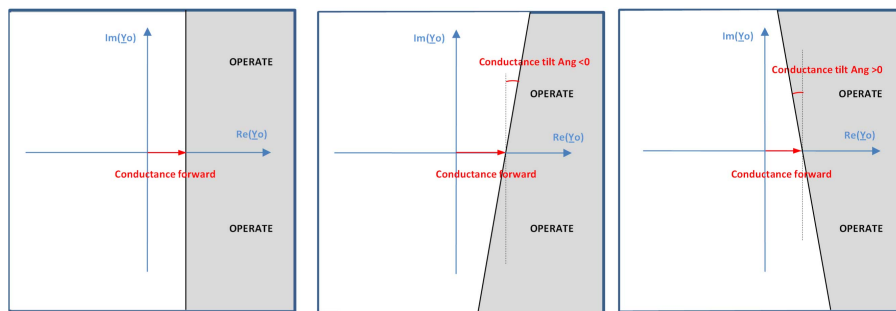


Figure 152: Forward directional overconductance characteristic. Left figure: classical forward directional overconductance criterion. Middle figure: characteristic is tilted with negative tilt angle. Right figure: characteristic is tilted with positive tilt angle.

**Forward directional oversusceptance characteristic**

The forward directional oversusceptance criterion is enabled with the *Operation mode* setting set to "Bo" and *Directional mode* to "Forward". The characteristic is defined by one oversusceptance boundary line with the *Susceptance forward* setting. For the sake of application flexibility, the boundary line can be tilted by the angle defined with the *Susceptance tilt Ang* setting. By default, the tilt angle is zero degrees, that is, the boundary line is a horizontal line in the admittance plane. A positive tilt value rotates the boundary line counterclockwise from the horizontal axis.

Operation is achieved when the measured admittance moves over the boundary line.



The forward directional oversusceptance criterion is applicable in unearthed networks. It must not be applied to compensated networks.

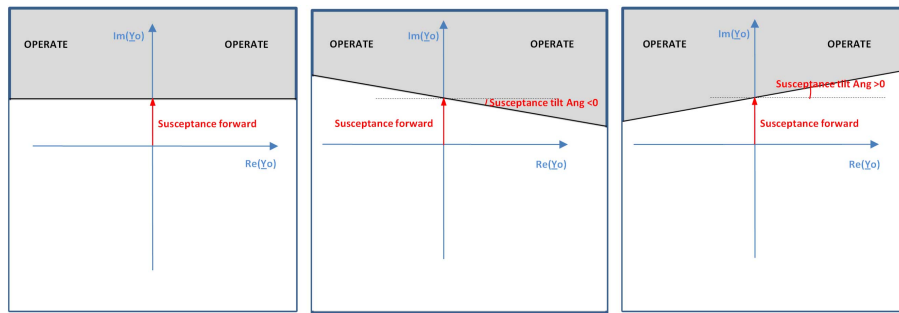


Figure 153: Forward directional oversusceptance characteristic. Left figure: classical forward directional oversusceptance criterion. Middle figure: characteristic is tilted with negative tilt angle. Right figure: characteristic is tilted with positive tilt angle.

### Combined overadmittance and overconductance characteristic

The combined overadmittance and overconductance criterion is enabled with the *Operation mode* setting set to "Yo, Go" and *Directional mode* to "Non-directional". The characteristic is a combination of a circle with the radius defined with the *Circle radius* setting and two overconductance boundary lines with the settings *Conductance forward* and *Conductance reverse*. For the sake of application flexibility, the midpoint of the circle can be moved from the origin with the *Circle conductance* and *Circle susceptance* settings. Also the boundary lines can be tilted by the angle defined with the *Conductance tilt Ang* setting. By default, the *Circle conductance* and *Circle susceptance* are 0.0 mS and *Conductance tilt Ang* equals zero degrees, that is, the characteristic is a combination of an origin-centered circle with two vertical overconductance boundary lines. A positive tilt value for the *Conductance tilt Ang* setting rotates boundary lines counterclockwise from the vertical axis.

In case of the non-directional conductance criterion, the *Conductance reverse* setting must be set to a smaller value than *Conductance forward*.

Operation is achieved when the measured admittance moves outside the characteristic.

The combined overadmittance and overconductance criterion is applicable in unearthed, high-resistance earthed and compensated networks or in systems where the system earthing may temporarily change during normal operation from compensated network to unearthed system.

Compared to the overadmittance criterion, the combined characteristic improves sensitivity in high-resistance earthed and compensated networks. Compared to the non-directional overconductance criterion, the combined characteristic enables the protection to be applied also in unearthed systems.

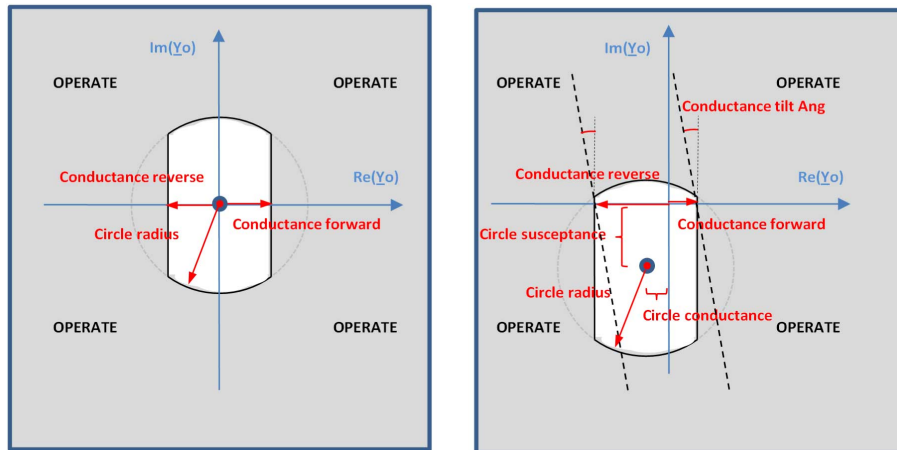


Figure 154: Combined overadmittance and overconductance characteristic. Left figure: classical origin-centered admittance circle combined with two overconductance boundary lines. Right figure: admittance circle is set off from the origin.

#### Combined overconductance and oversusceptance characteristic

The combined overconductance and oversusceptance criterion is enabled with the *Operation mode* setting set to "Go, Bo".

By setting *Directional mode* to "Forward", the characteristic is a combination of two boundary lines with the settings *Conductance forward* and *Susceptance forward*. See [Figure 155](#).

By setting *Directional mode* to "Non-directional", the characteristic is a combination of four boundary lines with the settings *Conductance forward*, *Conductance reverse*, *Susceptance forward* and *Susceptance reverse*. See [Figure 156](#).

For the sake of application flexibility, the boundary lines can be tilted by the angle defined with the *Conductance tilt Ang* and *Susceptance tilt Ang* settings. By default, the tilt angles are zero degrees, that is, the boundary lines are straight lines in the admittance plane. A positive *Conductance tilt Ang* value rotates the overconductance boundary line counterclockwise from the vertical axis. A positive *Susceptance tilt Ang* value rotates the oversusceptance boundary line counterclockwise from the horizontal axis.

In case of the non-directional conductance and susceptance criteria, the *Conductance reverse* setting must be set to a smaller value than *Conductance forward* and the *Susceptance reverse* setting must be set to a smaller value than *Susceptance forward*.

Operation is achieved when the measured admittance moves outside the characteristic.

The combined overconductance and oversusceptance criterion is applicable in high-resistance earthed, unearthed and compensated networks or in the systems where the system earthing may temporarily change during normal operation from compensated to unearthed system.



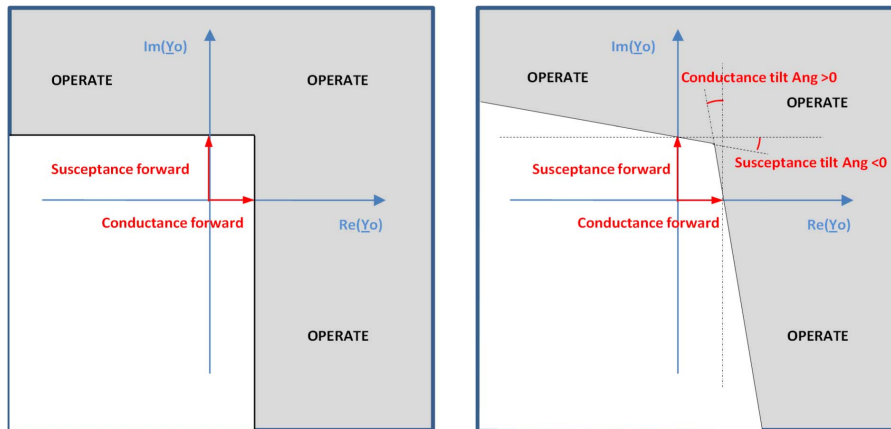


Figure 155: Combined forward directional overconductance and forward directional oversusceptance characteristic. Left figure: the Conductance tilt Ang and Susceptance tilt Ang settings equal zero degrees. Right figure: the setting Conductance tilt Ang > 0 degrees and the setting Susceptance tilt Ang < 0 degrees.

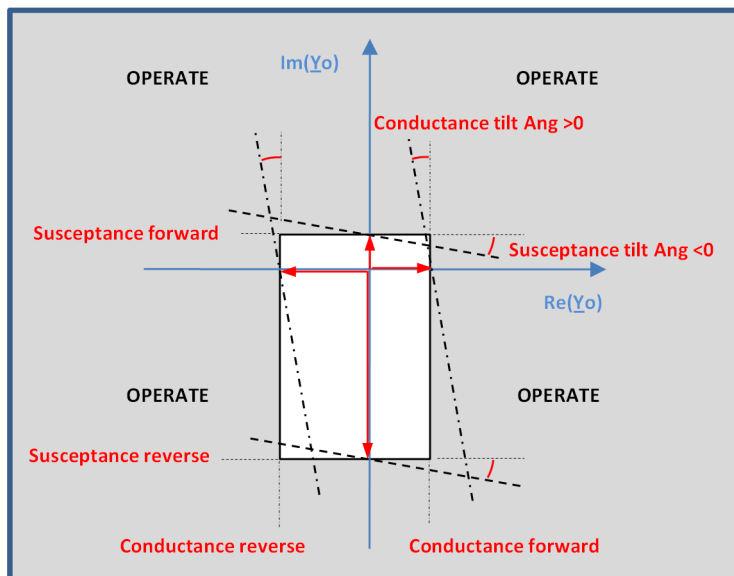


Figure 156: Combined non-directional overconductance and non-directional oversusceptance characteristic



The non-directional overconductance and non-directional oversusceptance characteristic provides a good sensitivity and selectivity when the characteristic is set to cover the total admittance of the protected feeder with a proper margin.



The sign of the admittance characteristic settings should be considered based on the location of characteristic boundary in the admittance plane. All forward-settings are given with positive sign and reverse-settings with negative sign.

### 3.2.4.6

#### Application

Admittance-based earth-fault protection provides a selective earth-fault protection for high-resistance earthed, unearthed and compensated networks. It can be

applied for the protection of overhead lines as well as with underground cables. It can be used as an alternative solution to traditional residual current-based earth-fault protection functions, for example the IoCos mode in DEFxPDEF. Main advantages of EFPADM include versatile applicability, good sensitivity and easy setting principles.

Residual overvoltage condition is used as a start condition for the admittance-based earth-fault protection. When the residual voltage exceeds the set threshold *Voltage start value*, an earth fault is detected and the neutral admittance calculation is released. In order to guarantee a high security of protection, that is, avoid false starts, the *Voltage start value* setting must be set above the highest possible value of  $U_0$  during normal operation with a proper margin. It should consider all possible operation conditions and configuration changes in the network. In unearthed systems, the healthy-state  $U_0$  is typically less than  $1\% \times U_{ph}$  ( $U_{ph}$  = nominal phase-to-earth voltage). In compensated networks, the healthy-state  $U_0$  may reach values even up to  $30\% \times U_{ph}$  if the network includes large parts of overheadlines without a phase transposition. Generally, the highest  $U_0$  is achieved when the compensation coil is tuned to the full resonance and when the parallel resistor of the coil is not connected.

The residual overvoltage-based start condition for the admittance protection enables a multistage protection principle. For example, one instance of EFPADM could be used for alarming to detect faults with a high fault resistance using a relatively low value for the *Voltage start value* setting. Another instance of EFPADM could then be set to trip with a lower sensitivity by selecting a higher value of the *Voltage start value* setting than in the alarming instance (stage).

To apply the admittance-based earth-fault protection, at least the following network data are required:

- System earthing method
- Maximum value for  $U_0$  during the healthy state
- Maximum earth-fault current of the protected feeder when the fault resistance  $R_f$  is zero ohm
- Maximum uncompensated earth-fault current of the system ( $R_f = 0 \Omega$ )
- Rated current of the parallel resistor of the coil (active current forcing scheme) in the case of a compensated neutral network
- Rated current of the neutral earthing resistor in the case of a high-resistance earthed system
- Knowledge of the magnitude of  $U_0$  as a function of the fault resistance to verify the sensitivity of the protection in terms of fault resistance

*Figure 157* shows the influence of fault resistance on the residual voltage magnitude in unearthed and compensated networks. Such information should be available to verify the correct *Voltage start value* setting, which helps fulfill the requirements for the sensitivity of the protection in terms of fault resistance.

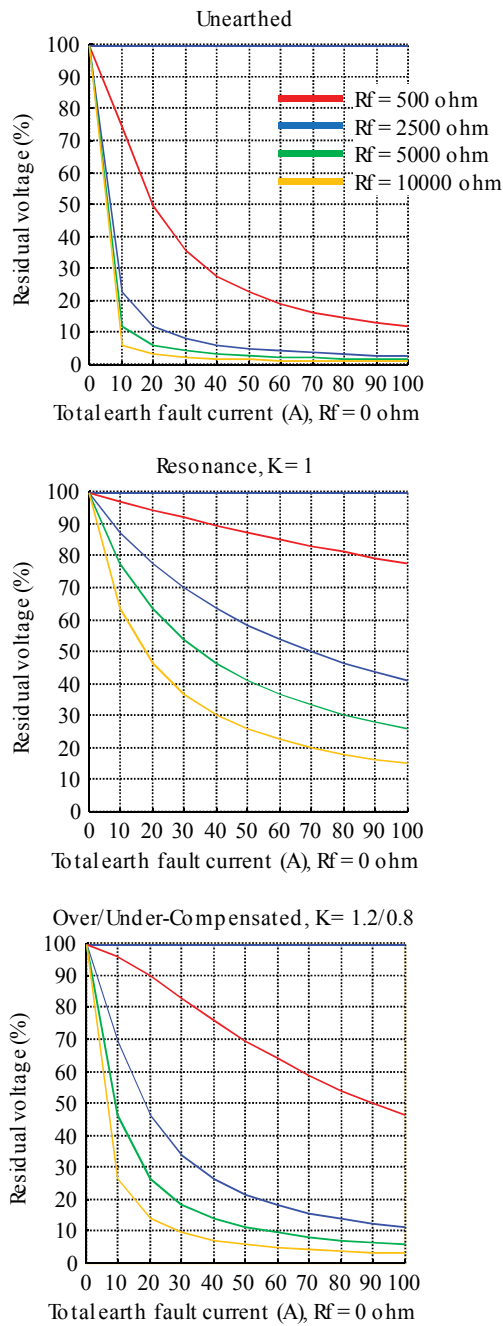


Figure 157: Influence of fault resistance on the residual voltage magnitude in 10 kV unearthed and compensated networks. The leakage resistance is assumed to be 30 times larger than the absolute value of the capacitive reactance of the network. Parallel resistor of the compensation coil is assumed to be disconnected.

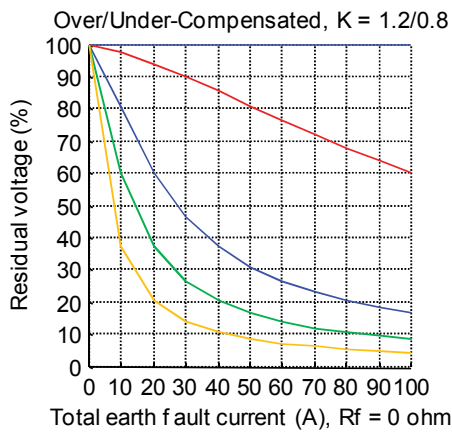
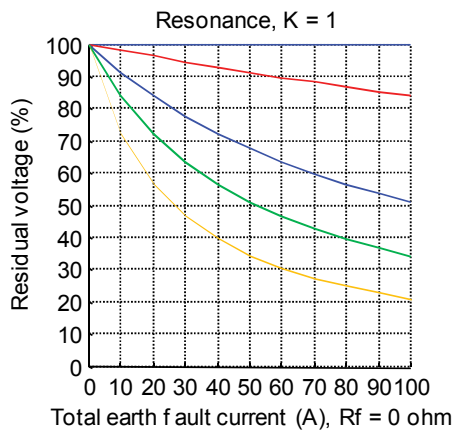
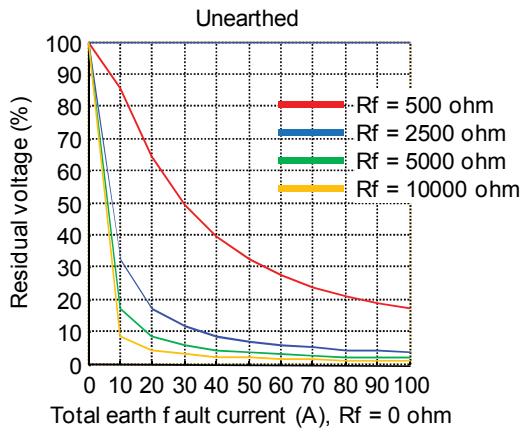
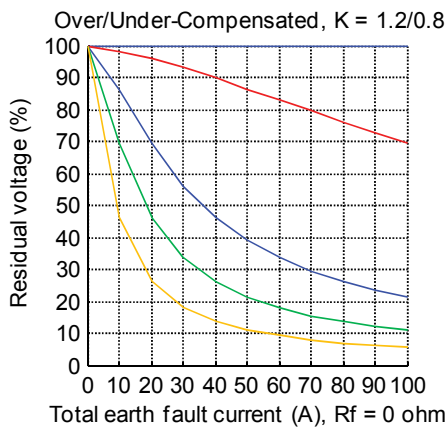
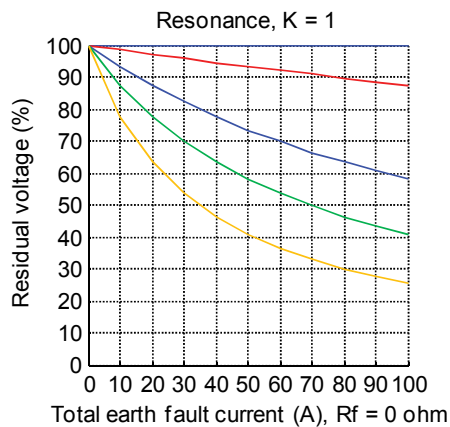
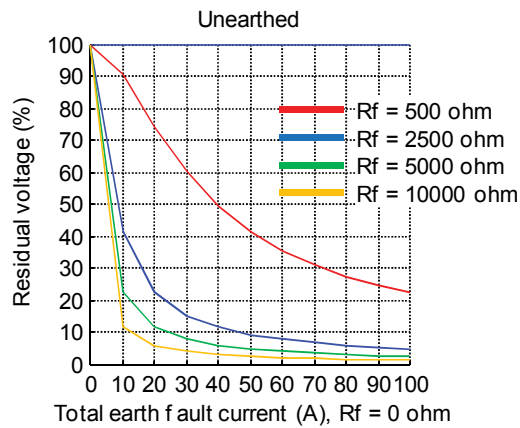


Figure 158: Influence of fault resistance on the residual voltage magnitude in 15 kV unearthed and compensated networks. The leakage resistance is assumed to be 30 times larger than the absolute value of the capacitive reactance of the network. Parallel resistor of the compensation coil is assumed to be disconnected.



*Figure 159: Influence of fault resistance on the residual voltage magnitude in 20 kV unearthed and compensated networks. The leakage resistance is assumed to be 30 times larger than the absolute value of the capacitive reactance of the network. Parallel resistor of the compensation coil is assumed to be disconnected.*

### Example

In a 15 kV, 50 Hz compensated network, the maximum value for  $U_0$  during the healthy state is  $10\% \times U_{ph}$ . Maximum earth-fault current of the system is 100 A. The maximum earth fault current of the protected feeder is 10 A ( $R_f = 0 \Omega$ ). The applied active current forcing scheme uses a 15 A resistor (at

15 kV), which is connected in parallel to the coil during the fault after a 1.0 second delay.

Solution: As a start condition for the admittance-based earth-fault protection, the internal residual overvoltage condition of EFPADM is used. The *Voltage start value* setting must be set above the maximum healthy-state  $U_0$  of  $10\% \times U_{ph}$  with a suitable margin.

$$\text{Voltage start value} = 0.15 \times U_n$$

According to [Figure 158](#), this selection ensures at least a sensitivity corresponding to a 2000 ohm fault resistance when the compensation degree varies between 80% and 120%. The greatest sensitivity is achieved when the compensation degree is close to full resonance.

An earth-fault current of 10 A can be converted into admittance.

$$\underline{Y}_{Fdtot} = \frac{10A}{15kV/\sqrt{3}} \approx j \cdot 1.15 \text{ mS}$$

(Equation 16)

A parallel resistor current of 15 A can be converted into admittance.

$$G_{cc} = \frac{15A}{15kV/\sqrt{3}} \approx 1.73 \text{ mS}$$

(Equation 17)

According to [Equation 5](#), during an outside fault EFPADM measures the following admittance:

$$\underline{Y}_O = -\underline{Y}_{Fdtot} \approx -j \cdot 1.15 \text{ mS}$$

(Equation 18)

According to [Equation 7](#), during an inside fault EFPADM measures the admittance after the connection of the parallel resistor:

$$\underline{Y}_O = \underline{Y}_{Bgtot} + \underline{Y}_{CC} \approx (1.73 + j \cdot B) \text{ mS}$$

(Equation 19)

Where the imaginary part of the admittance, B, depends on the tuning of the coil (compensation degree).

The admittance characteristic is selected to be the combined overconductance and oversusceptance characteristic ("Box"-characteristics) with four boundary lines:

*Operation mode* = "Go, Bo"

*Directional mode* = "Non-directional"

The admittance characteristic is set to cover the total admittance of the protected feeder with a proper margin, see [Figure 160](#). Different setting groups can be used to allow adaptation of protection settings to different feeder and network configurations.

### Conductance forward

This setting should be set based on the parallel resistor value of the coil. It must be set to a lower value than the conductance of the parallel resistor, in order to enable dependable operation. The selected value should move the boundary line from origin to include some margin for the admittance operation point due to CT/VT-errors, when fault is located outside the feeder.

*Conductance forward:*  $15 \text{ A}/(15 \text{ kV}/\sqrt{3}) * 0.2 = +0.35 \text{ mS}$  corresponding to 3.0 A (at 15 kV). The selected value provides margin considering also the effect of CT/VT-errors in case of outside faults.

In case of smaller rated value of the parallel resistor, for example, 5 A (at 15 kV), the recommended security margin should be larger, for example 0.7, so that sufficient margin for CT/VT-errors can be achieved.

### Susceptance forward

By default, this setting should be based on the minimum operate current of 1 A.

*Susceptance forward:*  $1 \text{ A}/(15 \text{ kV}/\sqrt{3}) = +0.1 \text{ mS}$

### Susceptance reverse

This setting should be set based on the value of the maximum earth-fault current produced by the feeder (considering possible feeder topology changes) with a security margin. This ensures that the admittance operating point stays inside the "Box"-characteristics during outside fault. The recommended security margin should not be lower than 1.5.

*Susceptance reverse:*  $-(10 \text{ A} * 1.5)/(15 \text{ kV}/\sqrt{3}) = -1.73 \text{ mS}$

### Conductance reverse

This setting is used to complete the non-directional characteristics by closing the "Box"-characteristic. In order to keep the shape of the characteristic reasonable and to allow sufficient margin for the admittance operating point during outside fault, it is recommended to use the same value as for setting Susceptance reverse.

*Conductance reverse = -1.73 mS*

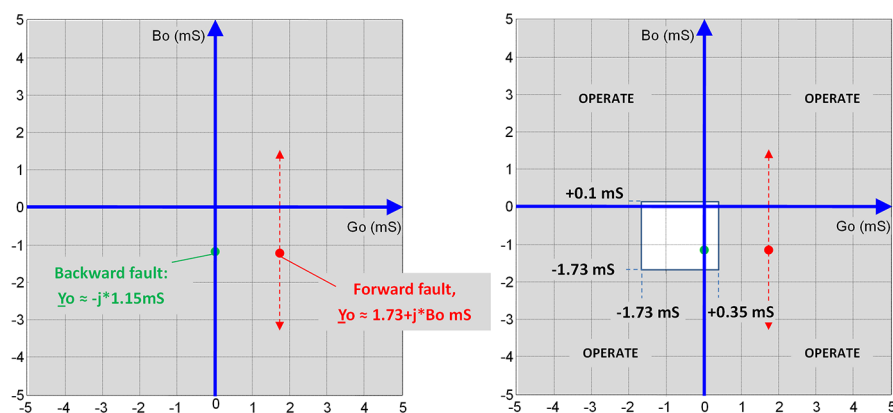


Figure 160: Admittances of the example

### 3.2.4.7 Signals

#### EFPADM Input signals

**Table 345: EFPADM Input signals**

| Name    | Type    | Default | Description   |
|---------|---------|---------|---|
| Io      | SIGNAL  | 0       | Residual current  |
| Uo      | SIGNAL  | 0       | Residual voltage  |
| BLOCK   | BOOLEAN | 0=False | Block signal for activating the blocking mode             |
| RELEASE | BOOLEAN | 0=False | External trigger to release neutral admittance protection |

#### EFPADM Output signals

**Table 346: EFPADM Output signals**

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

### 3.2.4.8 Settings

#### EFPADM Settings

**Table 347: EFPADM Group settings (Basic)**

| Parameter           | Values (Range)   | Unit | Step | Default   | Description         |
|---------------------|--|------|------|-----------|---------------------|
| Voltage start value | 0.01...2.00  | xUn  | 0.01 | 0.15      | Voltage start value |
| Directional mode    | 1=Non-directional<br>2=Forward<br>3=Reverse              |      |      | 2=Forward | Directional mode    |
| Operation mode      | 1=Yo<br>2=Go<br>3=Bo<br>4=Yo, Go<br>5=Yo, Bo<br>6=Go, Bo |      |      | 1=Yo      | Operation criteria  |

*Table continues on the next page*



| Parameter           | Values (Range)   | Unit | Step | Default | Description                                |
|---------------------|------------------|------|------|---------|--|
|                     | 7=Yo, Go, Bo     |      |      |         |  |
| Operate delay time  | 60...200000      | ms   | 10   | 60      | Operate delay time                         |
| Circle radius       | 0.05...500.00    | mS   | 0.01 | 1.00    | Admittance circle radius                   |
| Circle conductance  | -500.00...500.00 | mS   | 0.01 | 0.00    | Admittance circle mid-point, conductance   |
| Circle susceptance  | -500.00...500.00 | mS   | 0.01 | 0.00    | Admittance circle mid-point, susceptance   |
| Conductance forward | -500.00...500.00 | mS   | 0.01 | 1.00    | Conductance threshold in forward direction |
| Conductance reverse | -500.00...500.00 | mS   | 0.01 | -1.00   | Conductance threshold in reverse direction |
| Susceptance forward | -500.00...500.00 | mS   | 0.01 | 1.00    | Susceptance threshold in forward direction |
| Susceptance reverse | -500.00...500.00 | mS   | 0.01 | -1.00   | Susceptance threshold in reverse direction |

Table 348: EFPADM Group settings (Advanced)

| Parameter            | Values (Range) | Unit | Step | Default | Description                             |
|----------------------|----------------|------|------|---------|---|
| Conductance tilt Ang | -30...30       | deg  | 1    | 0       | Tilt angle of conductance boundary line |
| Susceptance tilt Ang | -30...30       | deg  | 1    | 0       | Tilt angle of susceptance boundary line |

Table 349: EFPADM Non group settings (Basic)

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on           |      |      | 1=on    | Operation Off / On |

| Parameter | Values (Range) | Unit | Step | Default | Description |
|-----------|----------------|------|------|---------|-------------|
|           | 5=off          |      |      |         |             |

Table 350: EFPADM Non group settings (Advanced)

| Parameter           | Values (Range)      | Unit | Step | Default  | Description                 |
|---------------------|---------------------|------|------|----------|-----------------------------|
| Admittance Clc mode | 1=Normal<br>2=Delta |      |      | 1=Normal | Admittance calculation mode |
| Reset delay time    | 0...60000           | ms   | 1    | 20       | Reset delay time            |
| Pol reversal        | 0=False<br>1=True   |      |      |          | Rotate polarizing quantity  |
| Min operate current | 0.01...1.00         | xIn  | 0.01 | 0.01     | Minimum operating current   |
| Min operate voltage | 0.01...1.00         | xUn  | 0.01 | 0.01     | Minimum operating voltage   |

### 3.2.4.9

## Monitored data

### EFPADM Monitored data

Table 351: EFPADM Monitored data

| Name      | Type    | Values (Range)                                 | Unit | Description                                     |
|-----------|---------|--|------|---|
| START_DUR | FLOAT32 | 0.00...100.00                                  | %    | Ratio of start time / operate time              |
| FAULT_DIR | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Detected fault direction                        |
| COND_RES  | FLOAT32 | -1000.00...1000.0<br>0                         | mS   | Real part of calculated neutral admittance      |
| SUS_RES   | FLOAT32 | -1000.00...1000.0<br>0                         | mS   | Imaginary part of calculated neutral admittance |
| EFPADM    | Enum    | 1=on<br>2=blocked                              |      | Status  |

| Name | Type | Values (Range)                    | Unit | Description |
|------|------|-----------------------------------|------|-------------|
|      |      | 3=test<br>4=test/blocked<br>5=off |      |             |

### 3.2.4.10 Technical data

Table 352: EFPADM Technical data

| Characteristic                   | Value  |         |         |
|----------------------------------|--|---------|---------|
| Operation accuracy <sup>36</sup> | At the frequency $f = f_n$                                   |         |         |
|                                  | ±1.0% or ±0.01 mS<br>(In range of 0.5...100 mS)              |         |         |
| Start time <sup>37</sup>         | Minimum  | Typical | Maximum |
|                                  | 56 ms  | 60 ms   | 64 ms   |
| Reset time                       | 40 ms  |         |         |
| Operate time accuracy            | ±1.0% of the set value of ±20 ms                             |         |         |
| Suppression of harmonics         | -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$ |         |         |

### 3.2.4.11 Technical revision history

Table 353: EFPADM Technical revision history

| Technical revision | Change   |
|--------------------|--|
| B                  | Internal improvement.  |
| C                  | <i>Voltage start value</i> setting range and default value change. |
| D                  | Internal improvement.  |
| E                  | Internal improvement.  |
| F                  | Modified for SSC600  |

## 3.2.5 Wattmetric-based earth-fault protection WPWDE

<sup>36</sup>  $U_0 = 1.0 \times U_n$

<sup>37</sup> Includes the delay of the signal output contact, results based on statistical distribution of 1000 measurements

### 3.2.5.1 Identification

| Function description                    | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|--------------------------|--------------------------|-------------------------------|
| Wattmetric-based earth-fault protection | WPWDE                    | Po> ->                   | 32N                           |

### 3.2.5.2 Function block

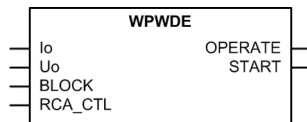


Figure 161: Function block

### 3.2.5.3 Functionality

The wattmetric-based earth-fault protection function WPWDE can be used to detect earth faults in unearthed networks, compensated networks (Petersen coil-earthed networks) or networks with a high-impedance earthing. It can be used as an alternative solution to the traditional residual current-based earth-fault protection functions, for example, the IoCos mode in the directional earth-fault protection function DEFxPDEF.

WPWDE measures the earth-fault power  $3U_oI_o\cos\phi$  and gives an operating signal when the residual current  $I_o$ , residual voltage  $U_o$  and the earth-fault power exceed the set limits and the angle ( $\phi$ ) between the residual current and the residual voltage is inside the set operating sector, that is, forward or backward sector. The operating time characteristic can be selected to be either definite time (DT) or a special wattmetric-type inverse definite minimum type (wattmetric type IDMT).

The wattmetric-based earth-fault protection is very sensitive to current transformer errors and it is recommended that a core balance CT is used for measuring the residual current.

WPWDE contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

### 3.2.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".



For WPWDE, certain notations and definitions are used.

Residual voltage  $U_o = (U_A+U_B+U_C)/3 = U_0$ , where  $U_0$  = zero-sequence voltage

Residual current  $I_o = -(I_A+I_B+I_C) = 3 \times -I_0$ , where  $I_0$  = zero-sequence current

The minus sign (-) is needed to match the polarity of calculated and measured residual currents.

The operation of WPWDE can be described with a module diagram. All the modules in the diagram are explained in the next sections.

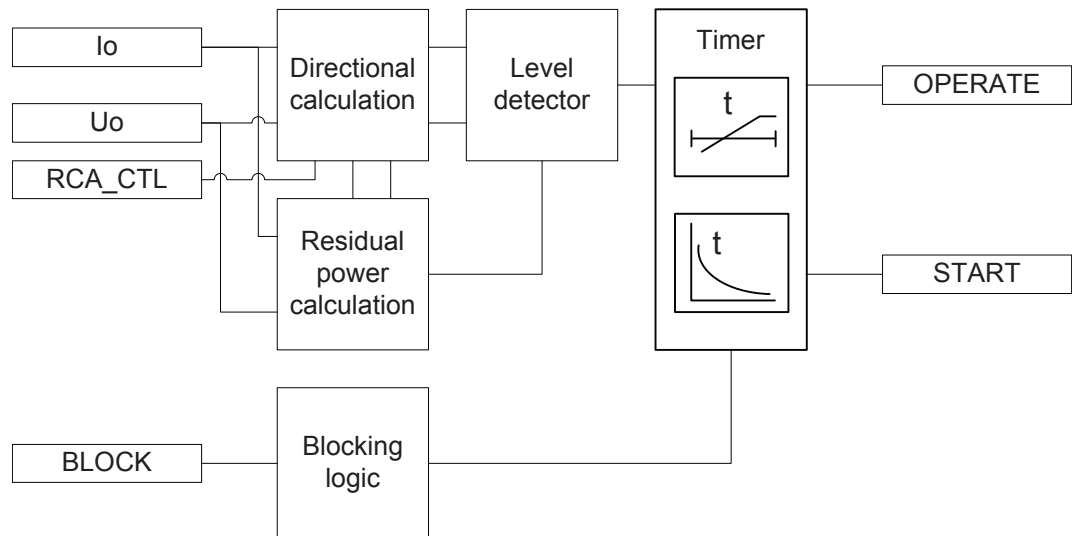


Figure 162: Function module diagram

### Directional calculation

The Directional calculation module monitors the angle between the operating quantity (residual current  $I_o$ ) and polarizing quantity (residual voltage  $U_o$ ). The operating quantity (residual current) can be selected within the ACT configuration. The options are "Measured  $I_o$ " and "Calculated  $I_o$ ". Measured  $I_o$  is selected when  $I_{RES}$  input of the corresponding SMVRECEIVE function is connected to  $I_o$  input of the function. Similarly Calculated  $I_o$  is selected, when  $I_{RES\_CALC}$  input is connected. CT ratios need to be defined in the parameters of the SMVRECEIVE function. The polarizing quantity can be selected with the setting *Pol signal Sel*. The selectable options are "Measured  $U_o$ " and "Calculated  $U_o$ ". When the angle between operating quantity and polarizing quantity after considering the *Characteristic angle* setting is in the operation sector, the module sends an enabling signal to Level detector. The directional operation is selected with the *Directional mode* setting. Either the "Forward" or "Reverse" operation mode can be selected. The direction of fault is calculated based on the phase angle difference between the operating quantity  $I_o$  and polarizing quantity  $U_o$ , and the value (ANGLE) is available in the monitored data view.

In the phasor diagrams representing the operation of WPWDE, the polarity of the polarizing quantity (residual voltage  $U_o$ ) is reversed. Reversing is done by switching the polarity of the residual current measuring channel (See the connection diagram in the application manual).

If the angle difference lies between  $-90^\circ$  to  $0^\circ$  or  $0^\circ$  to  $+90^\circ$ , a forward-direction fault is considered. If the phase angle difference lies within  $-90^\circ$  to  $-180^\circ$  or  $+90^\circ$  to  $+180^\circ$ , a reverse-direction fault is detected. Thus, the normal width of a sector is  $180^\circ$ .

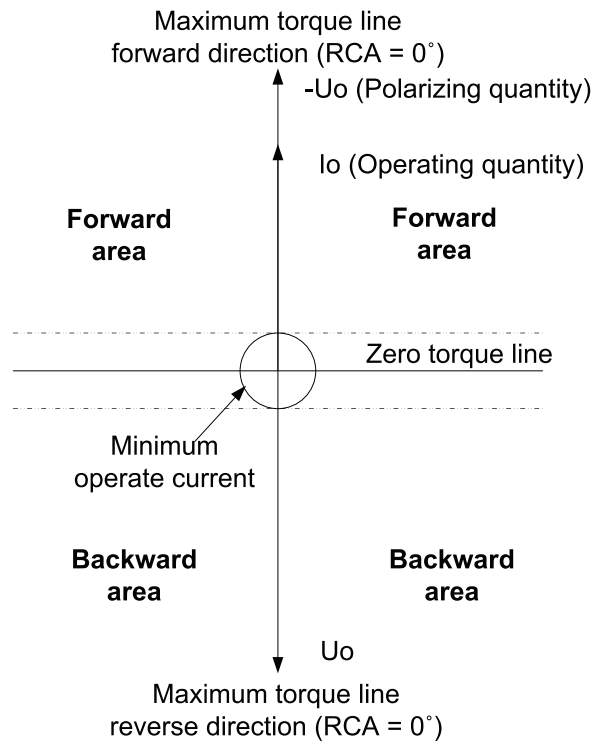


Figure 163: Definition of the relay characteristic angle

The phase angle difference is calculated based on the *Characteristic angle* setting (also known as Relay Characteristic Angle (RCA) or Relay Base Angle or Maximum Torque Angle (MTA)). The *Characteristic angle* setting is done based on the method of earthing employed in the network. For example, in case of an unearthed network, the *Characteristic angle* setting is set to  $-90^\circ$ , and in case of a compensated network, the *Characteristic angle* setting is set to  $0^\circ$ . In general, *Characteristic angle* is selected so that it is close to the expected fault angle value, which results in maximum sensitivity. *Characteristic angle* can be set anywhere between  $-179^\circ$  to  $+180^\circ$ . Thus, the effective phase angle ( $\phi$ ) for calculating the residual power considering characteristic angle is according to the equation.

$$\phi = (\angle(-U_o) - \angle I_o - \text{Characteristic angle})$$

In addition, the characteristic angle can be changed via the control signal `RCA_CTL`. The `RCA_CTL` input is used in the compensated networks where the compensation coil sometimes is temporarily disconnected. When the coil is disconnected, the compensated network becomes isolated and the *Characteristic angle* setting must be changed. This can be done automatically with the `RCA_CTL` input, which results in the addition of  $-90^\circ$  in the *Characteristic angle* setting.

The value (`ANGLE_RCA`) is available in the monitored data view.

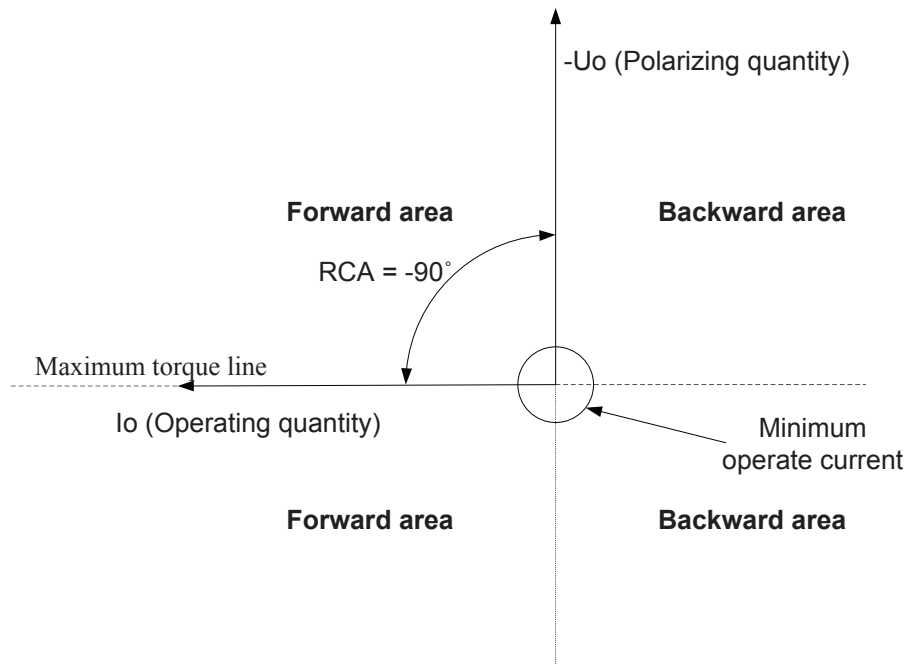


Figure 164: Definition of relay characteristic angle,  $RCA = -90^\circ$  in an isolated network



Characteristic angle should be set to a positive value if the operating signal lags the polarizing signal and to a negative value if the operating signal leads the polarizing signal.

| Type of network     | Recommended characteristic angle |
|---------------------|----------------------------------|
| Compensated network | 0°                               |
| Unearthed network   | -90°                             |



In unearthed networks, when the characteristic angle is  $-90^\circ$ , the measured residual power is reactive (varmetric power).

The fault direction is also indicated `FAULT_DIR` (available in the monitored data view), which indicates 0 if a fault is not detected, 1 for faults in the forward direction and 2 for faults in the backward direction.

The direction of the fault is detected only when the correct angle calculation can be made. If the magnitude of the operating quantity or polarizing quantity is not high enough, the direction calculation is not reliable. Hence, the magnitude of the operating quantity is compared to the *Min operate current* setting and the magnitude of the polarizing quantity is compared to *Min operate voltage*, and if both the operating quantity and polarizing quantity are higher than their respective limit, a valid angle is calculated and the residual power calculation module is enabled.

The *Correction angle* setting can be used to improve the selectivity when there are inaccuracies due to the measurement transformer. The setting decreases the operation sector. The *Correction angle* setting should be done carefully as the phase angle error of the measurement transformer varies with the connected burden as well as with the magnitude of the actual primary current that is being measured. An example of how *Correction angle* alters the operating region is as shown:

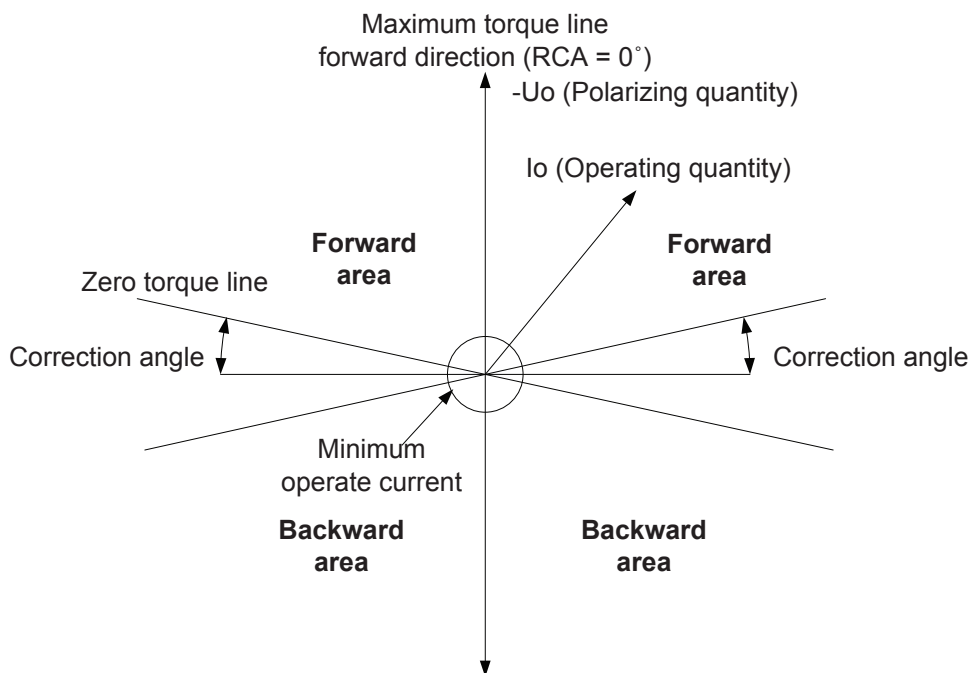


Figure 165: Definition of correction angle



The polarity of the polarizing quantity can be changed (rotated by 180°) by setting *Pol reversal* to "True" or by switching the polarity of the residual voltage measurement wires.

**Residual power calculation**

The Residual power calculation module calculates the magnitude of residual power  $3U_oI_o\cos\phi$ . Angle  $\phi$  is the angle between the operating quantity and polarizing quantity, compensated with a characteristic angle. The angle value is received from the Directional calculation module. The Directional calculation module enables the residual power calculation only if the minimum signal levels for both operating quantity and polarizing quantity are exceeded. However, if the angle calculation is not valid, the calculated residual power is zero. Residual power (RES\_POWER) is calculated continuously and it is available in the monitored data view. The power is given in relation to nominal power calculated as  $P_n = U_n \times I_n$ , where  $U_n$  and  $I_n$  are obtained from the entered voltage transformer and current transformer ratios entered, and depend on the SMVRECEIVE settings.

**Level detector**

Level detector compares the magnitudes of the measured operating quantity (residual current  $I_o$ ), polarizing quantity (residual voltage  $U_o$ ) and calculated residual power to the set *Current start value* ( $\times I_n$ ), *Voltage start value* ( $\times U_n$ ) and *Power start value* ( $\times P_n$ ) respectively. When all three quantities exceed the limits, Level detector enables the Timer module.

When calculating the setting values for Level detector, it must be considered that the nominal values for current, voltage and power depend on whether the residual quantities are measured from a dedicated measurement channel or calculated from phase quantities, as defined in the SMVRECEIVE settings.

For residual current  $I_o$ , if "Measured  $I_o$ " is selected, the nominal values for primary and secondary are obtained from the current transformer ratio entered for residual



current channel in SMVRECEIVE function settings. If "Calculated Io" is selected, the nominal values for primary and secondary are obtained from the current transformer ratio entered for phase current channels in SMVRECEIVE function settings.

For residual voltage Uo, if "Measured Uo" is selected, the nominal values for primary and secondary are obtained from the voltage transformer ratio entered for residual voltage channel in SMVRECEIVE function settings. If "Calculated Uo" is selected, the nominal values for primary and secondary are obtained from the voltage transformer ratio entered for phase voltage channels in SMVRECEIVE function settings.



Calculated Uo requires that all three phase-to-earth voltages are connected to the IED. Uo cannot be calculated from the phase-to-phase voltages.

As nominal power is the result of the multiplication of the nominal current and the nominal voltage  $P_n = U_n \times I_n$ , the calculation of the setting value for Power start value ( $\times P_n$ ) depends on whether Io and Uo are measured or calculated from the phase quantities.

**Table 354: Measured and calculated Io and Uo**

|               | Measured Io                        | Calculated Io                     |
|---------------|------------------------------------|-----------------------------------|
| Measured Uo   | $P_n = (U_o, VT) \times (I_o, CT)$ | $P_n = (U_o, VT) \times (3I, CT)$ |
| Calculated Uo | $P_n = (3U, VT) \times (I_o, CT)$  | $P_n = (3U, VT) \times (3I, CT)$  |

**Example 1.** Io is measured with cable core CT (100/1A) and Uo is measured from open delta-connected VTs (20/sqrt(3) kV:100/sqrt(3) V:100/3 V). In this case, "Measured Io" and "Measured Uo" are selected. The nominal values for residual current and residual voltage are obtained from CT and VT ratios.

Residual current Io: SMVRECEIVE function settings: 100 A:1 A

Residual voltage Uo: SMVRECEIVE function settings: 11.547 kV:100 V

*Residual Current start value* of  $1.0 \times I_n$  corresponds then  $1.0 \times 100 \text{ A} = 100 \text{ A}$  in primary

*Residual Voltage start value* of  $1.0 \times U_n$  corresponds then  $1.0 \times 11.547 \text{ kV} = 11.547 \text{ kV}$  in primary

*Residual Power start value* of  $1.0 \times P_n$  corresponds then  $1.0 \times 11.547 \text{ kV} \times 100 \text{ A} = 1154.7 \text{ kW}$  in primary

**Example 2.** Both Io and Uo are calculated from phase quantities. Phase CT-ratio is 100:1 A and Phase VT-ratio 20/sqrt(3) kV:100/sqrt(3) V. In this case "Calculated Io" and "Calculated Uo" are selected. The nominal values for residual current and residual voltage are obtained from CT and VT ratios entered in:

Residual current Io: SMVRECEIVE function settings: 100 A:1 A

Residual voltage Uo: SMVRECEIVE function settings: 20.000 kV:100 V

*Residual Current start value* of  $1.0 \times I_n$  corresponds then  $1.0 \times 100 \text{ A} = 100 \text{ A}$  in primary

*Residual Voltage start value* of  $1.0 \times U_n$  corresponds then  $1.0 \times 20.000 \text{ kV} = 20.000 \text{ kV}$  in primary

*Residual Power start value* of  $1.0 \times P_n$  corresponds then  $1.0 \times 20.000 \text{ kV} \times 100 \text{ A} = 2000\text{kW}$  in primary



If "Calculated  $U_0$ " is selected for the SMVRECEIVE setting, the nominal value for residual voltage  $U_n$  is always phase-to-phase voltage. Thus, the valid maximum setting for residual *Voltage start value* is  $0.577 \times U_n$ , which corresponds to full phase-to-earth voltage in primary.

### Timer

Once activated, Timer activates the `START` output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or wattmetric IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the `OPERATE` output is activated. If a drop-off situation happens, that is, a fault suddenly disappears before the operating delay is exceeded, the timer reset state is activated. The reset time is identical for both DT or wattmeter IDMT. The reset time depends on the *Reset delay time* setting.

Timer calculates the start duration value `START_DUR`, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration > System > Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the `OPERATE` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block `OPERATE` output" mode, the function operates normally but the `OPERATE` output is not activated.

## 3.2.5.5

### Timer characteristics

In the wattmetric IDMT mode, the `OPERATE` output is activated based on the timer characteristics:

$$t[s] = \frac{k * P_{ref}}{P_{cal}}$$

|           |                                     |
|-----------|-------------------------------------|
| $t[s]$    | operation time in seconds           |
| $k$       | set value of <i>Time multiplier</i> |
| $P_{ref}$ | set value of <i>Reference power</i> |
| $P_{cal}$ | calculated residual power           |

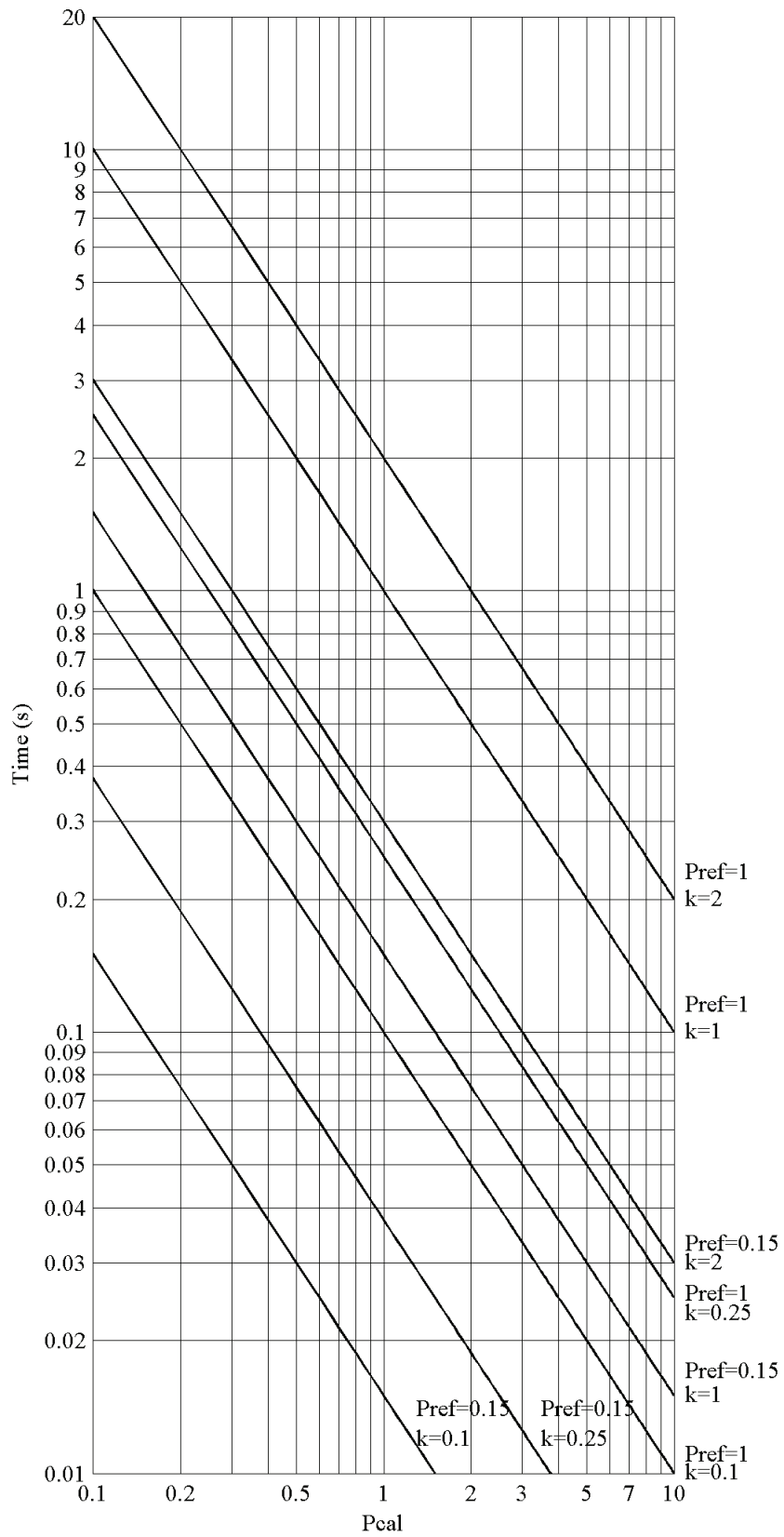


Figure 166: Operation time curves for wattmetric IDMT for Sref set at 0.15 xPn

### 3.2.5.6 Measurement modes

The function operates on three alternative measurement modes: "RMS", "DFT" and "Peak-to-Peak". The measurement mode is selected with the *Measurement mode* setting.

### 3.2.5.7 Application

The wattmetric method is one of the commonly used directional methods for detecting the earth faults especially in compensated networks. The protection uses the residual power component  $3U_0I_0\cos\phi$  ( $\phi$  is the angle between the polarizing quantity and operating quantity compensated with a relay characteristic angle).

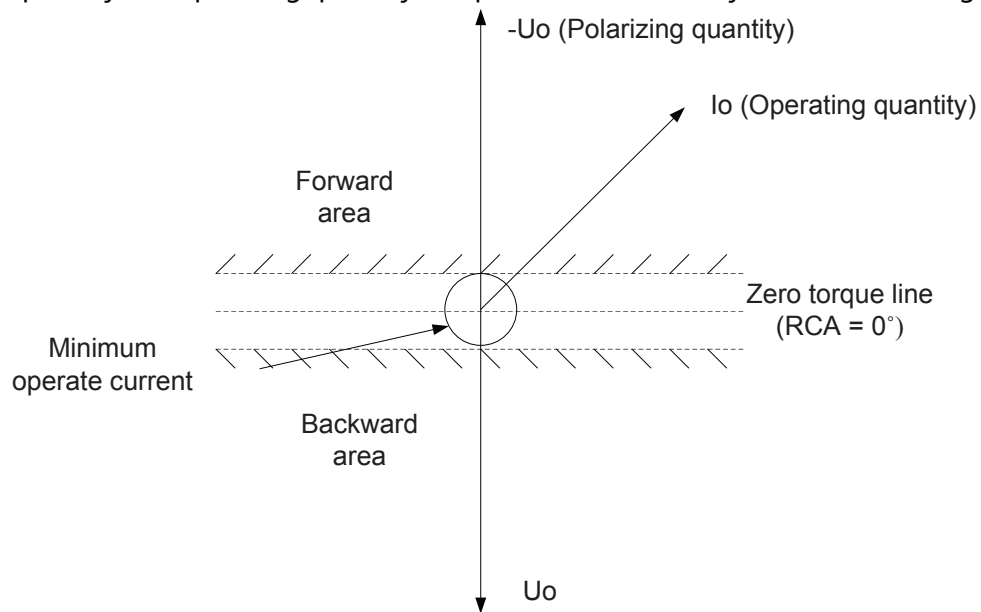


Figure 167: Characteristics of wattmetric protection

In a fully compensated radial network with two outgoing feeders, the earth-fault currents depend mostly on the system earth capacitances ( $C_0$ ) of the lines and the compensation coil ( $L$ ). If the coil is tuned exactly to the system capacitance, the fault current has only a resistive component. This is due to the resistances of the coil and distribution lines together with the system leakage resistances ( $R_0$ ). Often a resistor ( $R_L$ ) in parallel with the coil is used for increasing the fault current.

When a single phase-to-earth fault occurs, the capacitance of the faulty phase is bypassed and the system becomes unsymmetrical. The fault current is composed of the currents flowing through the earth capacitances of two healthy phases. The IED in the healthy feeder tracks only the capacitive current flowing through its earth capacitances. The capacitive current of the complete network (sum of all feeders) is compensated with the coil.

A typical network with the wattmetric protection is an undercompensated network where the coil current  $I_L = I_{C_{tot}} - I_{C_{fd}}$  ( $I_{C_{tot}}$  is the total earth-fault current of the network and  $I_{C_{fd}}$  is the earth-fault current of the healthy feeder).

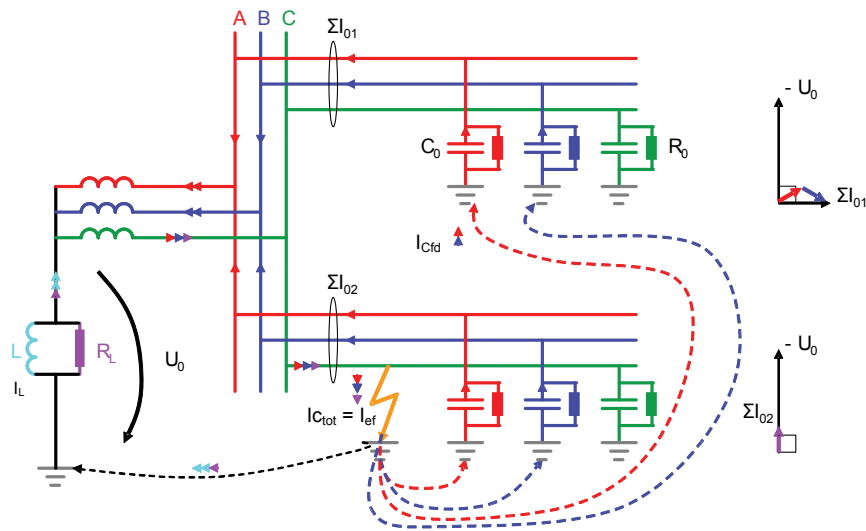


Figure 168: Typical radial compensated network employed with wattmetric protection

The wattmetric function is activated when the residual active power component exceeds the set limit. However, to ensure a selective operation it is also required that the residual current and residual voltage also exceed the set limit.

It is highly recommended that core balance current transformers are used for measuring  $I_0$  when using the wattmetric method. When a low transformation ratio is used, the current transformer can suffer accuracy problems and even a distorted secondary current waveform with some core balance current transformers. Therefore, to ensure a sufficient accuracy of the residual current measurement and consequently a better selectivity of the scheme, the core balance current transformer should preferably have a transformation ratio of at least 70:1. Lower transformation ratios such as 50:1 or 50:5 are not recommended, unless the phase displacement errors and current transformer amplitude are checked first.

It is not recommended to use the directional wattmetric protection in case of a ring or meshed system as the wattmetric requires a radial power flow to operate.

The relay characteristic angle needs to be set based on the system earthing. In an unearthed network, that is, when the network is only coupled to earth via the capacitances between the phase conductors and earth, the characteristic angle is chosen as  $-90^\circ$ .

In compensated networks, the capacitive fault current and inductive resonance coil current compensate each other, meaning that the fault current is mainly resistive and has zero phase shift compared to the residual voltage. In such networks, the characteristic angle is chosen as  $0^\circ$ . Often the magnitude of an active component is small and must be increased by means of a parallel resistor in a compensation coil. In networks where the neutral point is earthed through a low resistance, the characteristic angle is always  $0^\circ$ .

As the amplitude of the residual current is independent of the fault location, the selectivity of the earth-fault protection is achieved with time coordination.

The use of wattmetric protection gives a possibility to use the dedicated inverse definite minimum time characteristics. This is applicable in large high-impedance earthed networks with a large capacitive earth-fault current.

In a network employing a low-impedance earthed system, a medium-size neutral point resistor is used. Such a resistor gives a resistive earth-fault current component of about 200 - 400 A for an excessive earth fault. In such a system, the directional residual power protection gives better possibilities for selectivity enabled by the inverse time power characteristics.

### 3.2.5.8 Signals

#### WPWDE Input signals

Table 355: WPWDE Input signals

| Name    | Type    | Default | Description                                   |
|---------|---------|---------|---|
| Io      | SIGNAL  | 0       | Residual current                              |
| Uo      | SIGNAL  | 0       | Residual voltage                              |
| BLOCK   | BOOLEAN | 0=False | Block signal for activating the blocking mode |
| RCA_CTL | BOOLEAN | 0=False | Relay characteristic angle control            |

#### WPWDE Output signals

Table 356: WPWDE Output signals

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

### 3.2.5.9 Settings

#### WPWDE Settings

Table 357: WPWDE Group settings (Basic)

| Parameter           | Values (Range)         | Unit | Step  | Default   | Description   |
|---------------------|------------------------|------|-------|-----------|---|
| Directional mode    | 2=Forward<br>3=Reverse |      |       | 2=Forward | Directional mode  |
| Current start value | 0.010...5.000          | xIn  | 0.001 | 0.010     | Minimum operate residual current for deciding fault direction |

Table continues on the next page

| Parameter            | Values (Range)   | Unit | Step  | Default          | Description  |
|----------------------|--|------|-------|------------------|--|
| Voltage start value  | 0.010...1.000  | xUn  | 0.001 | 0.010            | Start value for residual voltage                             |
| Power start value    | 0.003...1.000  | xPn  | 0.001 | 0.003            | Start value for residual active power                        |
| Reference power      | 0.050...1.000  | xPn  | 0.001 | 0.150            | Reference value of residual power for Wattmetric IDMT curves |
| Characteristic angle | -179...180   | deg  | 1     | -90              | Characteristic angle   |
| Time multiplier      | 0.05...2.00  |      | 0.01  | 1.00             | Time multiplier for Wattmetric IDMT curves                   |
| Operating curve type | 5=ANSI Def. Time<br>15=IEC Def. Time<br>20=Wattmetric IDMT |      |       | 15=IEC Def. Time | Selection of time delay curve type                           |
| Operate delay time   | 60...200000  | ms   | 10    | 60               | Operate delay time for definite time                         |

**Table 358: WPWDE Non group settings (Basic)**

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

**Table 359: WPWDE Non group settings (Advanced)**

| Parameter        | Values (Range)                   | Unit | Step | Default | Description                           |
|------------------|----------------------------------|------|------|---------|---------------------------------------|
| Measurement mode | 1=RMS<br>2=DFT<br>3=Peak-to-Peak |      |      | 2=DFT   | Selects used current measurement mode |
| Correction angle | 0.0...10.0                       | deg  | 0.1  | 2.0     | Angle correction                      |

*Table continues on the next page*

| Parameter           | Values (Range)    | Unit | Step  | Default | Description                |
|---------------------|-------------------|------|-------|---------|----------------------------|
| Min operate current | 0.010...1.000     | xIn  | 0.001 | 0.010   | Minimum operating current  |
| Min operate voltage | 0.01...1.00       | xUn  | 0.01  | 0.01    | Minimum operating voltage  |
| Reset delay time    | 0...60000         | ms   | 1     | 20      | Reset delay time           |
| Pol reversal        | 0=False<br>1=True |      |       | 0=False | Rotate polarizing quantity |

### 3.2.5.10 Monitored data

#### WPWDE Monitored data

Table 360: WPWDE Monitored data

| Name      | Type    | Values (Range)                                 | Unit | Description  |
|-----------|---------|--|------|--|
| FAULT_DIR | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Detected fault direction                               |
| START_DUR | FLOAT32 | 0.00...100.00                                  | %    | Ratio of start time / operate time                     |
| DIRECTION | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Direction information                                  |
| ANGLE     | FLOAT32 | -180.00...180.00                               | deg  | Angle between polarizing and operating quantity        |
| ANGLE_RCA | FLOAT32 | -180.00...180.00                               | deg  | Angle between operating angle and characteristic angle |
| RES_POWER | FLOAT32 | -160.000...160.00<br>0                         | xPn  | Calculated residual active power                       |
| WPWDE     | Enum    | 1=on<br>2=blocked                              |      | Status   |



| Name | Type | Values (Range)                    | Unit | Description |
|------|------|-----------------------------------|------|-------------|
|      |      | 3=test<br>4=test/blocked<br>5=off |      |             |

### 3.2.5.11 Technical data

Table 361: WPWDE Technical data

| Characteristic                              | Value  |
|---|--|
| Operation accuracy                          | Depending on the frequency of the measured current: $f_n \pm 2$ Hz<br>Current and voltage:<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$<br>Power:<br>$\pm 3\%$ of the set value or $\pm 0.002 \times P_n$ |
| Start time <sup>3839</sup>                  | Typically 63 ms  |
| Reset time                                  | Typically 40 ms  |
| Reset ratio                                 | Typically 0.96   |
| Operate time accuracy in definite time mode | $\pm 1.0\%$ of the set value or $\pm 20$ ms  |
| Operate time accuracy in IDMT mode          | $\pm 5.0\%$ of the set value or $\pm 20$ ms  |
| Suppression of harmonics                    | -50 dB at $f = n \times f_n$ , where $n = 2,3,4,5,\dots$   |

### 3.2.5.12 Technical revision history

Table 362: WPWDE Technical revision history

| Technical revision | Change   |
|--------------------|--|
| B                  | Equation for residual power calculation has been updated: $P_o = 3U_o I_o \cos\phi$ . The previous equation was: $P_o = U_o I_o \cos\phi$ . The change has an effect on the Power start value definition.<br><br>The previous equation is in use in the 615 Ver.4.0 with SW revision 4.0 and 615 Ver.4.0 FP1 with SW revision 4.1. All newer versions of 615 series have the updated equation. |
| C                  | Internal improvement.  |
| D                  | Modified for SSC600  |

<sup>38</sup>  $I_o$  varied during the test,  $U_o = 1.0 \times U_n =$  phase to earth voltage during earth fault in compensated or un-earthed network, the residual power value before fault = 0.0 pu,  $f_n = 50$  Hz, results based on statistical distribution of 1000 measurements

<sup>39</sup> Includes the delay of the signal output contact

### 3.2.6 Multifrequency admittance-based earth-fault protection MFADPSDE

#### 3.2.6.1 Identification

| Description  | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--|--------------------------|--------------------------|-------------------------------|
| Multifrequency admittance-based earth-fault protection | MFADPSDE                 | Io> ->Y                  | 67YN                          |

#### 3.2.6.2 Function block

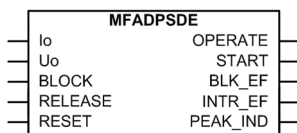


Figure 169: Function block

#### 3.2.6.3 Functionality

The multifrequency admittance-based earth-fault protection function MFADPSDE provides selective directional earth-fault protection for high-impedance earthed networks, that is, for compensated, unearthed and high resistance earthed systems. It can be applied for the earth-fault protection of overhead lines and underground cables.

The operation of MFADPSDE is based on multifrequency neutral admittance measurement, utilizing cumulative phasor summing technique. This concept provides extremely secure, dependable and selective earth-fault protection also in cases where the residual quantities are highly distorted and contain non-fundamental frequency components.

The sensitivity that can be achieved is comparable with traditional fundamental frequency based methods such as IoCos/IoSIn (DEFxPTOC), Watt/Varmetric (WPWDE) and neutral admittance (EFPADM).

MFADPSDE is capable of detecting faults with dominantly fundamental frequency content as well as transient, intermittent and restriking earth faults. MFADPSDE can be used as an alternative solution to transient or intermittent function INTRPTEF.

MFADPSDE supports fault direction indication both in operate and non-operate direction, which may be utilized during fault location process. The inbuilt transient detector can be used to identify restriking or intermittent earth faults, and discriminate them from permanent or continuous earth faults.

The operation characteristic is defined by a tilted operation sector, which is universally valid for unearthed and compensated networks.

The operating time characteristic is according to the definite time (DT).

MFADPSDE contains a blocking functionality to block function outputs, timers or the function itself.

### 3.2.6.4 Operation principle

The *Operation* setting is used to enable or disable the function. The corresponding parameter values are "On" and "Off".

The operation of MFADPSDE can be described using a module diagram. All the modules in the diagram are explained in the following sections.

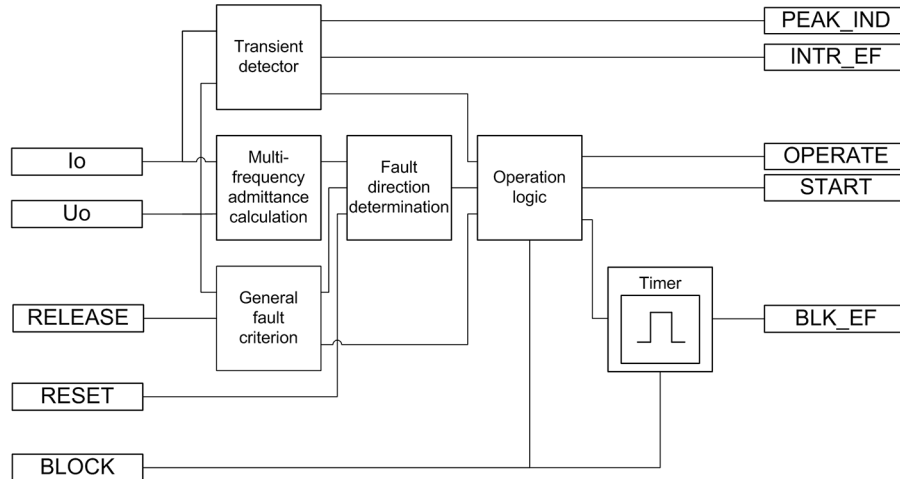


Figure 170: Functional module diagram

#### General fault criterion

The General fault criterion (GFC) module monitors the presence of earth fault in the network and it is based on the value of the fundamental frequency zero-sequence voltage defined as the vector sum of fundamental frequency phase voltage phasors divided by three.

$$\overline{U}_0^1 = (\overline{U}_A^1 + \overline{U}_B^1 + \overline{U}_C^1) / 3$$

When the magnitude of  $\overline{U}_0^1$  exceeds setting *Voltage start value*, an earth fault is detected. The GFC module reports the exceeded value to the Fault direction determination module and Operation logic. The reporting is referenced as General Fault Criterion release.

The setting *Voltage start value* defines the basic sensitivity of the MFADPSDE function. To avoid unselective start or operation, *Voltage start value* must always be set to a value which exceeds the maximum healthy-state zero-sequence voltage value, taking into consideration of possible network topology changes, compensation coil and parallel resistor switching status and compensation degree variations.

As an alternative for internal residual zero-sequence overvoltage based start-condition, MFADPSDE function can also be externally released by utilizing the RELEASE input. In this case, the external release signal overrides the *Voltage start value* setting and sets the internal limit to minimum value.

#### Multi-frequency admittance calculation

Multi-frequency admittance calculation module calculates neutral admittances utilising fundamental frequency and the 2nd, 3rd, 5th, 7th and 9th harmonic

components of residual current and zero-sequence voltage. The following admittances are calculated, if the magnitude of a particular harmonic in residual current and zero-sequence voltage are measurable by the IED.

Fundamental frequency admittance (conductance and susceptance)

$$\overline{Y}_0^1 = \frac{3 \cdot \overline{I}_0^1}{-\overline{U}_0^1} = G_o^1 + j \cdot B_o^1$$

$\overline{Y}_0^1$  The fundamental frequency neutral admittance phasor.

$\overline{I}_0^1$  The fundamental frequency zero-sequence current phasor  
(=  $(\overline{I}_A^1 + \overline{I}_B^1 + \overline{I}_C^1) / 3$ )

$\overline{U}_0^1$  The fundamental frequency zero-sequence voltage phasor  
(=  $(\overline{U}_A^1 + \overline{U}_B^1 + \overline{U}_C^1) / 3$ )  $\text{Re}(\overline{Y}_0^1)$

$G_o^1$  The fundamental frequency conductance,  $\text{Re}(\overline{Y}_0^1)$

$B_o^1$  The fundamental frequency susceptance,  $\text{Im}(\overline{Y}_0^1)$

Harmonic susceptance

$$\text{Im}[\overline{Y}_0^n] = \text{Im}\left[\frac{3 \cdot \overline{I}_0^n}{-\overline{U}_0^n}\right] = j \cdot B_o^n$$

where n = 2, 3, 5, 7 and 9

$\overline{Y}_0^n$  The nth harmonic frequency neutral admittance phasor.

$\overline{I}_0^n$  The nth harmonic frequency zero-sequence current phasor.

$\overline{U}_0^n$  The nth harmonic frequency zero-sequence voltage phasor.

$B_o^n$  The nth harmonic frequency susceptance,  $\text{Im}(\overline{Y}_0^n)$

For fault direction determination, the fundamental frequency admittance and harmonic susceptances are summed together in phasor format. The result is the sum admittance phasor defined as below.

$$\overline{Y}_{osum} = \text{Re}[\overline{Y}_0^1] + j \cdot \text{Im}\left[\overline{Y}_0^1 + \sum_{n=2}^9 \overline{Y}_0^n\right] = G_o^1 + j \cdot B_{osum}$$



The polarity of the polarizing quantity (residual voltage) can be changed (rotated by 180 degrees) by setting the *Pol reversal* parameter to "True" or by switching the polarity of the residual voltage measurement wires.

### Fault direction determination

If an earth fault is detected by the GFC module, the fault direction is evaluated

based on the calculated sum admittance phasor  $\bar{Y}_{osum}$  obtained from the Multi-frequency admittance calculation module. To obtain dependable and secure fault direction determination regardless of the fault type (transient, intermittent, restriking, permanent, high or low ohmic), the fault direction is calculated using a special filtering algorithm, Cumulative Phasor Summing (CPS) technique. This filtering method is advantageous during transient, intermittent and restriking earth faults with dominantly non-sinusoidal or transient content. It is equally valid during continuous (stable) earth faults.

The concept of CPS is illustrated in *Figure 171*. It is the result of adding values of the measured sum admittance phasors together in phasor format in chronological

order during the fault. Using the discrete sum admittance phasors  $\bar{Y}_{osum}$  in different time instants ( $t_1...t_5$ ), the corresponding accumulated sum admittance phasor

$\bar{Y}_{osum\_CPS}$  is calculated. This phasor is used as directional phasor in determining the direction of the fault.

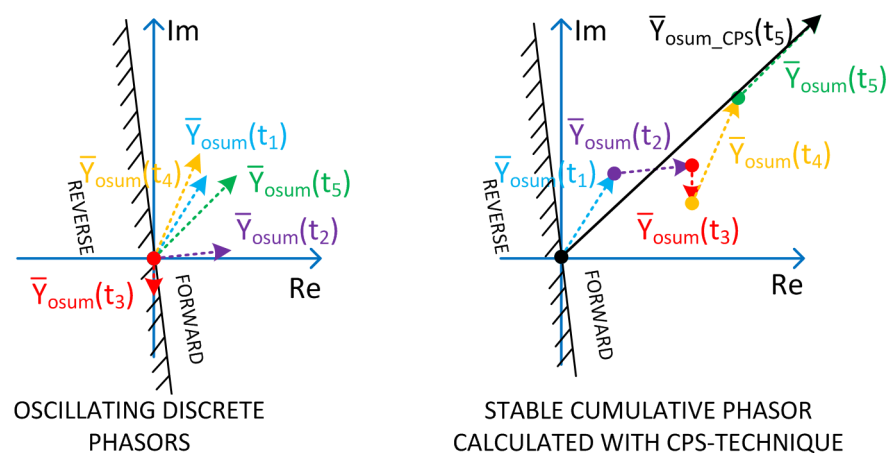
$$\bar{Y}_{osum\_CPS}(t_1) = \bar{Y}_{osum}(t_1)$$

$$\bar{Y}_{osum\_CPS}(t_2) = \bar{Y}_{osum}(t_1) + \bar{Y}_{osum}(t_2)$$

$$\bar{Y}_{osum\_CPS}(t_3) = \bar{Y}_{osum}(t_1) + \bar{Y}_{osum}(t_2) + \bar{Y}_{osum}(t_3)$$

$$\bar{Y}_{osum\_CPS}(t_4) = \bar{Y}_{osum}(t_1) + \bar{Y}_{osum}(t_2) + \bar{Y}_{osum}(t_3) + \bar{Y}_{osum}(t_4)$$

$$\bar{Y}_{osum\_CPS}(t_5) = \bar{Y}_{osum}(t_1) + \bar{Y}_{osum}(t_2) + \bar{Y}_{osum}(t_3) + \bar{Y}_{osum}(t_4) + \bar{Y}_{osum}(t_5)$$



*Figure 171: Principle of Cumulative Phasor Summing (CPS)*

The CPS technique provides a stable directional phasor quantity despite individual phasors varying in magnitude and phase angle in time due to a non-stable fault type such as restriking or intermittent earth fault. This is also true for harmonic

components included in the sum admittance phasor. Harmonics have typically a highly fluctuating character.

Harmonic components provide a more distinctive directional determination in compensated networks than the fundamental frequency component. The higher the frequencies, the compensation coil appears as very high impedance and the harmonics are not affected by compensation coil and degree of compensation. When harmonics are present, they cause the sum admittance phasor to behave as in case of an unearthed network, where directional phasors point in fully opposite directions in the faulty and healthy feeder.

The direction of the MFADPSDE function is defined with setting *Directional mode* as “Forward” or “Reverse”. The operation characteristic is defined by tilted operation sector as illustrated in *Figure 172*. The characteristic provides universal applicability, that is, it is valid both in compensated and unearthed networks, also if the compensation coil is temporarily switched off. The tilt of the operation sector is defined with setting *Tilt angle* to compensate the measurement errors of residual current and voltage transformers. The typical setting value of 5 degrees is recommended, but it should always reflect the actual maximum expected measurement errors.



In case of unearthed network operation, adequate tilt angle must be allowed to ensure dependable operation of MFADPSDE.

In *Figure 173*, phasors 1...4 demonstrate the behavior of the directional phasor in different network fault conditions.

- Phasor 1 depicts the direction of accumulated sum admittance phasor in case of earth fault outside the protected feeder (assuming that the admittance of the protected feeder is dominantly capacitive). The result is valid regardless of the fault type (low ohmic, high(er) ohmic, permanent, intermittent or restriking). In case harmonic components are present in the fault quantities, they would turn the phasor align to the negative  $\text{Im}(\bar{Y}_o)$  axis.
- Phasor 2 depicts the direction of accumulated sum admittance phasor in case of earth fault inside the protected feeder when the network is unearthed. The result is also valid in compensated networks when there are harmonic components present in the fault quantities (typically low ohmic permanent or intermittent or restriking fault). In this case, the result is valid regardless of network's actual compensation degree. Harmonics would turn the phasor align to the positive  $\text{Im}(\bar{Y}_o)$  axis.
- Phasors 3 and 4 depict the direction of accumulated sum admittance phasor in case of higher-ohmic earth fault in the protected feeder without harmonics in the fault quantities when the network is compensated. As no harmonic components are present, the phase angle of the accumulated phasor is determined by the compensation degree of the network. With high degree of overcompensation, the phasor turns towards the negative  $\text{Im}(\bar{Y}_o)$  axis (as phasor 4).

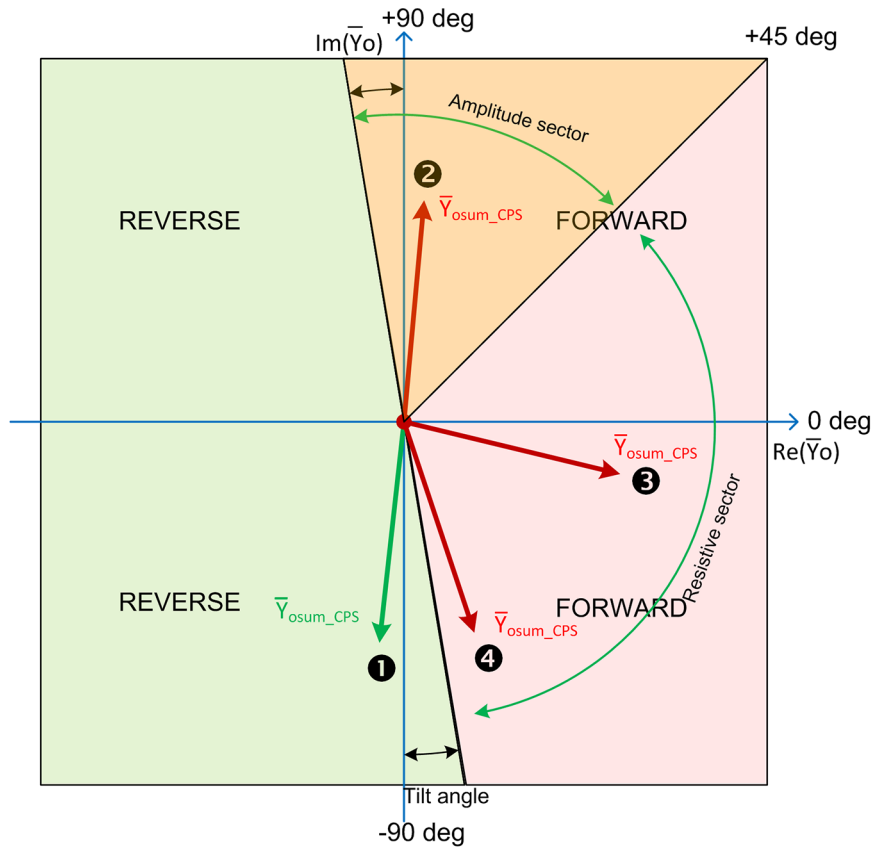


Figure 172: Directional characteristic of MFADPSDE



The residual current is recommended to be measured with accurate core balance current transformer to minimize the measurement errors, especially phase displacement. This is especially important, when high sensitivity of protection is targeted.



The characteristic *Tilt angle* should reflect the measurement errors, that is, the larger the measurement errors, the larger the *Tilt angle* setting should be. Typical setting value of 5 degrees is recommended.

The detected fault direction is available in the Monitored data view as parameter *DIRECTION*.

To adapt the fault direction determination to possible fault direction change during the fault, for example, during manual fault location process, a cyclic accumulation of sum admittance phasors is conducted. The duration of this directional evaluation cycle is  $1.2 \cdot \text{Reset delay time}$  (minimum of 600 ms). If the fault direction based on the cyclic phasor accumulation is opposite to the function direction output for *Reset delay time* or 500 ms (minimum of 500 ms), the function is reset and fault direction calculation of MFADPSDE is restarted.

In case the earth-fault protection is alarming, the function MFADPSDE includes also a *RESET* input, which can be utilised to externally re-trigger the fault direction determination, if re-evaluation of fault direction during a persistent earth fault is required. It is also recommended to connect the start-signal of non-directional earth-fault protection (EFxPTOC), set to operate in case of a cross-country fault, to *RESET* input of MFADPSDE to reset phasor accumulation during a cross-country fault. MFADPSDE is then able to adapt to possible fault direction change more

rapidly, if single phase earth fault still persists in the system after the other faulty feeder has been tripped (cross-country fault has been transformed back to a single phase earth fault).

The direction of the MFADPSDE function is supervised by a settable current magnitude threshold. The operate current used in the magnitude supervision is measured with a special filtering method, which provides very stable residual current estimate regardless of the fault type. This stabilized current estimate is the result from fundamental frequency admittance calculation utilizing the CPS technique. The stabilized current value is obtained (after conversion) from the corresponding admittance value by multiplying it with the system nominal phase-to-earth voltage value, which is entered as a base value for the residual voltage ( $U_{bases}$ ). The equations for calculating the stabilized values of the fundamental frequency admittance and the corresponding current are given below.

$$\overline{Y}_{o\ stab}^1 = \frac{3 \cdot \overline{I}_{0\ CPS}^1}{-\overline{U}_{0\ CPS}^1} = \text{Re} \left[ \overline{Y}_{o\ stab}^1 \right] + j \cdot \text{Im} \left[ \overline{Y}_{o\ stab}^1 \right] = G_{ostab}^1 + j \cdot B_{ostab}^1$$

|                            |  |
|----------------------------|--|
| $\overline{Y}_{o\ stab}^1$ | The stabilized fundamental frequency admittance estimate, which is result from fundamental frequency admittance calculation utilizing the Cumulative Phasor Summing (CPS) technique. |
| $\overline{I}_{0\ CPS}^1$  | The fundamental frequency zero-sequence current phasor calculated utilizing the Cumulative Phasor Summing (CPS) technique.   |
| $\overline{U}_{0\ CPS}^1$  | The fundamental frequency zero-sequence voltage phasor calculated utilizing the Cumulative Phasor Summing (CPS) technique.   |
| $G_{ostab}^1$              | The real-part of stabilized fundamental frequency conductance estimate.  |
| $B_{ostab}^1$              | The imaginary part of stabilized fundamental frequency susceptance estimate.   |

$$\overline{I}_{o\ stab}^1 = (G_{ostab}^1 + j \cdot B_{ostab}^1) \cdot U_{bases} = I_{o\ Cosstab}^1 + j \cdot I_{o\ Sinstab}^1$$

|                               |  |
|-------------------------------|--|
| $\overline{I}_{o\ stab}^1$    | The stabilized fundamental frequency residual current estimate, which is obtained (after conversion) from the corresponding admittance value by multiplying it with the system nominal phase-to-earth voltage value. |
| $\overline{I}_{o\ Cosstab}^1$ | The real-part of stabilized fundamental frequency residual current estimate.   |
| $\overline{I}_{o\ Sinstab}^1$ | The imaginary-part of stabilized fundamental frequency residual current estimate.  |

The main advantage of the filtering method is that due to the admittance calculation, the resulting current value does not depend on the value of fault resistance, that is, the estimated current magnitude equals the value that would be measured during a solid earth fault ( $R_f = 0 \Omega$ ). Another advantage of the method is that it is capable of estimating correct current magnitude also during intermittent or restriking faults.

The setting *Min operate current* defines the minimum operate current.

Setting *Operating quantity* defines whether the current magnitude supervision is based on either the "Adaptive" or "Amplitude" methods.



When “Adaptive” is selected, the method adapts the principle of magnitude supervision automatically to the system earthing condition. In case the phase angle of accumulated sum admittance phasor is greater than 45 degrees, the

set minimum operate current threshold is compared to the amplitude of  $\overline{I_{o\,stab}^1}$  (see [Figure 173](#)). In case the phase angle of accumulated sum admittance phasor is below 45 degrees, the set minimum operate current threshold is

compared to the resistive component of  $\overline{I_{o\,stab}^1}$ . This automatic adaptation of the magnitude supervision enables secure and dependable directional determination in compensated networks, and it is also valid when the network is unearthed (compensation coil is switched off).

In case operation direction is set to reverse, the resistive and amplitude sectors are mirrored in the operation characteristics.

When “Amplitude” is selected, the set minimum operate current threshold is

compared to the amplitude of  $\overline{I_{o\,stab}^1}$ . This selection can be used in unearthed networks.



In compensated networks, setting *Operating quantity* should be set to “Adaptive”. This enables secure and dependable directional determination on compensated networks and it is also valid when compensation coil is switched off and network becomes unearthed.

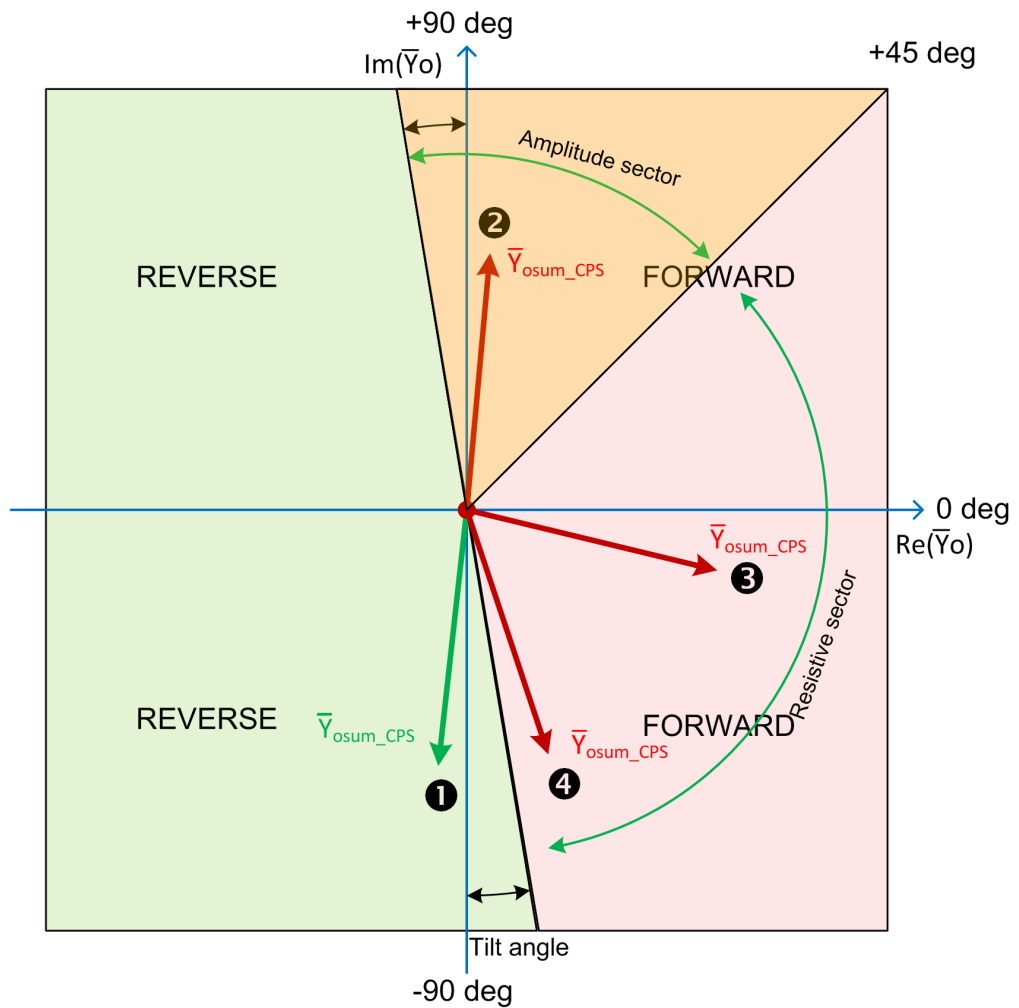


Figure 173: Illustration of amplitude and resistive current sectors if Operating quantity is set “Adaptive” and Directional mode is set “Forward”

The setting rules for current thresholds are given below.

In case the “Adaptive” operating quantity is selected, the setting *Min operate current* should be set to value:

$$[pu] < p \cdot IR_{tot}$$

- IR<sub>tot</sub>                      The total resistive earth-fault current of the network corresponding to the resistive current of the parallel resistor of the coil and the natural losses of the system (typically in order of 1...5 % of the total capacitive earth-fault current of the network).
- p                              security factor = 0.5...0.7

This setting should be set based on the total resistive earth-fault current of the network including the parallel resistor of the coil and the network losses. It must be set to a value which is lower than total resistive earth-fault current in order to enable dependable operation.

For example, if the resistive current of the parallel resistor is 10 A (at primary voltage level), then a value of 0.5 · 10 A = 5 A could be used. The same setting is also

applicable in case the coil is disconnected and the network becomes unearthed (as in this case this setting is compared to the amplitude of  $\overline{I_{o\,stab}^1}$ ). The selected setting value must never exceed the ampere value of the parallel resistor in order to allow operation in the faulty feeder. In case of smaller ampere value of the parallel resistor, for example 5 A, the recommended security factor should be larger, for example 0.7, so that sufficient margin for CT and VT errors can be achieved.

In case the “Amplitude” operating quantity is selected, the setting should be selected based on the capacitive earth-fault current values produced by the background network in case of a solid earth fault with a security margin.



The main task of the current magnitude supervision module is to secure the correct directional determination of an earth fault, so that only the faulty feeder is disconnected or alarmed. Therefore, the threshold values should be selected carefully and not set too high as this can inhibit the disconnection of the faulty feeder.



The residual current should be measured with accurate core balance current transformer to minimize the measurement errors, especially phase displacement.

### Transient detector

The Transient detector module is used for detecting transients in the residual current and zero-sequence voltage signals. Whenever transient is detected, this is indicated with the PEAK\_IND output. When the number of detected transients equals or exceeds the *Peak counter limit* setting (without the function being reset, depending on the drop-off time set with the *Reset delay time* setting), INTR\_EF output is activated. This indicates detection of restriking or intermittent earth fault in the network. Transient detector affects the operation of MFADPSDE (START and OPERATE outputs) when operation mode is “Intermittent EF”. For other operation modes, (“General EF”, “Alarming EF”), PEAK\_IND and INTR\_EF outputs can be used for monitoring purposes. The operation of the Transient detector is illustrated in [Figure 174](#).



Several factors affect the magnitude and frequency of fault transients, such as the fault inception angle on the voltage wave, fault location, fault resistance and the parameters of the feeders and the supplying transformers. If the fault is permanent (non-transient) in nature, the initial fault transient in current and voltage can be measured, whereas the intermittent fault creates repetitive transients. The practical sensitivity of transient detection is limited to approximately few hundreds of ohms of fault resistance. Therefore the application of transient detection is limited to low ohmic earth faults.

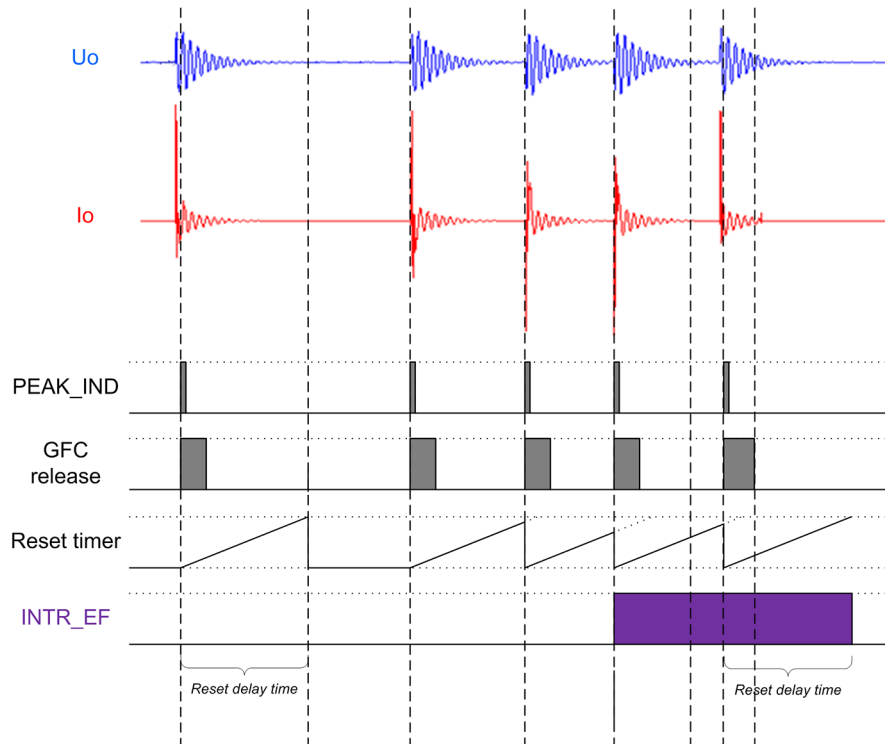


Figure 174: Example of operation of Transient detector: indication of detected transient by PEAK\_IND output and detection of restriking or intermittent earth fault by INTR\_EF output (setting Peak counter limit = 3)

### Operation logic

MFADPSDE supports three operation modes selected with setting Operation mode: “General EF”, “Alarming EF” and “Intermittent EF”.

Operation mode “General EF” is applicable in all kinds of earth faults in unearthed and compensated networks. It is intended to detect all kinds of earth faults regardless of their type (transient, intermittent or restriking, permanent, high or low ohmic). The setting *Voltage start value* defines the basic sensitivity of the MFADPSDE function.

In “General EF” mode, the operate timer is started in the following conditions.

- Earth-fault is detected by the General Fault Criterion (GFC)
- Fault direction equals *Directional mode* setting
- Estimated stabilized fundamental frequency residual current exceeds the set *Min operate current* level

The START output is activated once *Start delay time* has elapsed. OPERATE output is activated once *Operate delay time* has elapsed and the above three conditions are valid. Reset timer is started if any of the above three conditions is not valid. In case fault is transient and self-extinguishes, START output stays activated until the elapse of reset timer (setting Reset delay time). After OPERATE output activation, START and OPERATE outputs are reset immediately, if any of the above three conditions is not valid. The start duration value START\_DUR, available in the Monitored data view, indicates the percentage ratio of the start situation and the set operating time.



In case detection of temporary earth faults is not desired, the activation of *START* output can be delayed with setting *Start delay time*. The same setting can be also used to avoid restarting of the function during long lasting post-fault oscillations, if time constant of post-fault oscillations is very long (network losses and damping is low).



To keep the operate timer activated between current spikes during intermittent or restriking earth fault, the *Reset delay time* should be set to a value exceeding the maximum expected time interval between fault spikes (obtained at full resonance condition). Recommended value is at least 300 ms.

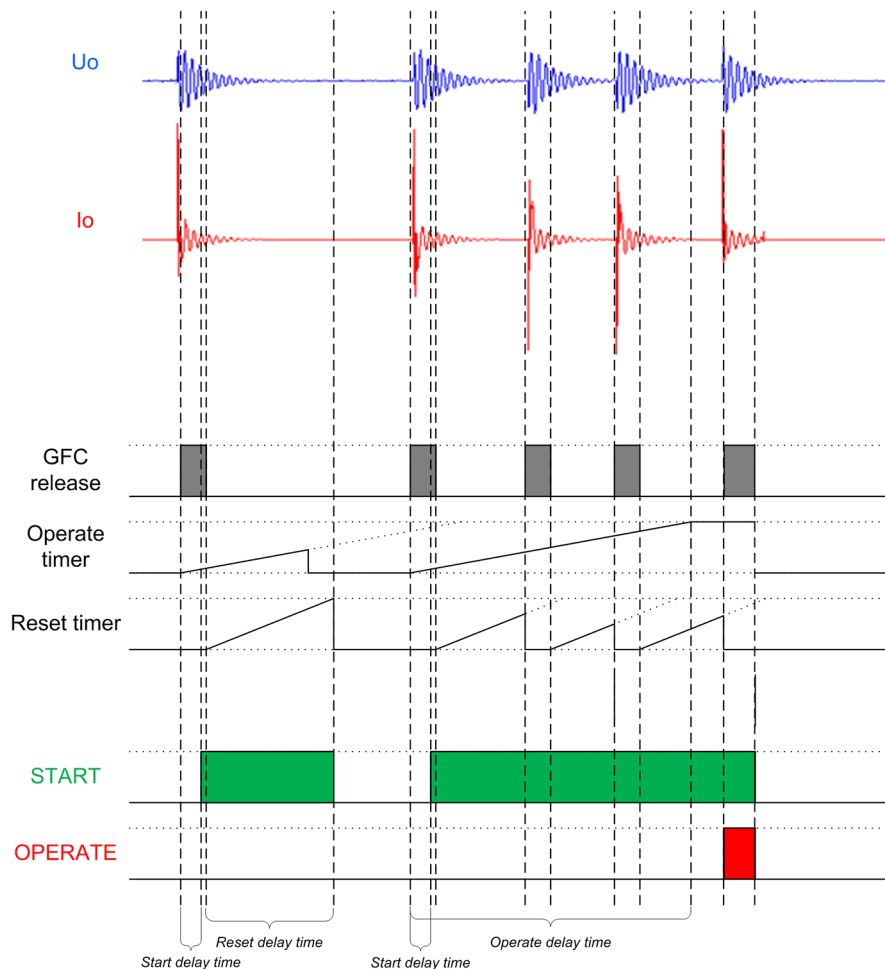


Figure 175: Operation in "General EF" mode

Operation mode "Alarming EF" is applicable in all kinds of earth faults in unearthed and compensated networks, where fault detection is only alarming. It is intended to detect earth faults regardless of their type (transient, intermittent or restriking, permanent, high or low ohmic). The setting *Voltage start value* defines the basic sensitivity of the MFADPSDE function. In "Alarming EF" mode, the operate timer is started during the following conditions.

- Earth fault is detected by the GFC
- Fault direction equals *Directional mode setting*
- Estimated stabilized fundamental frequency residual current exceeds the set *Min operate current* level

The **START** output is activated once *Start delay time* has elapsed. **OPERATE** output is not valid in the “Alarming EF” mode. Reset timer is started if any of the above three conditions are not valid. In case the fault is transient and self-extinguishes, **START** output stays activated until the elapse of reset timer (setting *Reset delay time*).



In case detection of temporary earth faults is not desired, the activation of **START** output can be delayed with setting *Start delay time*.



To keep the operate timer activated between current spikes during intermittent or restriking earth fault, the *Reset delay time* should be set to a value exceeding the maximum expected time interval between fault spikes (obtained at full resonance condition). The recommended value is at least 300 ms.

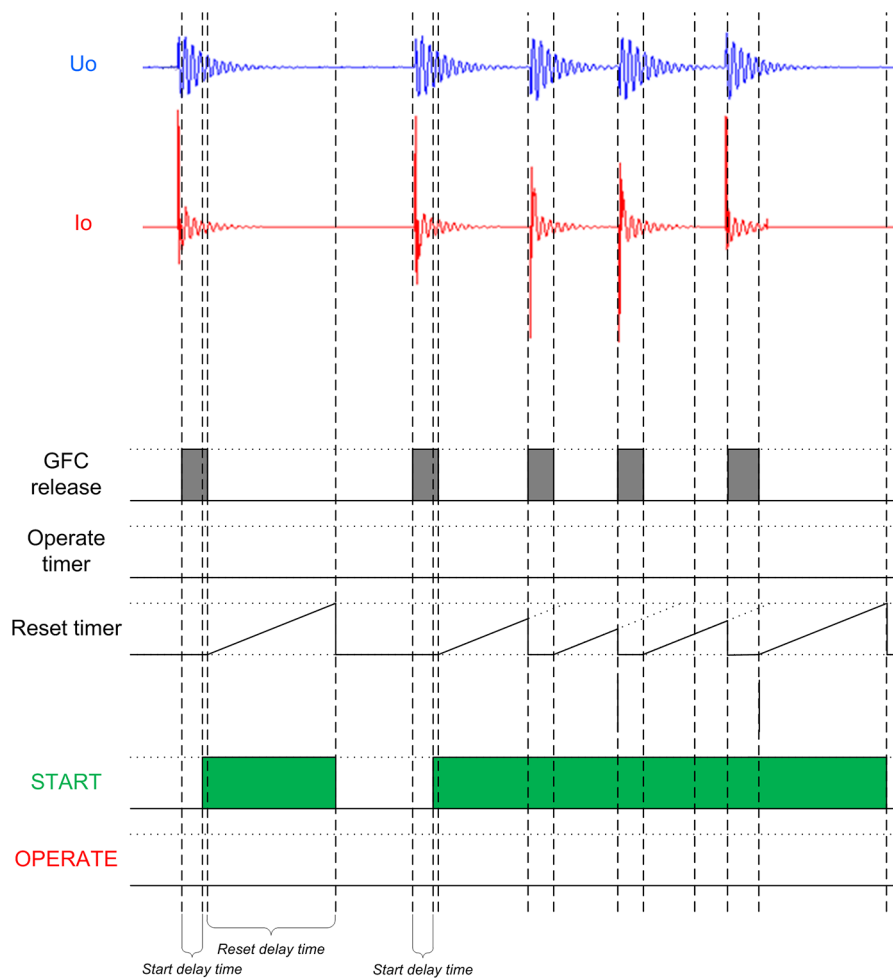


Figure 176: Operation in “Alarming EF” mode

Operation mode “Intermittent EF” is dedicated for detecting restriking or intermittent earth faults. A required number of intermittent earth fault transients set with the *Peak counter limit* setting must be detected for operation. Therefore, transient faults or permanent faults with only initial fault ignition transient are not detected in “Intermittent EF” mode. The application of “Intermittent EF” mode is limited to low ohmic intermittent or restriking earth faults.

In the “Intermittent EF” mode, the operate timer is started when the following conditions are met.

- Transient is detected by the Transient detector (indicated with `PEAK_IND` output)
- Earth fault is detected by the GFC at time of transient
- Fault direction equals *Directional mode* setting
- Estimated stabilized fundamental frequency residual current exceeds the set *Min operate current level*

When a required number of intermittent earth-fault transients set with the *Peak counter limit* setting are detected without the function being reset (depends on the drop-off time set with the *Reset delay time* setting), the `START` output is activated. The `INTR_EF` output is activated to indicate the fault type is intermittent or restriking earth fault. The operate timer is kept activated as long as transients occur during the drop-off time defined by setting *Reset delay time*.

The `OPERATE` output is activated when *Operate delay time* has elapsed, required number of transients has been detected, earth fault is detected by the GFC, fault direction matches the *Directional mode* setting and estimated stabilized fundamental frequency residual current exceeds set *Minimum operate current* setting.

The *Reset delay time* starts to elapse from each detected transient. Function is reset if time between current peaks is more than *Reset delay time* or if the General Fault Criterion release is reset. After `OPERATE` output activation, `START` and `OPERATE` outputs are reset immediately at the falling edge of General Fault Criterion release, that is, when zero-sequence voltage falls below *Voltage start value*. This should be considered if “Intermittent EF” mode is applied in case earth faults are only alarmed to avoid repetitive start and operate events.



To keep the operate timer activated between current spikes during intermittent or restriking earth fault, *Reset delay time* should be set to a value exceeding the maximum expected time interval between (obtained at full resonance condition). The recommended value is at least 300 ms.

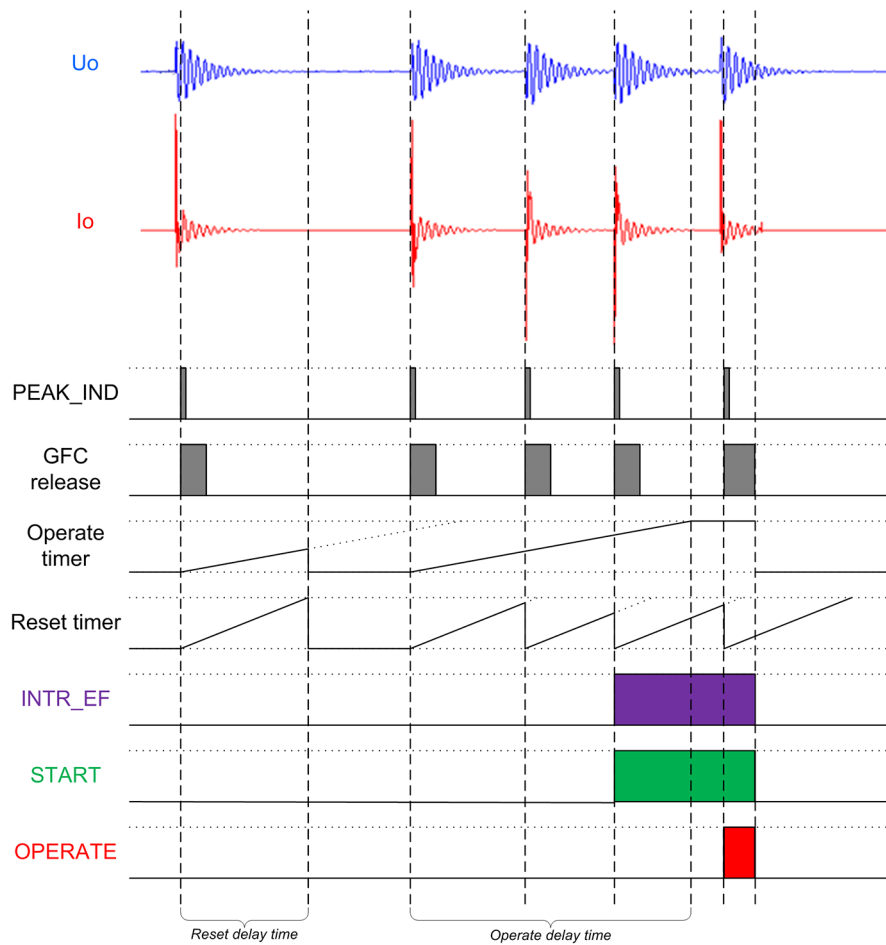


Figure 177: Operation in “Intermittent EF” mode, Peak counter limit = 3

**Blocking logic**

There are three operation modes in the blocking functionality. The operation modes are controlled by the BLOCK input and the global setting **Configuration > System > Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

**Timer**

If the detected fault direction is opposite to the set directional mode and GFC release is active, BLK\_EF output is activated once *Start delay time* has elapsed. Reset timer is activated at the falling edge of General Fault Criterion release, that is, when zero-sequence voltage falls below *Voltage start value*. BLK\_EF is reset once the reset delay time elapses. Activation of the BLOCK input deactivates the BLK\_EF output and resets Timer.



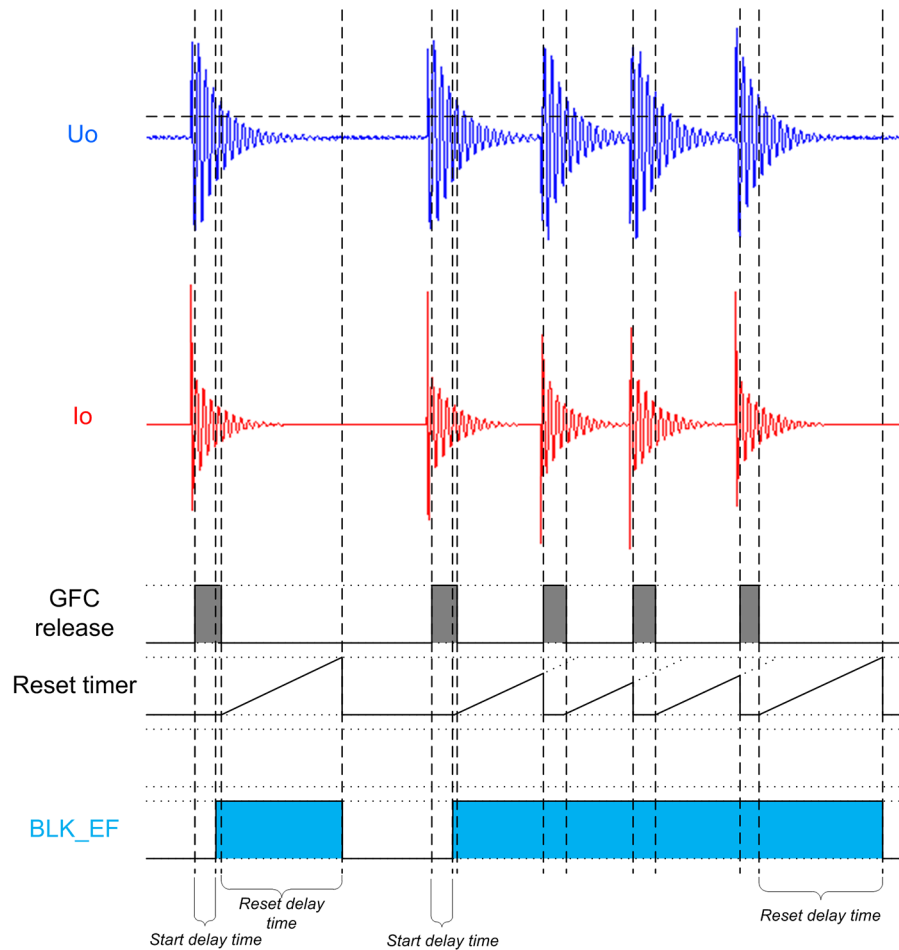


Figure 178: Activation of BLK\_EF output (indication that fault is located opposite to the set operate direction)

### 3.2.6.5 Application

MFADPSDE provides selective directional earth-fault protection for high-impedance earthed networks, that is, for compensated, ungrounded and high resistance earthed systems. It can be applied for the earth-fault protection of overhead lines and underground cables.

The operation of MFADPSDE is based on multi-frequency neutral admittance measurement utilizing cumulative phasor summing technique. This concept provides extremely secure, dependable and selective earth-fault protection also in cases where the residual quantities are highly distorted and contain non-fundamental frequency components. MFADPSDE is well-suited for compensated networks where measurement signals may have such characteristics, for example, during intermittent earth faults.

MFADPSDE is capable of operating with both low ohmic and higher ohmic earth faults, where the sensitivity limit is defined with residual overvoltage condition. This allows earth faults with several kilohms of fault resistance to be detected in a symmetrical system. The sensitivity that can be achieved is comparable with traditional fundamental frequency based methods such as the  $I_o\cos/I_o\sin$  (DEFxPTOC), Watt/Varmetric (WPWDE) and neutral admittance (EFPADM).

MFADPSDE is capable of detecting faults with dominantly fundamental frequency content as well as transient, intermittent or restriking earth faults. MFADPSDE can be used as an alternative solution to transient or intermittent function INTRPTEF.

MFADPSDE supports Fault direction indication in operate and non-operate direction which may be utilized during fault location process. The inbuilt transient detector can be used to identify restriking or intermittent earth faults, and discriminate them from permanent or continuous earth faults.

The direction of MFADPSDE can be set as forward or reverse. The operation characteristic is defined by a tilted operation sector, which is universally valid both in unearthed and compensated networks. The tilt of the operation sector should be selected based on the measurement errors of the applied residual current and voltage measurement transformers.

The operating time characteristic is according to the definite time (DT).

The function contains a blocking functionality to block function outputs, timers or the function itself.

MFADPSDE supports both tripping and alarming mode of operation. For alarming earth-fault protection application, the function contains a dedicated operation mode.

MFADPSDE provides reliability and sensitivity of protection with a single function. This enables simpler implementation of protection schemes as separate fault type dedicated earth-fault functions and coordination between them are not necessarily required. Other advantages of MFADPSDE includes versatile applicability, good selectivity, good sensitivity and easy setting principles.

One instance (stage) of MFADPSDE function is available.

### 3.2.6.6

## Signals

### MFADPSDE Input signals

**Table 363: MFADPSDE Input signals**

| Name    | Type    | Default | Description   |
|---------|---------|---------|---|
| Io      | SIGNAL  | 0       | Residual current  |
| Uo      | SIGNAL  | 0       | Residual voltage  |
| BLOCK   | BOOLEAN | 0=False | Block signal for activating the blocking mode             |
| RELEASE | BOOLEAN | 0=False | External trigger to release neutral admittance protection |
| RESET   | BOOLEAN | 0=False | External trigger to reset direction calculation           |

**MFADPSDE Output signals****Table 364: MFADPSDE Output signals**

| Name     | Type    | Description  |
|----------|---------|--|
| OPERATE  | BOOLEAN | Operate  |
| START    | BOOLEAN | Start  |
| BLK_EF   | BOOLEAN | Block signal for EF to indicate opposite direction peaks |
| INTR_EF  | BOOLEAN | Intermittent earth-fault indication                      |
| PEAK_IND | BOOLEAN | Current transient detection indication                   |

**3.2.6.7****Settings****MFADPSDE Settings****Table 365: MFADPSDE Group settings (Basic)**

| Parameter           | Values (Range)         | Unit | Step | Default   | Description         |
|---------------------|------------------------|------|------|-----------|---------------------|
| Directional mode    | 2=Forward<br>3=Reverse |      |      | 2=Forward | Directional mode    |
| Voltage start value | 0.01...1.00            | xUn  | 0.01 | 0.10      | Voltage start value |
| Operate delay time  | 60...1200000           | ms   | 10   | 500       | Operate delay time  |

**Table 366: MFADPSDE Group settings (Advanced)**

| Parameter           | Values (Range)            | Unit | Step  | Default    | Description                  |
|---------------------|---------------------------|------|-------|------------|------------------------------|
| Operating quantity  | 1=Adaptive<br>2=Amplitude |      |       | 1=Adaptive | Operating quantity selection |
| Min operate current | 0.005...5.000             | xIn  | 0.001 | 0.010      | Minimum operate current      |
| Tilt angle          | 2.0...20.0                | deg  | 0.1   | 5.0        | Characteristic tilt angle    |

**Table 367: MFADPSDE Non group settings (Basic)**

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on           |      |      | 1=on    | Operation Off / On |

*Table continues on the next page*

| Parameter      | Values (Range)                                     | Unit | Step | Default      | Description        |
|----------------|--|------|------|--------------|--------------------|
|                | 5=off  |      |      |              |                    |
| Operation mode | 1=Intermittent EF<br>3=General EF<br>4=Alarming EF |      |      | 3=General EF | Operation criteria |

**Table 368: MFADPSDE Non group settings (Advanced)**

| Parameter          | Values (Range)    | Unit | Step | Default | Description                           |
|--------------------|-------------------|------|------|---------|---------------------------------------|
| Peak counter limit | 2...20            |      | 1    | 2       | Peak counter limit for re-striking EF |
| Start delay time   | 30...60000        | ms   | 1    | 30      | Start delay time                      |
| Reset delay time   | 0...60000         | ms   | 1    | 500     | Reset delay time                      |
| Pol reversal       | 0=False<br>1=True |      |      | 0=False | Rotate polarizing quantity            |

**3.2.6.8**

**Monitored data**

**MFADPSDE Monitored data**

**Table 369: MFADPSDE Monitored data**

| Name      | Type    | Values (Range)                                 | Unit | Description                        |
|-----------|---------|--|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00                                  | %    | Ratio of start time / operate time |
| FAULT_DIR | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Detected fault direction           |
| DIRECTION | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Direction information              |

*Table continues on the next page*

| Name     | Type    | Values (Range)   | Unit | Description                                     |
|----------|---------|--|------|---|
| ANGLE    | FLOAT32 | -180.00...180.00                                       | deg  | Angle between polarizing and operating quantity |
| MFADPSDE | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status  |

### 3.2.6.9 Technical data

Table 370: MFADPSDE Technical data

| Characteristic           | Value   |
|--------------------------|---|
| Operation accuracy       | Depending on the frequency of the measured voltage:<br>$f_n \pm 2 \text{ Hz}$<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times U_n$ |
| Start time <sup>40</sup> | Typically 35 ms   |
| Reset time               | Typically 40 ms   |
| Operate time accuracy    | $\pm 1.0\%$ of the set value or $\pm 20 \text{ ms}$   |

### 3.2.6.10 Technical revision history

Table 371: MFADPSDE Technical revision history

| Technical revision | Change              |
|--------------------|---------------------|
| B                  | Modified for SSC600 |

## 3.3 Differential protection

### 3.3.1 Stabilized and instantaneous differential protection for two-winding transformers TR2PTDF

<sup>40</sup> Includes the delay of the signal output contact, results based on statistical distribution of 1000 measurements

### 3.3.1.1 Identification

| Function description  | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|--------------------------|--------------------------|-------------------------------|
| Stabilized and instantaneous differential protection for two-winding transformers | TR2PTDF                  | 3dl>T                    | 87T                           |

### 3.3.1.2 Function block

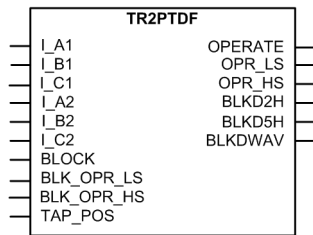


Figure 179: Function block

### 3.3.1.3 Functionality

The stabilized and instantaneous differential protection function TR2PTDF is designed to protect two-winding transformers and generator-transformer blocks. TR2PTDF includes low biased and high instantaneous stages.

The biased low stage provides a fast clearance of faults while remaining stable with high currents passing through the protected zone increasing errors on current measuring. The second harmonic restraint, together with the waveform based algorithms, ensures that the low stage does not operate due to the transformer inrush currents. The fifth harmonic restraint ensures that the low stage does not operate on apparent differential current caused by a harmless transformer over-excitation.

The instantaneous high stage provides a very fast clearance of severe faults with a high differential current regardless of their harmonics.

The setting characteristic can be set more sensitive with the aid of tap changer position compensation. The correction of transformation ratio due to the changes in tap position is done automatically based on the tap changer status information.

### 3.3.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of TR2PTDF can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

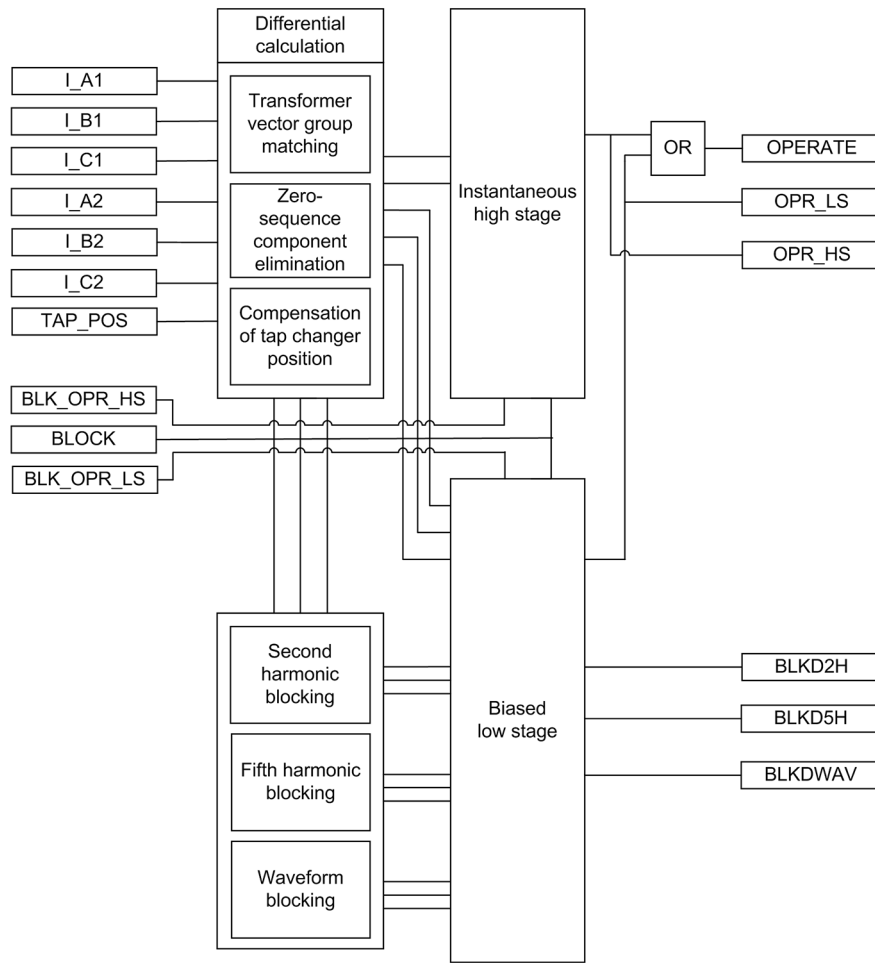


Figure 180: Functional module diagram

**Differential calculation**

TR2PTDF operates phase-wise on a difference of incoming and outgoing currents. The positive direction of the currents is towards the protected object.

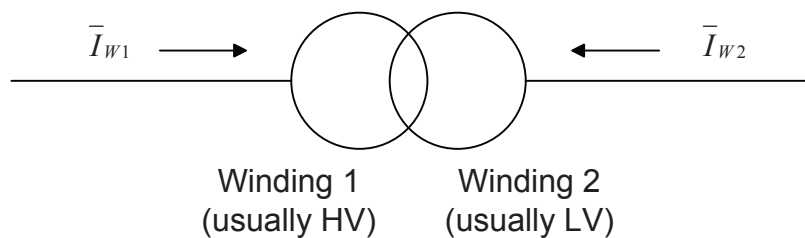


Figure 181: Positive direction of the currents

$$I_d = |\bar{I}_{W1} + \bar{I}_{W2}|$$

In a normal situation, no fault occurs in the area protected by TR2PTDF. Then the currents  $\bar{I}_{W1}$  and  $\bar{I}_{W2}$  are equal and the differential current  $I_d$  is zero. In practice, however, the differential current deviates from zero in normal situations.

In the power transformer protection, the differential current is caused by CT inaccuracies, variations in tap changer position (if not compensated), transformer no-load current and instantaneous transformer inrush currents. An increase in the load current causes the differential current, caused by the CT inaccuracies and the tap changer position, to grow at the same percentage rate.

In a biased differential IED in normal operation or during external faults, the higher the load current is the higher is the differential current required for tripping. When an internal fault occurs, the currents on both sides of the protected object are flowing into it. This causes the biasing current to be considerably smaller, which makes the operation more sensitive during internal faults.

$$I_b = \frac{|\bar{I}_{W1} - \bar{I}_{W2}|}{2}$$

If the biasing current is small compared to the differential current or if the phase angle between the winding 1 and winding 2 phase currents is close to zero (in a normal situation, the phase difference is 180 degrees), a fault has most certainly occurred in the area protected by the differential IED. Then the operation value set for the instantaneous stage is automatically halved and the internal blocking signals of the biased stage are inhibited.

### Transformer vector group matching

The phase difference of the winding 1 and winding 2 currents that is caused by the vector group of the power transformer is numerically compensated. The matching of the phase difference is based on the phase shifting and the numerical delta connection inside the IED. The *Winding 1 type* parameter determines the connection on winding 1 ("Y", "YN", "D", "Z", "ZN"). The *Winding 2 type* parameter determines the connections of the phase windings on the low voltage side ("y", "yn", "d", "z", "zn").

The vector group matching can be implemented either on both, winding 1 and winding 2, or only on winding 1 or winding 2, at intervals of 30° with the *Clock number* setting.

When the vector group matching is Yy0 and the *CT connection type* is according to "Type 2", the phase angle of the phase currents connected to the IED does not change. When the vector group matching is Yy6, the phase currents are turned 180° in the IED.

### Example 1

Vector group matching of a Ynd11-connected power transformer on winding 1, *CT connection type* according to type 1. The *Winding 1 type* setting is "YN", *Winding 2 type* is "d" and *Clock number* is "Clk Num 11". This is compensated internally by giving winding 1 internal compensation value +30° and winding 2 internal compensation value 0°:

$$\bar{I}_{L1mHV} = \frac{\bar{I}_{L1} - \bar{I}_{L2}}{\sqrt{3}}$$

$$\bar{I}_{L2mHV} = \frac{\bar{I}_{L2} - \bar{I}_{L3}}{\sqrt{3}}$$

$$\bar{I}_{L3mHV} = \frac{\bar{I}_{L3} - \bar{I}_{L1}}{\sqrt{3}}$$



**Example 2**

But if vector group is Yd11 and *CT connection type* is according to type 1, the compensation is a little different. The *Winding 1 type* setting is "Y", *Winding 2 type* is "d" and *Clock number* is "Clk Num 11". This is compensated internally by giving winding 1 internal compensation value 0° and winding 2 internal compensation value -30°;

$$\bar{I}_{L1mLV} = \frac{\bar{I}_{L1} - \bar{I}_{L3}}{\sqrt{3}}$$

$$\bar{I}_{L2mLV} = \frac{\bar{I}_{L2} - \bar{I}_{L1}}{\sqrt{3}}$$

$$\bar{I}_{L3mLV} = \frac{\bar{I}_{L3} - \bar{I}_{L2}}{\sqrt{3}}$$

The "Y" side currents stay untouched, while the "d" side currents are compensated to match the currents actually flowing in the windings.

In this example there is no neutral current on either side of the transformer (assuming there are no earthing transformers installed). In the previous example, however, the matching is done differently to have the winding 1 neutral current compensated at the same time.

**Zero-sequence component elimination**

If *Clock number* is "Clk Num 2", "Clk Num 4", "Clk Num 8" or "Clk Num 10", the vector group matching is always done on both, winding 1 and winding 2. The combination results in the correct compensation. In this case the zero-sequence component is always removed from both sides automatically. The *Zro A elimination* parameter cannot change this.

If *Clock number* is "Clk Num 1", "Clk Num 5", "Clk Num 7" or "Clk Num 11", the vector group matching is done on one side only. A possible zero-sequence component of the phase currents at earth faults occurring outside the protection area is eliminated in the numerically implemented delta connection before the differential current and the biasing current are calculated. This is why the vector group matching is almost always made on the star connected side of the "Ynd" and "Dyn" connected transformers.

If *Clock number* is "Clk Num 0" or "Clk Num 6", the zero-sequence component of the phase currents is not eliminated automatically on either side. Therefore, the zero-sequence component on the star connected side that is earthed at its star point has to be eliminated by using the *Zro A elimination* parameter.

The same parameter has to be used to eliminate the zero-sequence component if there is, for example, an earthing transformer on the delta-connected side of the "Ynd" power transformer in the area to be protected. In this case, the vector group matching is normally made on the side of the star connection. On the side of the delta connection, the elimination of the zero-sequence component has to be separately selected.

By using the *Zro A elimination* parameter, the zero-sequence component of the phase currents is calculated and reduced for each phase current:

$$\bar{I}_{L1m} = \bar{I}_{L1} - \frac{1}{3}x(\bar{I}_{L1} + \bar{I}_{L2} + \bar{I}_{L3})$$

$$\bar{I}_{L2m} = \bar{I}_{L2} - \frac{1}{3}x(\bar{I}_{L1} + \bar{I}_{L2} + \bar{I}_{L3})$$

$$\bar{I}_{L3m} = \bar{I}_{L3} - \frac{1}{3}x(\bar{I}_{L1} + \bar{I}_{L2} + \bar{I}_{L3})$$



In many cases with the earthed neutral of a "wye" winding, it is possible to make the compensation so that a zero-sequence component of the phase currents is automatically eliminated. For example, in a case of a "Ynd" transformer, the compensation is made on the winding 1 side to automatically eliminate the zero-sequence component of the phase currents on that side (and the "d" side does not have them). In those cases, explicit elimination is not needed.

### Compensation of tap changer position

The position of the tap changer used for voltage control can be compensated and the position information is provided for the protection function through the tap position indication function TPOSYLTC.

Typically, the tap changer is located within the high voltage winding, that is, winding 1, of the power transformer. The *Tapped winding* parameter specifies whether the tap changer is connected to the high voltage side winding or the low voltage side winding. This parameter is also used to enable and disable the automatic adaptation to the tap changer position. The possible values are "Not in use", "Winding 1" or "Winding 2".

The *Tap nominal* parameter tells the number of the tap, which results in the nominal voltage (and current). When the current tap position deviates from this value, the input current values on the side where the tap changer resides are scaled to match the currents on the other side.

A correct scaling is determined by the number of steps and the direction of the deviation from the nominal tap and the percentage change in voltage resulting from a deviation of one tap step. The percentage value is set using the *Step of tap* parameter.

The operating range of the tap changer is defined by the *Min winding tap* and *Max winding tap* parameters. The *Min winding tap* parameter tells the tap position number resulting in the minimum effective number of winding turns on the side of the transformer where the tap changer is connected. Correspondingly, the *Max winding tap* parameter tells the tap position number resulting in the maximum effective number of winding turns.

The *Min winding tap* and *Max winding tap* parameters help the tap position compensation algorithm know in which direction the compensation is being made. This ensures also that if the current tap position information is corrupted for some reason, the automatic tap changer position adaptation does not try to adapt to any unrealistic position values.

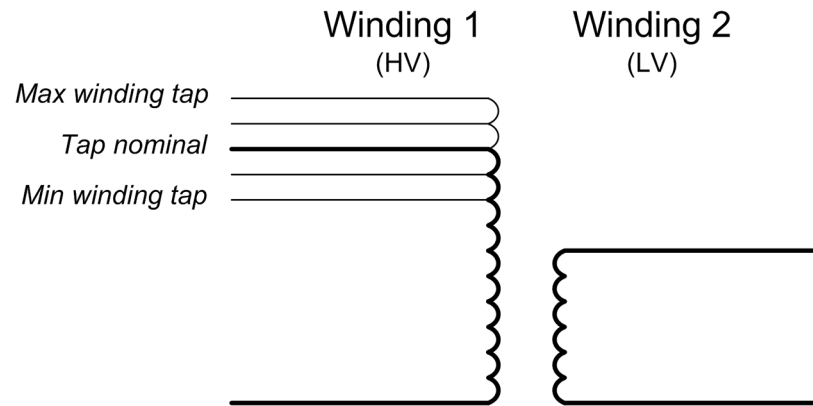


Figure 182: Simplified presentation of the high voltage and medium voltage windings with demonstration of the Max winding tap, Min winding tap and Tap nominal parameters

The position value is available through the Monitored data view on WHMI or through other communication tools in the tap position indication function. When the quality of the TAP\_POS value is not good, the position information in TAP\_POS is not used but the last value with the good quality information is used instead. In addition, the minimum sensitivity of the biased stage, set by the *Low operate value* setting, is automatically desensitized with the total range of the tap position correction. The new acting low operate value is

$$\text{Desensitized Low operate value} = \text{Low operate value} + \text{ABS}(\text{MaxWinding tap} - \text{Min winding tap}) \times \text{Step of tap}$$

### Second harmonic blocking

The transformer magnetizing inrush currents occur when energizing the transformer after a period of de-energization. The inrush current can be many times the rated current and the halving time can be up to several seconds. To the differential protection, the inrush current represents a differential current, which would cause the differential protection to operate almost always when the transformer is connected to the network. Typically, the inrush current contains a large amount of second harmonics.

Blocking the operation of the TR2PTDF biased low stage at a magnetizing inrush current is based on the ratio of the amplitudes of the second harmonic digitally filtered from the differential current and the fundamental frequency ( $I_{d2f} / I_{d1f}$ ).

The blocking also prevents unwanted operation at the recovery and sympathetic magnetizing inrushes. At the recovery inrush, the magnetizing current of the transformer to be protected increases momentarily when the voltage returns to normal after the clearance of a fault outside the protected area. The sympathetic inrush is caused by the energization of another transformer running in parallel with the protected transformer already connected to the network.

The ratio of the second harmonic to a fundamental component can vary considerably between the phases. Especially when the delta compensation is done for a Ynd1 connected transformer and the two phases of the inrush currents are otherwise equal but opposite in phase angle, the subtraction of the phases in a delta compensation results in a very small second harmonic component.

Some measures have to be taken in order to avoid the false tripping of a phase having too low a ratio of the second harmonic to the fundamental component. One

way could be to always block all the phases when the second harmonic blocking conditions are fulfilled in at least one phase. The other way is to calculate the weighted ratios of the second harmonic to the fundamental component for each phase using the original ratios of the phases. The latter option is used here. The second harmonic ratios  $I_{2H\_RAT\_x}$  are given in Monitored data.

The ratio to be used for second harmonic blocking is, therefore, calculated as a weighted average on the basis of the ratios calculated from the differential currents of the three phases. The ratio of the concerned phase is of most weight compared to the ratios of the other two phases. In this IED, if the weighting factors are four, one and one, four is the factor of the phase concerned. The operation of the biased stage on the concerned phase is blocked if the weighted ratio of that phase is above the set blocking limit *Start value 2.H* and if blocking is enabled through the *Restraint mode* parameter.

Using separate blocking for the individual phases and weighted averages calculated for the separate phases provides a blocking scheme that is stable at the connection inrush currents.

If the peak value of the differential current is very high, that is  $I_r > 12 \times I_n$ , the limit for the second harmonic blocking is desensitized (in the phase in question) by increasing it proportionally to the peak value of the differential current.

The connection of the power transformer against a fault inside the protected area does not delay the operation of the tripping, because in such a situation the blocking based on the second harmonic of the differential current is prevented by a separate algorithm based on a different waveform and a different rate of change of the normal inrush current and the inrush current containing the fault current. The algorithm does not eliminate the blocking at inrush currents, unless there is a fault in the protected area.

The feature can also be enabled and disabled with the *Harmonic deblock 2.H* parameter.

### **Fifth harmonic blocking**

The inhibition of TR2PTDF operation in the situations of overexcitation is based on the ratio of the fifth harmonic and the fundamental component of the differential current ( $I_{d5f}/I_{d1f}$ ). The ratio is calculated separately for each phase without weighting. If the ratio exceeds the setting value of *Start value 5.H* and if blocking is enabled through the *Restraint mode* parameter, the operation of the biased stage of TR2PTDF in the concerned phase is blocked. The fifth harmonic ratios  $I_{5H\_RAT\_x}$  are given in Monitored data.

At dangerous levels of overvoltage, which can cause damage to the transformer, the blocking can be automatically eliminated. If the ratio of the fifth harmonic and the fundamental component of the differential current exceeds the *Stop value 5.H* parameter, the blocking removal is enabled. The enabling and disabling of deblocking feature is also done through the *Harmonic deblock 5.H* parameter.

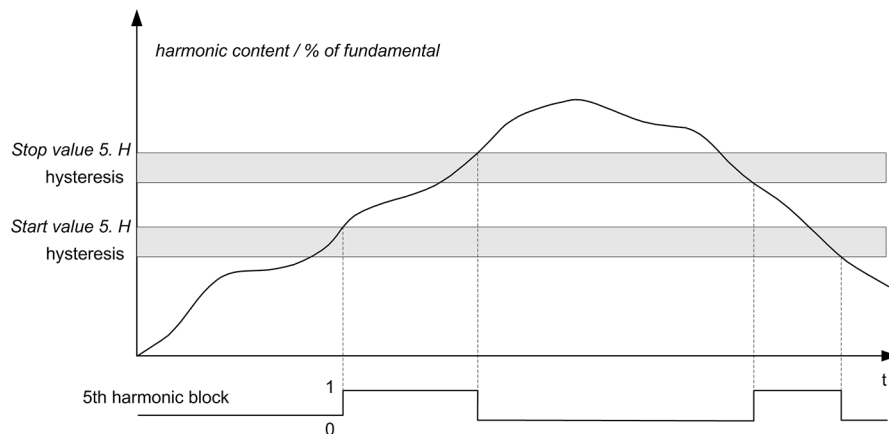


Figure 183: The limits and operation of the fifth harmonic blocking when both blocking and deblocking features are enabled using the Harmonic deblock 5.H control parameter.

The fifth harmonic blocking has a hysteresis to avoid rapid fluctuation between "TRUE" and "FALSE". The blocking also has a counter, which counts the required consecutive fulfillments of the condition. When the condition is not fulfilled, the counter is decreased (if >0).

Also the fifth harmonic deblocking has a hysteresis and a counter which counts the required consecutive fulfillments of the condition. When the condition is not fulfilled, the counter is decreased (if >0).

### Waveform blocking

The biased low stage can always be blocked with waveform blocking. The stage can not be disabled with the *Restraint mode* parameter. This algorithm has two parts. The first part is intended for external faults while the second is intended for inrush situations. The algorithm has criteria for a low current period during inrush where also the differential current (not derivative) is checked.

### Biased low stage

The current differential protection needs to be biased because the possible appearance of a differential current can be due to something else than an actual fault in the transformer (or generator).

In the case of transformer protection, a false differential current can be caused by:

- CT errors
- Varying tap changer positions (if not automatically compensated)
- Transformer no-load current
- Transformer inrush currents
- Transformer overexcitation in overvoltage
- Underfrequency situations
- CT saturation at high currents passing through the transformer

The differential current caused by CT errors or tap changer positions increases at the same percent ratio as the load current.

In the protection of generators, the false differential current can be caused by various factors.

- CT errors
- CT saturation at high currents passing through the generator

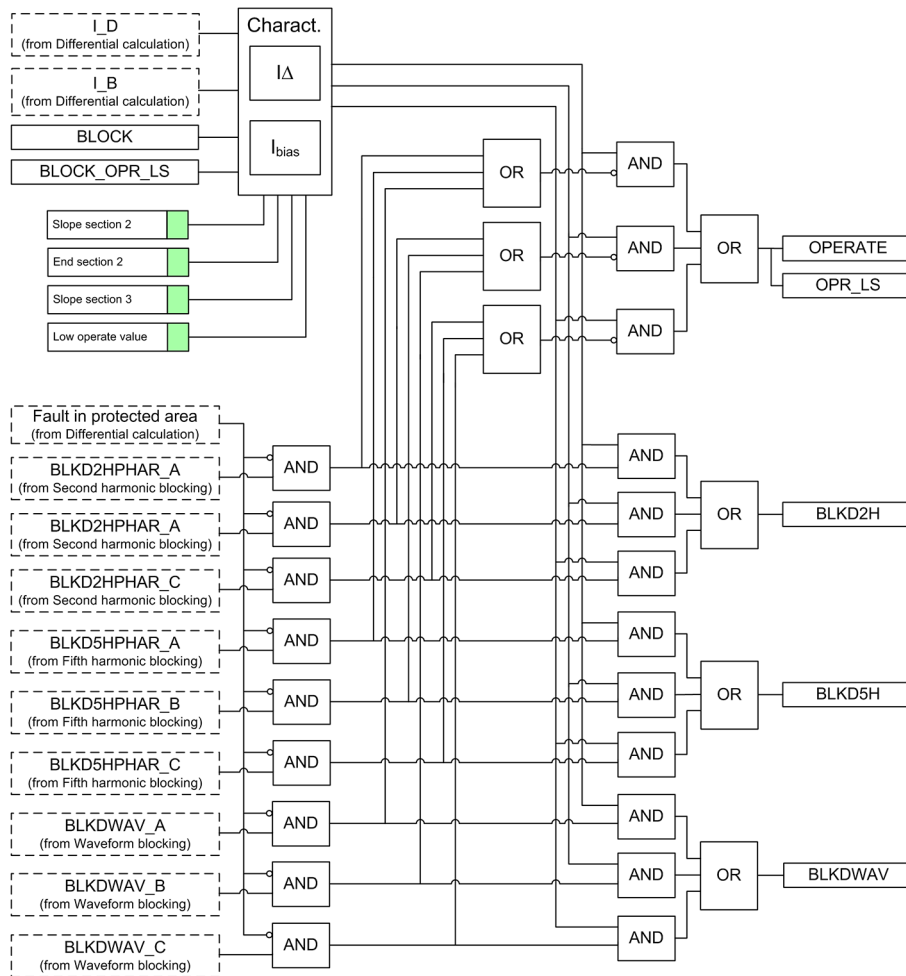


Figure 184: Operation logic of the biased low stage

The high currents passing through a protected object can be caused by the short circuits outside the protected area, the large currents fed by the transformer in motor startup or the transformer inrush situations. Therefore, the operation of the differential protection is biased in respect to the load current. In biased differential protection, the higher the differential current required for the protection to operate, the higher the load current.

The operating characteristic of the biased low stage is determined by *Low operate value*, *Slope section 2* and the setting of the second turning point of the operating characteristic curve, *End section 2* (the first turning point is fixed). The settings are the same for all the phases. When the differential current exceeds the operating value determined by the operating characteristic, the differential function awakes. If the differential current stays above the operating value continuously for a suitable period, which is 1.1 times the fundamental cycle, the *OPR\_LS* output is activated. The *OPERATE* output is always activated when the *OPR\_LS* output is activated.

The stage can be blocked internally by the second or fifth harmonic restraint, or by special algorithms detecting inrush and current transformer saturation at external faults. When the operation of the biased low stage is blocked by the second harmonic blocking functionality, the *BLKD2H* output is activated.

When operation of the biased low stage is blocked by the fifth harmonic blocking functionality, the `BLKD5H` output is activated. Correspondingly, when the operation of the biased low stage is blocked by the waveform blocking functionality, the `BLKDWAV` output is activated according to the phase information.

When required, the operate outputs of the biased low stage can be blocked by the `BLK_OPR_LS` or `BLOCK` external control signals.

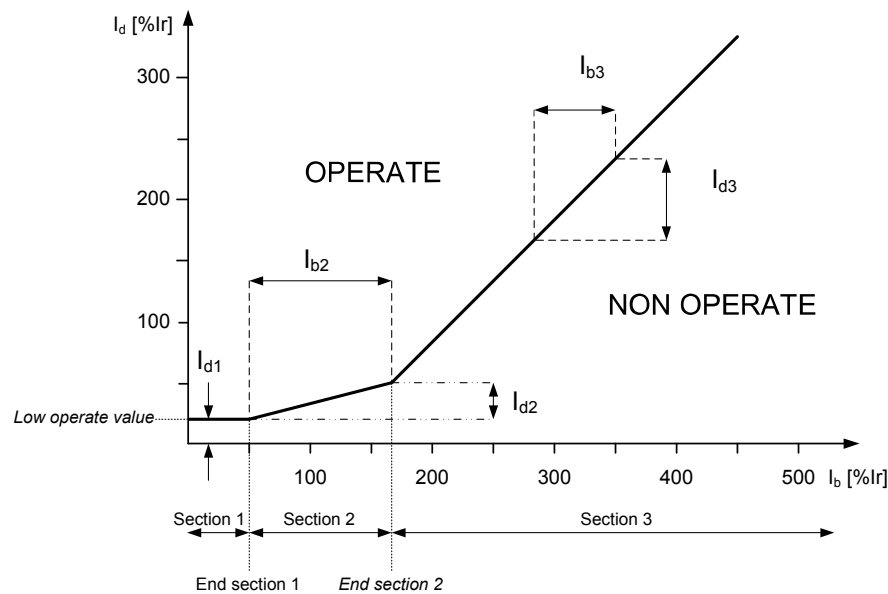


Figure 185: Operation characteristic for biased operation of TR2PTDF

The *Low operate value* of the biased stage of the differential function is determined according to the operation characteristic:

$$\text{Low operate value} = I_{d1}$$

*Slope section 2* and *Slope section 3* are determined correspondingly:

$$\text{Slope section 2} = \frac{I_{d2}}{I_{b2}} \cdot 100\%$$

$$\text{Slope section 3} = \frac{I_{d3}}{I_{b3}} \cdot 100\%$$

The second turning point *End section 2* can be set in the range of 100 percent to 500 percent.

The slope of the differential function's operating characteristic curve varies in the different sections of the range.

- In section 1, where 0 percent  $I_r < I_b < \text{End section 1}$ , *End section 1* being fixed to 50 percent  $I_r$ , the differential current required for tripping is constant. The value of the differential current is the same as the *Low operate value* selected for the function. *Low operate value* basically allows the no-load current of the power transformer and small inaccuracies of the current transformers, but it can also be used to influence the overall level of the operating characteristic. At the rated current, the no-load losses of the power transformer are about 0.2 percent. If the supply voltage of the power transformer suddenly increases due to operational disturbances, the magnetizing current of the transformer increases as well. In

general the magnetic flux density of the transformer is rather high at rated voltage and a rise in voltage by a few percent causes the magnetizing current to increase by tens of percent. This should be considered in *Low operate value*

- In section 2, where  $I_b/I_n < \text{End section 2}$ , is called the influence area of *Slope section 2*. In this section, variations in the starting ratio affect the slope of the characteristic, that is, how big a change in the differential current is required for tripping in comparison with the change in the load current. The starting ratio should consider CT errors and variations in the transformer tap changer position (if not compensated). Too high a starting ratio should be avoided, because the sensitivity of the protection for detecting inter-turn faults depends basically on the starting ratio.
- In section 3, where  $I_b/I_n > \text{End section 2}$ , the slope of the characteristic can be set by *Slope section 3* that defines the increase in the differential current to the corresponding increase in the biasing current.

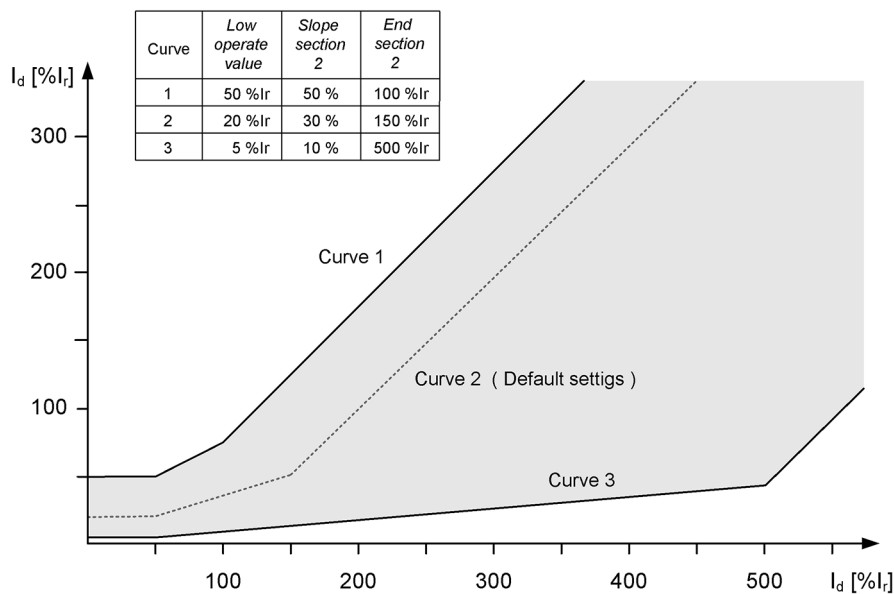


Figure 186: Setting range for biased low stage

If the biasing current is small compared to the differential current of the phase angle between the winding 1 and winding 2 phase currents is close to zero (in a normal situation, the phase difference is 180 degrees), a fault has most likely occurred in the area protected by TR2PTDF. Then the internal blocking signals of the biased stage are inhibited.

**Instantaneous high stage**

The instantaneous high stage operation can be enabled and disabled with the *Enable high set* setting. The corresponding parameter values are "TRUE" and "FALSE."

The operation of the instantaneous high stage is not biased. The instantaneous stage operates and the output OPR\_HS is activated when the amplitude of the fundamental frequency component of the differential current exceeds the set *High operate value* or when the instantaneous value of the differential current exceeds 2.5 times the value of *High operate value*. The factor 2.5 (=1.8 × √2) is due to the maximum asymmetric short circuit current.



If the biasing current is small compared to the differential current or the phase angle between the winding 1 and winding 2 phase currents is close to zero (in a normal situation, the phase difference is 180 degrees), a fault has occurred in the area protected by TR2PTDF. Then the operation value set for the instantaneous stage is automatically halved and the internal blocking signals of the biased stage are inhibited.

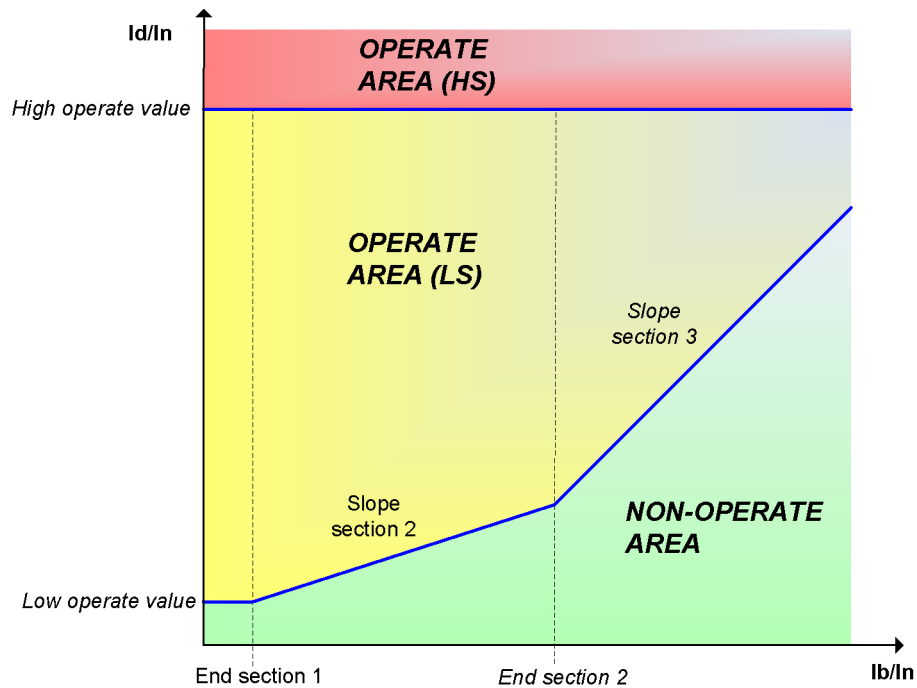


Figure 187: Operating characteristics of the protection. (LS) stands for the biased low stage and (HS) for the instantaneous high stage

The OPERATE output is activated always when the OPR\_HS output activates .

The internal blocking signals of the differential function do not prevent the operate signal of the instantaneous differential current stage. When required, the operate outputs of the instantaneous high stage can be blocked by the BLK\_OPR\_HS and BLOCK external control signals.

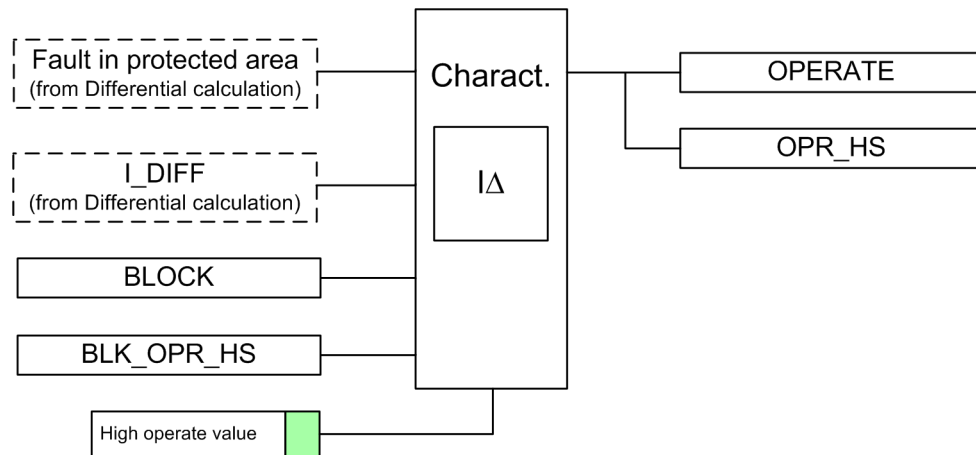


Figure 188: Operation logic of instantaneous high stage

### Reset of the blocking signals (de-block)

All three blocking signals, that is, waveform and second and fifth harmonic, have a counter, which holds the blocking on for a certain time after the blocking conditions have ceased to be fulfilled. The deblocking takes place when those counters have elapsed. This is a normal case of deblocking.

The blocking signals can be reset immediately if a very high differential current is measured or if the phase difference of the compared currents (the angle between the compared currents) is close to zero after the automatic vector group matching has been made (in a normal situation, the phase difference is 180 degrees). This does not, however, reset the counters holding the blockings, so the blocking signals may return when these conditions are not valid anymore.

### External blocking functionality

TR2PTDF has three inputs for blocking.

- When the `BLOCK` input is active ("TRUE"), the operation of the function is blocked but measurement output signals are still updated.
- When the `BLK_OPR_LS` input is active ("TRUE"), TR2PTDF operates normally except that the `OPR_LS` output is not active or activated in any circumstance. Additionally, the `OPERATE` output can be activated only by the instantaneous high stage (if not blocked as well).
- When the `BLK_OPR_HS` input is active ("TRUE"), TR2PTDF operates normally except that the `OPR_HS` output is not active or activated in any circumstance. Additionally, the `OPERATE` output can be activated only by the biased low stage (if not blocked as well).

### 3.3.1.5

#### Application

TR2PTDF is a unit protection function serving as the main protection for transformers in case of winding failure. The protective zone of a differential protection includes the transformer, the bus-work or the cables between the current transformer and the power transformer. When bushing current transformers are used for the differential IED, the protective zone does not include the bus work or cables between the circuit breaker and the power transformer.

In some substations, there is a current differential protection for the busbar. The busbar protection includes bus work or cables between the circuit breaker and the power transformer. Internal electrical faults are very serious and cause immediate damage. Short circuits and earth faults in windings and terminals are normally detected by the differential protection. If enough turns are short-circuited, the interturn faults, which are flashovers between the conductors within the same physical winding, are also detected. The interturn faults are the most difficult transformer-winding faults to detect with electrical protections. A small interturn fault including a few turns results in an undetectable amount of current until the fault develops into an earth fault. Therefore, it is important that the differential protection has a high level of sensitivity and that it is possible to use a sensitive setting without causing unwanted operations for external faults.

It is important that the faulty transformer is disconnected as fast as possible. As TR2PTDF is a unit protection function, it can be designed for fast tripping, thus providing a selective disconnection of the faulty transformer. TR2PTDF should never operate to faults outside the protective zone.

TR2PTDF compares the current flowing into the transformer to the current leaving the transformer. A correct analysis of fault conditions by TR2PTDF must consider the changes to voltages, currents and phase angles. The traditional transformer differential protection functions required auxiliary transformers for the correction of the phase shift and turns ratio. The numerical microprocessor based differential algorithm implemented in TR2PTDF compensates for both the turns ratio and the phase shift internally in the software.

The differential current should theoretically be zero during normal load or external faults if the turns ratio and the phase shift are correctly compensated. However, there are several different phenomena other than internal faults that cause unwanted and false differential currents. The main reasons for unwanted differential currents are:

- Mismatch due to varying tap changer positions
- Different characteristics, loads and operating conditions of the current transformers
- Zero sequence currents that only flow on one side of the power transformer
- Normal magnetizing currents
- Magnetizing inrush currents
- Overexcitation magnetizing currents.

TR2PTDF is designed mainly for the protection of two-winding transformers. TR2PTDF can also be utilized for the protection of generator-transformer blocks as well as short cables and overhead lines. If the distance between the measuring points is relatively long in line protection, interposing CTs can be required to reduce the burden of the CTs.

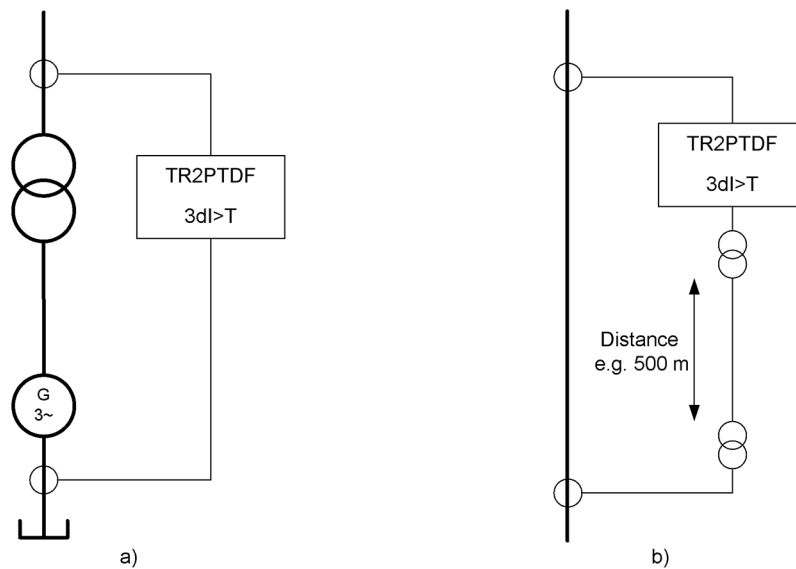


Figure 189: Differential protection of a generator-transformer block and short cable/line

TR2PTDF can also be used in three-winding transformer applications or two-winding transformer applications with two output feeders.

On the double-feeder side of the power transformer, the current of the two CTs per phase must be summed by connecting the two CTs of each phase in parallel. Generally this requires the interposing CTs to handle the vector group and/or ratio mismatch between the two windings/feeders.

The accuracy limit factor for the interposing CT must fulfill the same requirements as the main CTs. Please note that the interposing CT imposes an additional burden to the main CTs.

The most important rule in these applications is that at least 75 percent of the short-circuit power has to be fed on the side of the power transformer with only one connection to the IED.

TR2PTDF can also be used for the protection of the power transformer feeding the frequency converter. An interposing CT is required for matching the three-winding transformer currents to a two-winding IED.

The fundamental frequency component is numerically filtered with a Fourier filter, DFT. The filter suppresses frequencies other than the set fundamental frequency, and therefore the IED is not adapted for measuring the output of the frequency converter, that is, TR2PTDF is not suited for protecting of a power transformer or motor fed by a frequency converter

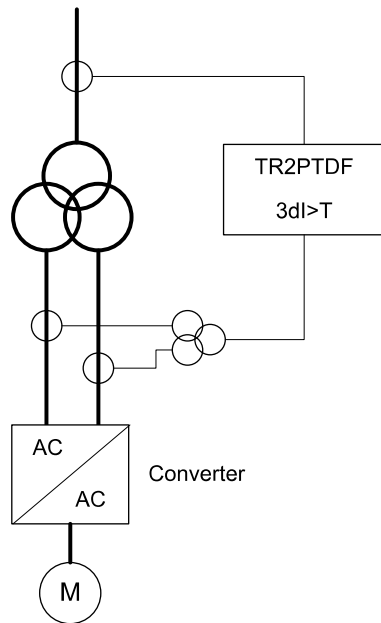


Figure 190: Protection of the power transformer feeding the frequency converter

#### Transforming ratio correction of CTs

The CT secondary currents often differ from the rated current at the rated load of the power transformer. The CT transforming ratios can be corrected on both sides of the power transformer with the *CT ratio Cor Wnd 1* and *CT ratio Cor Wnd 2* settings.

First, the rated load of the power transformer must be calculated on both sides when the apparent power and phase-to-phase voltage are known.

$$I_{nT} = \frac{S_n}{\sqrt{3} \times U_n}$$

(FranksTitel 20)

|          |                                      |
|----------|--------------------------------------|
| $I_{nT}$ | rated load of the power transformer  |
| $S_n$    | rated power of the power transformer |
| $U_n$    | rated phase-to-phase voltage         |

Next, the settings for the CT ratio correction can be calculated.

$$CT \text{ ratio correction} = \frac{I_{1n}}{I_{nT}}$$

(test 21)

|          |                                   |
|----------|-----------------------------------|
| $I_{1n}$ | nominal primary current of the CT |
|----------|-----------------------------------|

After the CT ratio correction, the measured currents and corresponding setting values of TR2PTDF are expressed in multiples of the rated power transformer current  $I_r$  ( $\times I_r$ ) or percentage value of  $I_r$  ( $\%I_r$ ).

The rated input current (1A or 5A) of the relay does not have to be same for the HV and the LV side. For example, the rated secondary current of 5 A can be used on the HV side, while 1A is used on the LV side or vice versa.

**Example**

The rated power of the transformer is 25 MVA, the ratio of the CTs on the 110 kV side is 300/1 and that on the 21 kV side is 1000/1

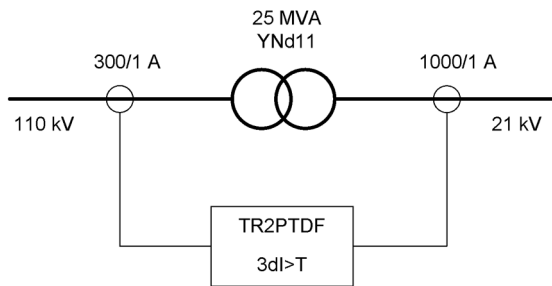


Figure 191: Example of two-winding power transformer differential protection

The rated load of the transformer is calculated:

HV side:  $I_{nT\_Wnd1} = 25 \text{ MVA} / (1.732 \times 110 \text{ kV}) = 131.2 \text{ A}$

LV side:  $I_{nT\_Wnd2} = 25 \text{ MVA} / (1.732 \times 21 \text{ kV}) = 687.3 \text{ A}$

**Settings:**

CT ratio Cor Wnd 1=  $300 \text{ A} / 131.2 \text{ A} = \text{“2.29”}$

CT ratio Cor Wnd 2=  $1000 \text{ A} / 687.3 \text{ A} = \text{“1.45”}$

**Vector group matching and elimination of the zero-sequence component**

The vector group of the power transformer is numerically matched on the high voltage and low voltage sides by means of the *Winding 1 type*, *Winding 2 type* and *Clock number* settings. Thus no interposing CTs are needed if there is only a power transformer inside the protected zone. The matching is based on phase shifting and a numerical delta connection in the IED. If the neutral of a star-connected power transformer is earthed, any earth fault in the network is perceived by the IED as a differential current. The elimination of the zero-sequence component can be selected for that winding by setting the *Zro A elimination* parameter.

Table 372: TR2PTDF settings corresponding to the power transformer vector groups and zero-sequence elimination

| Vector group of the transformer | Winding 1 type | Winding 2 type | Clock number | Zro A Elimination |
|---------------------------------|----------------|----------------|--------------|-------------------|
| Yy0                             | Y              | y              | Clk Num 0    | Not needed        |
| YNy0                            | YN             | y              | Clk Num 0    | HV side           |
| YNyn0                           | YN             | yn             | Clk Num 0    | HV & LV side      |
| Yyn0                            | Y              | yn             | Clk Num 0    | LV side           |
| Yy2                             | Y              | y              | Clk Num 2    | Not needed        |

Table continues on the next page

| Vector group of the transformer | Winding 1 type | Winding 2 type | Clock number | Zro A Elimination |
|---------------------------------|----------------|----------------|--------------|-------------------|
| YNy2                            | YN             | y              | Clk Num 2    | Not needed        |
| YNyn2                           | YN             | yn             | Clk Num 2    | Not needed        |
| Yyn2                            | Y              | yn             | Clk Num 2    | Not needed        |
| Yy4                             | Y              | y              | Clk Num 4    | Not needed        |
| YNy4                            | YN             | y              | Clk Num 4    | Not needed        |
| YNyn4                           | YN             | yn             | Clk Num 4    | Not needed        |
| Yyn4                            | Y              | yn             | Clk Num 4    | Not needed        |
| Yy6                             | Y              | y              | Clk Num 6    | Not needed        |
| YNy6                            | YN             | y              | Clk Num 6    | HV side           |
| YNyn6                           | YN             | yn             | Clk Num 6    | HV & LV side      |
| Yyn6                            | Y              | yn             | Clk Num 6    | LV side           |
| Yy8                             | Y              | y              | Clk Num 8    | Not needed        |
| YNy8                            | YN             | y              | Clk Num 8    | Not needed        |
| YNyn8                           | YN             | yn             | Clk Num 8    | Not needed        |
| Yyn8                            | Y              | yn             | Clk Num 8    | Not needed        |
| Yy10                            | Y              | y              | Clk Num 10   | Not needed        |
| YNy10                           | YN             | y              | Clk Num 10   | Not needed        |
| YNyn10                          | YN             | yn             | Clk Num 10   | Not needed        |
| Yyn10                           | Y              | yn             | Clk Num 10   | Not needed        |
| Yd1                             | Y              | d              | Clk Num 1    | Not needed        |
| YNd1                            | YN             | d              | Clk Num 1    | Not needed        |
| Yd5                             | Y              | d              | Clk Num 5    | Not needed        |
| YNd5                            | YN             | d              | Clk Num 5    | Not needed        |
| Yd7                             | Y              | d              | Clk Num 7    | Not needed        |
| YNd7                            | YN             | d              | Clk Num 7    | Not needed        |
| Yd11                            | Y              | d              | Clk Num 11   | Not needed        |
| YNd11                           | YN             | d              | Clk Num 11   | Not needed        |
| Dd0                             | D              | d              | Clk Num 0    | Not needed        |
| Dd2                             | D              | d              | Clk Num 2    | Not needed        |
| Dd4                             | D              | d              | Clk Num 4    | Not needed        |
| Dd6                             | D              | d              | Clk Num 6    | Not needed        |
| Dd8                             | D              | d              | Clk Num 8    | Not needed        |
| Dd10                            | D              | d              | Clk Num 10   | Not needed        |
| Dy1                             | D              | y              | Clk Num 1    | Not needed        |
| Dyn1                            | D              | yn             | Clk Num 1    | Not needed        |
| Dy5                             | D              | y              | Clk Num 5    | Not needed        |
| Dyn5                            | D              | yn             | Clk Num 5    | Not needed        |

*Table continues on the next page*

| Vector group of the transformer | Winding 1 type | Winding 2 type | Clock number | Zro A Elimination |
|---------------------------------|----------------|----------------|--------------|-------------------|
| Dy7                             | D              | y              | Clk Num 7    | Not needed        |
| Dyn7                            | D              | yn             | Clk Num 7    | Not needed        |
| Dy11                            | D              | y              | Clk Num 11   | Not needed        |
| Dyn11                           | D              | yn             | Clk Num 11   | Not needed        |
| Yz1                             | Y              | z              | Clk Num 1    | Not needed        |
| YNz1                            | YN             | z              | Clk Num 1    | Not needed        |
| YNzn1                           | YN             | zn             | Clk Num 1    | LV side           |
| Yzn1                            | Y              | zn             | Clk Num 1    | Not needed        |
| Yz5                             | Y              | z              | Clk Num 5    | Not needed        |
| YNz5                            | YN             | z              | Clk Num 5    | Not needed        |
| YNzn5                           | YN             | zn             | Clk Num 5    | LV side           |
| Yzn5                            | Y              | zn             | Clk Num 5    | Not needed        |
| Yz7                             | Y              | z              | Clk Num 7    | Not needed        |
| YNz7                            | YN             | z              | Clk Num 7    | Not needed        |
| YNzn7                           | YN             | zn             | Clk Num 7    | LV side           |
| Yzn7                            | Y              | zn             | Clk Num 7    | Not needed        |
| Yz11                            | Y              | z              | Clk Num 11   | Not needed        |
| YNz11                           | YN             | z              | Clk Num 11   | Not needed        |
| YNzn11                          | YN             | zn             | Clk Num 11   | LV side           |
| Yzn11                           | Y              | zn             | Clk Num 11   | Not needed        |
| Zy1                             | Z              | y              | Clk Num 1    | Not needed        |
| Zyn1                            | Z              | yn             | Clk Num 1    | Not needed        |
| ZNyn1                           | ZN             | yn             | Clk Num 1    | HV side           |
| ZNy1                            | ZN             | y              | Clk Num 1    | Not needed        |
| Zy5                             | Z              | y              | Clk Num 5    | Not needed        |
| Zyn5                            | Z              | yn             | Clk Num 5    | Not needed        |
| ZNyn5                           | ZN             | yn             | Clk Num 5    | HV side           |
| ZNy5                            | ZN             | y              | Clk Num 5    | Not needed        |
| Zy7                             | Z              | y              | Clk Num 7    | Not needed        |
| Zyn7                            | Z              | yn             | Clk Num 7    | Not needed        |
| ZNyn7                           | ZN             | yn             | Clk Num 7    | HV side           |
| ZNy7                            | ZN             | y              | Clk Num 7    | Not needed        |
| Zy11                            | Z              | y              | Clk Num 11   | Not needed        |
| Zyn11                           | Z              | yn             | Clk Num 11   | Not needed        |
| ZNyn11                          | ZN             | yn             | Clk Num 11   | HV side           |
| ZNy11                           | ZN             | y              | Clk Num 11   | Not needed        |
| Dz0                             | D              | z              | Clk Num 0    | Not needed        |

*Table continues on the next page*



| Vector group of the transformer | Winding 1 type | Winding 2 type | Clock number | Zro A Elimination |
|---------------------------------|----------------|----------------|--------------|-------------------|
| Dzn0                            | D              | zn             | Clk Num 0    | LV side           |
| Dz2                             | D              | z              | Clk Num 2    | Not needed        |
| Dzn2                            | D              | zn             | Clk Num 2    | Not needed        |
| Dz4                             | D              | z              | Clk Num 4    | Not needed        |
| Dzn4                            | D              | zn             | Clk Num 4    | Not needed        |
| Dz6                             | D              | z              | Clk Num 6    | Not needed        |
| Dzn6                            | D              | zn             | Clk Num 6    | LV side           |
| Dz8                             | D              | z              | Clk Num 8    | Not needed        |
| Dzn8                            | D              | zn             | Clk Num 8    | Not needed        |
| Dz10                            | D              | z              | Clk Num 10   | Not needed        |
| Dzn10                           | D              | zn             | Clk Num 10   | Not needed        |
| Zd0                             | Z              | d              | Clk Num 0    | Not needed        |
| ZNd0                            | ZN             | d              | Clk Num 0    | HV side           |
| Zd2                             | Z              | d              | Clk Num 2    | Not needed        |
| ZNd2                            | ZN             | d              | Clk Num 2    | Not needed        |
| Zd4                             | Z              | d              | Clk Num 4    | Not needed        |
| ZNd4                            | ZN             | d              | Clk Num 4    | Not needed        |
| Zd6                             | Z              | d              | Clk Num 6    | Not needed        |
| ZNd6                            | ZN             | d              | Clk Num 6    | HV side           |
| Zd8                             | Z              | d              | Clk Num 8    | Not needed        |
| ZNd8                            | ZN             | d              | Clk Num 8    | Not needed        |
| Zd10                            | Z              | d              | Clk Num 10   | Not needed        |
| ZNd10                           | ZN             | d              | Clk Num 10   | Not needed        |
| Zz0                             | Z              | z              | Clk Num 0    | Not needed        |
| ZNz0                            | ZN             | z              | Clk Num 0    | HV side           |
| ZNzn0                           | ZN             | zn             | Clk Num 0    | HV & LV side      |
| Zzn0                            | Z              | zn             | Clk Num 0    | LV side           |
| Zz2                             | Z              | z              | Clk Num 2    | Not needed        |
| ZNz2                            | ZN             | z              | Clk Num 2    | Not needed        |
| ZNzn2                           | ZN             | zn             | Clk Num 2    | Not needed        |
| Zzn2                            | Z              | zn             | Clk Num 2    | Not needed        |
| Zz4                             | Z              | z              | Clk Num 4    | Not needed        |
| ZNz4                            | ZN             | z              | Clk Num 4    | Not needed        |
| ZNzn4                           | ZN             | zn             | Clk Num 4    | Not needed        |
| Zzn4                            | Z              | zn             | Clk Num 4    | Not needed        |
| Zz6                             | Z              | z              | Clk Num 6    | Not needed        |
| ZNz6                            | ZN             | z              | Clk Num 6    | HV side           |

*Table continues on the next page*

| Vector group of the transformer | Winding 1 type | Winding 2 type | Clock number | Zro A Elimination |
|---------------------------------|----------------|----------------|--------------|-------------------|
| ZNzn6                           | ZN             | zn             | Clk Num 6    | HV & LV side      |
| Zzn6                            | Z              | zn             | Clk Num 6    | LV side           |
| Zz8                             | Z              | z              | Clk Num 8    | Not needed        |
| ZNz8                            | ZN             | z              | Clk Num 8    | Not needed        |
| ZNzn8                           | ZN             | zn             | Clk Num 8    | Not needed        |
| Zzn8                            | Z              | zn             | Clk Num 8    | Not needed        |
| Zz10                            | Z              | z              | Clk Num 10   | Not needed        |
| ZNz10                           | ZN             | z              | Clk Num 10   | Not needed        |
| ZNzn10                          | ZN             | zn             | Clk Num 10   | Not needed        |
| Zzn10                           | Z              | zn             | Clk Num 10   | Not needed        |
| Yy0                             | Y              | y              | Clk Num 0    | Not needed        |
| YNy0                            | YN             | y              | Clk Num 0    | HV side           |
| YNyn0                           | YN             | yn             | Clk Num 0    | HV & LV side      |
| Yyn0                            | Y              | yn             | Clk Num 0    | LV side           |
| Yy2                             | Y              | y              | Clk Num 2    | Not needed        |
| YNy2                            | YN             | y              | Clk Num 2    | Not needed        |
| YNyn2                           | YN             | yn             | Clk Num 2    | Not needed        |
| Yyn2                            | Y              | yn             | Clk Num 2    | Not needed        |
| Yy4                             | Y              | y              | Clk Num 4    | Not needed        |
| YNy4                            | YN             | y              | Clk Num 4    | Not needed        |
| YNyn4                           | YN             | yn             | Clk Num 4    | Not needed        |
| Yyn4                            | Y              | yn             | Clk Num 4    | Not needed        |
| Yy6                             | Y              | y              | Clk Num 6    | Not needed        |
| YNy6                            | YN             | y              | Clk Num 6    | HV side           |
| YNyn6                           | YN             | yn             | Clk Num 6    | HV & LV side      |
| Yyn6                            | Y              | yn             | Clk Num 6    | LV side           |
| Yy8                             | Y              | y              | Clk Num 8    | Not needed        |
| YNy8                            | YN             | y              | Clk Num 8    | Not needed        |
| YNyn8                           | YN             | yn             | Clk Num 8    | Not needed        |
| Yyn8                            | Y              | yn             | Clk Num 8    | Not needed        |
| Yy10                            | Y              | y              | Clk Num 10   | Not needed        |
| YNy10                           | YN             | y              | Clk Num 10   | Not needed        |
| YNyn10                          | YN             | yn             | Clk Num 10   | Not needed        |
| Yyn10                           | Y              | yn             | Clk Num 10   | Not needed        |
| Yd1                             | Y              | d              | Clk Num 1    | Not needed        |
| YNd1                            | YN             | d              | Clk Num 1    | Not needed        |
| Yd5                             | Y              | d              | Clk Num 5    | Not needed        |

*Table continues on the next page*

| Vector group of the transformer | Winding 1 type | Winding 2 type | Clock number | Zro A Elimination |
|---------------------------------|----------------|----------------|--------------|-------------------|
| YNd5                            | YN             | d              | Clk Num 5    | Not needed        |
| Yd7                             | Y              | d              | Clk Num 7    | Not needed        |
| YNd7                            | YN             | d              | Clk Num 7    | Not needed        |
| Yd11                            | Y              | d              | Clk Num 11   | Not needed        |
| YNd11                           | YN             | d              | Clk Num 11   | Not needed        |
| Dd0                             | D              | d              | Clk Num 0    | Not needed        |
| Dd2                             | D              | d              | Clk Num 2    | Not needed        |
| Dd4                             | D              | d              | Clk Num 4    | Not needed        |
| Dd6                             | D              | d              | Clk Num 6    | Not needed        |
| Dd8                             | D              | d              | Clk Num 8    | Not needed        |
| Dd10                            | D              | d              | Clk Num 10   | Not needed        |
| Dy1                             | D              | y              | Clk Num 1    | Not needed        |
| Dyn1                            | D              | yn             | Clk Num 1    | Not needed        |
| Dy5                             | D              | y              | Clk Num 5    | Not needed        |
| Dyn5                            | D              | yn             | Clk Num 5    | Not needed        |
| Dy7                             | D              | y              | Clk Num 7    | Not needed        |
| Dyn7                            | D              | yn             | Clk Num 7    | Not needed        |
| Dy11                            | D              | y              | Clk Num 11   | Not needed        |
| Dyn11                           | D              | yn             | Clk Num 11   | Not needed        |
| Yz1                             | Y              | z              | Clk Num 1    | Not needed        |
| YNz1                            | YN             | z              | Clk Num 1    | Not needed        |
| YNzn1                           | YN             | zn             | Clk Num 1    | LV side           |
| Yzn1                            | Y              | zn             | Clk Num 1    | Not needed        |
| Yz5                             | Y              | z              | Clk Num 5    | Not needed        |
| YNz5                            | YN             | z              | Clk Num 5    | Not needed        |
| YNzn5                           | YN             | zn             | Clk Num 5    | LV side           |
| Yzn5                            | Y              | zn             | Clk Num 5    | Not needed        |
| Yz7                             | Y              | z              | Clk Num 7    | Not needed        |
| YNz7                            | YN             | z              | Clk Num 7    | Not needed        |
| YNzn7                           | YN             | zn             | Clk Num 7    | LV side           |
| Yzn7                            | Y              | zn             | Clk Num 7    | Not needed        |
| Yz11                            | Y              | z              | Clk Num 11   | Not needed        |
| YNz11                           | YN             | z              | Clk Num 11   | Not needed        |
| YNzn11                          | YN             | zn             | Clk Num 11   | LV side           |
| Yzn11                           | Y              | zn             | Clk Num 11   | Not needed        |
| Zy1                             | Z              | y              | Clk Num 1    | Not needed        |
| Zyn1                            | Z              | yn             | Clk Num 1    | Not needed        |

*Table continues on the next page*

| Vector group of the transformer | Winding 1 type | Winding 2 type | Clock number | Zro A Elimination |
|---------------------------------|----------------|----------------|--------------|-------------------|
| ZNyn1                           | ZN             | yn             | Clk Num 1    | HV side           |
| ZNy1                            | ZN             | y              | Clk Num 1    | Not needed        |
| Zy5                             | Z              | y              | Clk Num 5    | Not needed        |
| Zyn5                            | Z              | yn             | Clk Num 5    | Not needed        |
| ZNyn5                           | ZN             | yn             | Clk Num 5    | HV side           |
| ZNy5                            | ZN             | y              | Clk Num 5    | Not needed        |
| Zy7                             | Z              | y              | Clk Num 7    | Not needed        |
| Zyn7                            | Z              | yn             | Clk Num 7    | Not needed        |
| ZNyn7                           | ZN             | yn             | Clk Num 7    | HV side           |
| ZNy7                            | ZN             | y              | Clk Num 7    | Not needed        |
| Yy0                             | Y              | y              | Clk Num 0    | Not needed        |

### Commissioning

The correct settings, which are *CT connection type*, *Winding 1 type*, *Winding 2 type* and *Clock number*, for the connection group compensation can be verified by monitoring the angle values  $I\_ANGL\_A1\_B1$ ,  $I\_ANGL\_B1\_C1$ ,  $I\_ANGL\_C1\_A1$ ,  $I\_ANGL\_A2\_B2$ ,  $I\_ANGL\_B2\_C2$ ,  $I\_ANGL\_C2\_A2$ ,  $I\_ANGL\_A1\_A2$ ,  $I\_ANGL\_B1\_B2$  and  $I\_ANGL\_C1\_C2$  while injecting the current into the transformer. These angle values are calculated from the compensated currents. See signal description from Monitored data table.

When a station service transformer is available, it can be used to provide current to the high voltage side windings while the low voltage side windings are short-circuited. This way the current can flow in both the high voltage and low voltage windings. The commissioning signals can be provided by other means as well. The minimum current to allow for phase current and angle monitoring is  $0.015 I_r$ .

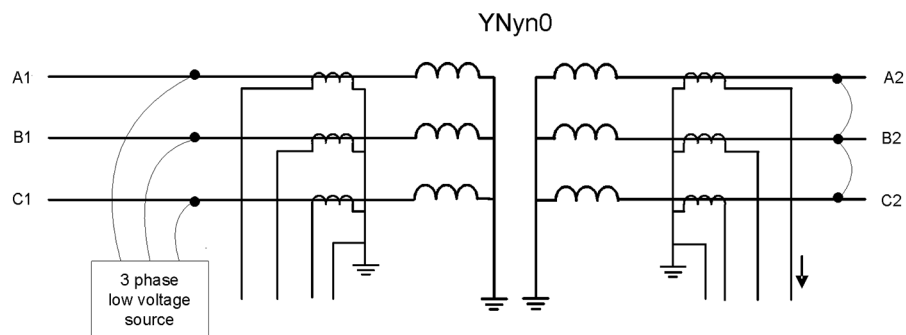


Figure 192: Low voltage test arrangement. The three-phase low voltage source can be the station service transformer.

The *Tapped winding* control setting parameter has to be set to “Not in use” to make sure that the monitored current values are not scaled by the automatic adaptation to the tap changer position. When only the angle values are required, the setting of *Tapped winding* is not needed since angle values are not affected by the tap changer position adaptation.

When injecting the currents in the high voltage winding, the angle values  $I\_ANGL\_A1\_B1$ ,  $I\_ANGL\_B1\_C1$ ,  $I\_ANGL\_C1\_A1$ ,  $I\_ANGL\_A2\_B2$ ,  $I\_ANGL\_B2\_C2$

and `I_ANGL_C2_A2` have to show +120 deg. Otherwise the phase order can be wrong or the polarity of a current transformer differs from the polarities of the other current transformers on the same side.

If the angle values `I_ANGL_A1_B1`, `I_ANGL_B1_C1` and `I_ANGL_C1_A1` show -120 deg, the phase order is wrong on the high voltage side. If the angle values `I_ANGL_A2_B2`, `I_ANGL_B2_C2` and `I_ANGL_C2_A2` show -120 deg, the phase order is wrong on the low voltage side. If the angle values `I_ANGL_A1_B1`, `I_ANGL_B1_C1` and `I_ANGL_C1_A1` do not show the same value of +120, the polarity of one current transformer can be wrong. For instance, if the polarity of the current transformer measuring IL2 is wrong, `I_ANGL_A1_B1` shows -60 deg, `I_ANGL_B1_C1` shows -60 deg and `I_ANGL_C1_A1` shows +120 deg.

When the phase order and the angle values are correct, the angle values `I_ANGL_A1_A2`, `I_ANGL_B1_B2` and `I_ANGL_C1_C2` usually show  $\pm 180$  deg. There can be several reasons if the angle values are not  $\pm 180$  deg. If the values are 0 deg, the value given for *CT connection type* is probably wrong. If the angle values are something else, the value for *Clock number* can be wrong. Another reason is that the combination of *Winding 1 type* and *Winding 2 type* does not match *Clock number*. This means that the resulting connection group is not supported.

#### Example

If *Winding 1 type* is set to "Y", *Winding 2 type* is set to "y" and *Clock number* is set to "Clk num 1", the resulting connection group "Yy1" is not a supported combination. Similarly if *Winding 1 type* is set to "Y", *Winding 2 type* is set to "d" and *Clock number* is set to "Clk num 0", the resulting connection group "Yd0" is not a supported combination. All the non-supported combinations of *Winding 1 type*, *Winding 2 type* and *Clock number* settings result in the default connection group compensation that is "Yy0".

### 3.3.1.6

#### CT connections and transformation ratio correction

The connections of the primary current transformers are designated as "Type 1" and "Type 2".

- If the positive directions of the winding 1 and winding 2 IED currents are opposite, the *CT connection type* setting parameter is "Type 1". The connection examples of "Type 1" are as shown in [Figure 193](#) and [Figure 194](#).
- If the positive directions of the winding 1 and winding 2 IED currents equate, the *CT connection type* setting parameter is "Type 2". The connection examples of "Type 2" are as shown in [Figure 195](#) and [Figure 196](#).
- The default value of the *CT connection type* setting is "Type 1".

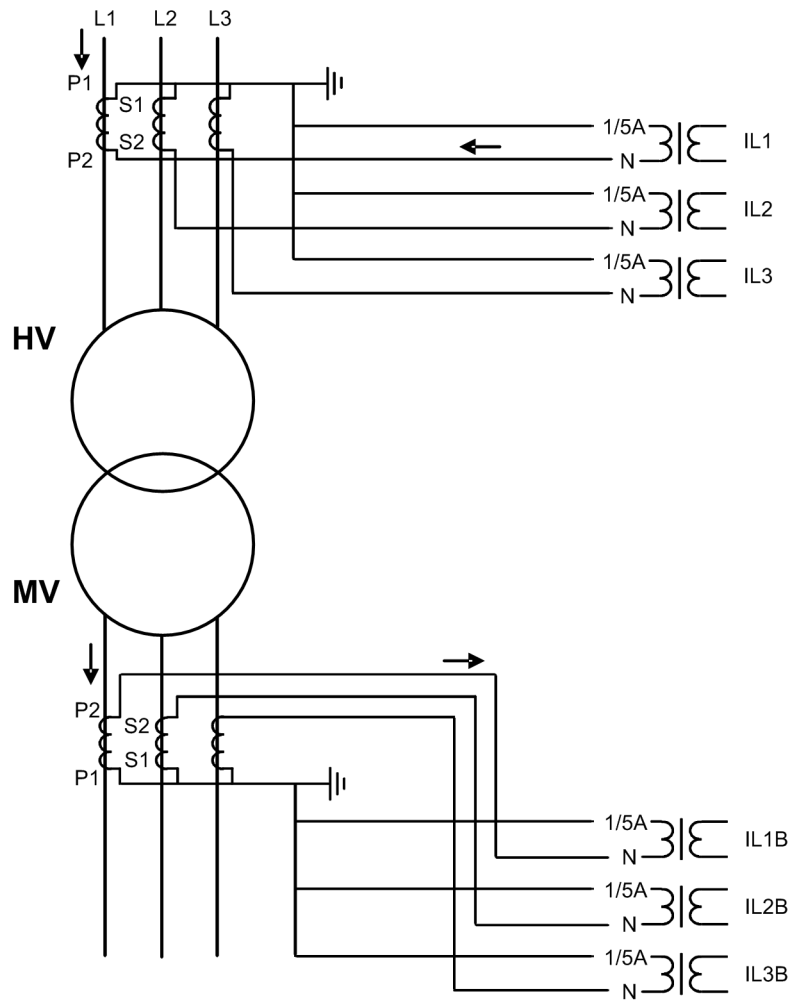


Figure 193: Connection example of current transformers of Type 1

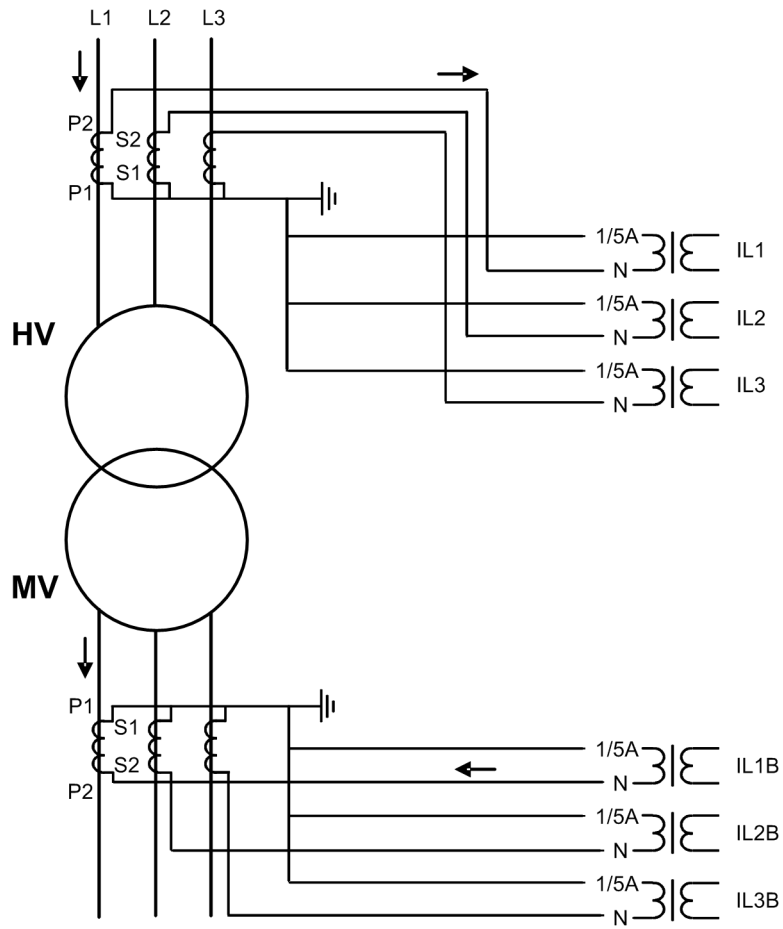


Figure 194: Alternative connection example of current transformers of Type 1

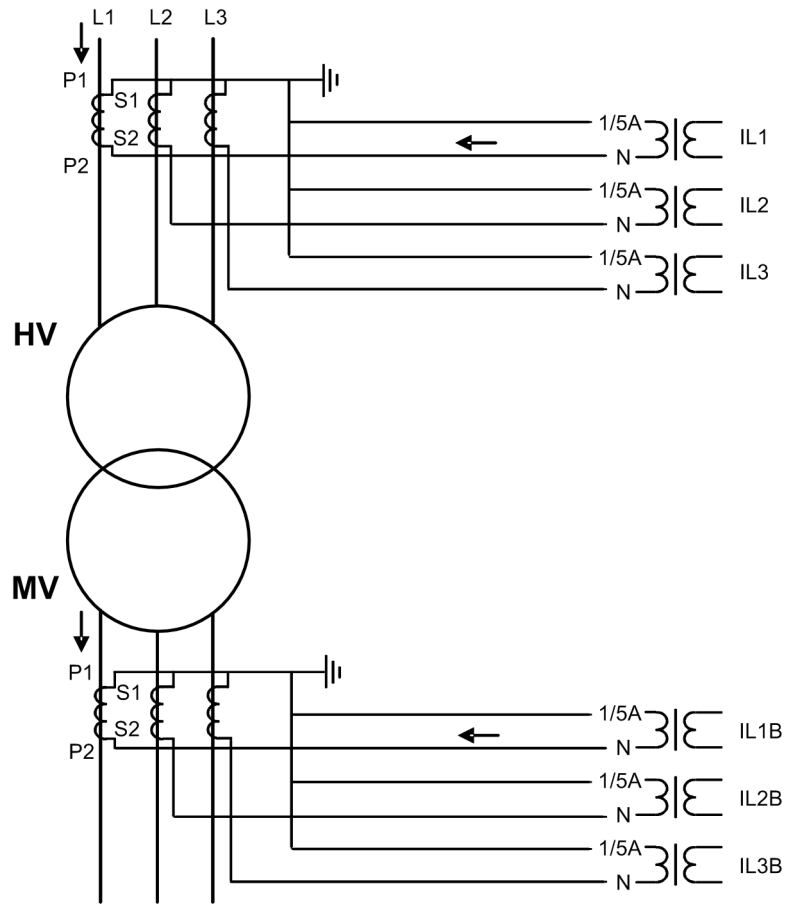


Figure 195: Connection of current transformers of Type 2 and example of the currents during an external fault



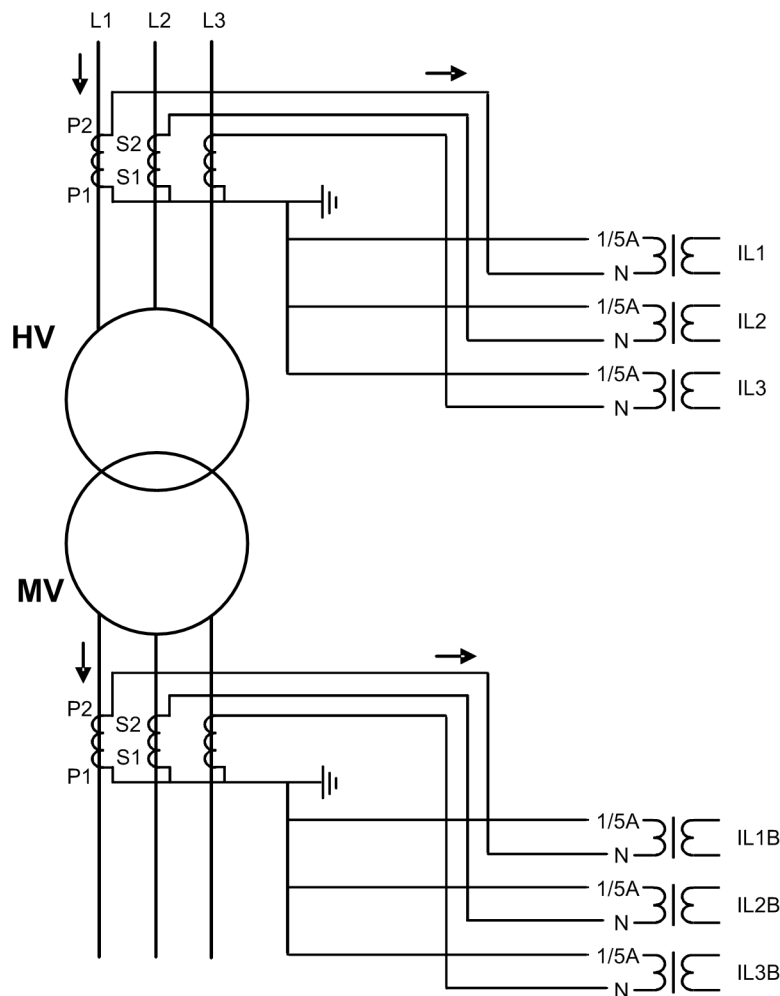


Figure 196: Alternative connection example of current transformers of Type 2

The CT secondary currents often differ from the rated current at the rated load of the power transformer. The CT transforming ratios can be corrected on both sides of the power transformer with the *CT ratio Cor Wnd 1* and *CT ratio Cor Wnd 2* settings.

### 3.3.1.7 Signals

#### TR2PTDF Input signals

Table 373: TR2PTDF Input signals

| Name | Type   | Default | Description             |
|------|--------|---------|-------------------------|
| I_A1 | SIGNAL | 0       | Phase A primary current |
| I_B1 | SIGNAL | 0       | Phase B primary current |

Table continues on the next page

| Name       | Type    | Default | Description                                     |
|------------|---------|---------|---|
| I_C1       | SIGNAL  | 0       | Phase C primary current                         |
| I_A2       | SIGNAL  | 0       | Phase A secondary current                       |
| I_B2       | SIGNAL  | 0       | Phase B secondary current                       |
| I_C2       | SIGNAL  | 0       | Phase C secondary current                       |
| BLOCK      | BOOLEAN | 0=False | Block   |
| BLK_OPR_LS | BOOLEAN | 0=False | Blocks operate outputs from biased stage        |
| BLK_OPR_HS | BOOLEAN | 0=False | Blocks operate outputs from instantaneous stage |
| TAP_POS    | INT8    | 0       | Tap position indication                         |

### TR2PTDF Output signals

Table 374: TR2PTDF Output signals

| Name    | Type    | Description                         |
|---------|---------|-------------------------------------|
| OPERATE | BOOLEAN | Operate combined                    |
| OPR_LS  | BOOLEAN | Operate from low set                |
| OPR_HS  | BOOLEAN | Operate from high set               |
| BLKD2H  | BOOLEAN | 2nd harmonic restraint block status |
| BLKD5H  | BOOLEAN | 5th harmonic restraint block status |
| BLKDWAV | BOOLEAN | Waveform blocking status            |

### 3.3.1.8 Settings

## TR2PTDF Settings

Table 375: TR2PTDF Group settings (Basic)

| Parameter          | Values (Range)  | Unit | Step | Default           | Description   |
|--------------------|---|------|------|-------------------|---|
| High operate value | 500...3000  | %lr  | 10   | 1000              | Instantaneous stage setting   |
| Low operate value  | 5...50  | %lr  | 1    | 20                | Basic setting for biased operation  |
| Slope section 2    | 10...50   | %    | 1    | 30                | Slope of the second line of the operating characteristics                         |
| End section 2      | 100...500   | %lr  | 1    | 150               | Turn-point between the second and the third line of the operating characteristics |
| Restraint mode     | 5=Waveform<br>6=2.h + waveform<br>8=5.h + waveform<br>9=2.h + 5.h + wav |      |      | 9=2.h + 5.h + wav | Restraint mode  |
| Start value 2.H    | 7...20  | %    | 1    | 15                | 2. harmonic blocking ratio  |
| Start value 5.H    | 10...50   | %    | 1    | 35                | 5. harmonic blocking ratio  |

Table 376: TR2PTDF Group settings (Advanced)

| Parameter       | Values (Range)    | Unit | Step | Default | Description  |
|-----------------|-------------------|------|------|---------|--|
| Enable high set | 0=False<br>1=True |      |      | 1=True  | Enable high set stage                                    |
| Slope section 3 | 10...100          | %    | 1    | 100     | Slope of the third line of the operating characteristics |

*Table continues on the next page*

| Parameter            | Values (Range)    | Unit | Step | Default | Description  |
|----------------------|-------------------|------|------|---------|--|
| Harmonic de-block 2. | 0=False<br>1=True |      |      | 1=True  | 2. harmonic deblocking in case of switch on to fault |
| Stop value 5.H       | 10...50           | %    | 1    | 35      | 5. harmonic deblocking ratio                         |
| Harmonic de-block 5. | 0=False<br>1=True |      |      | 0=False | 5. harmonic deblocking in case of severe overvoltage |

Table 377: TR2PTDF Non group settings (Basic)

| Parameter          | Values (Range)   | Unit | Step | Default     | Description  |
|--------------------|--|------|------|-------------|--|
| Operation          | 1=on<br>5=off  |      |      | 1=on        | Operation Off/On   |
| CT connection type | 1=Type 1<br>2=Type 2                                     |      |      | 1=Type 1    | CT connection type. Determined by the directions of the connected current transformers |
| Winding 1 type     | 1=Y<br>2=YN<br>3=D<br>4=Z<br>5=ZN                        |      |      | 1=Y         | Connection of the HV side windings   |
| Winding 2 type     | 1=y<br>2=yn<br>3=d<br>4=z<br>5=zn                        |      |      | 1=y         | Connection of the LV side windings   |
| Clock number       | 0=Clk Num 0<br>1=Clk Num 1<br>2=Clk Num 2<br>4=Clk Num 4 |      |      | 0=Clk Num 0 | Setting the phase shift between HV and LV with clock number for connec-                |

*Table continues on the next page*

| Parameter          | Values (Range)   | Unit | Step | Default          | Description                                |
|--------------------|--|------|------|------------------|--|
|                    | 5=Clk Num 5<br>6=Clk Num 6<br>7=Clk Num 7<br>8=Clk Num 8<br>10=Clk Num 10<br>11=Clk Num 11 |      |      |                  | tion group compensation (e.g. Dyn11 -> 11) |
| Zro A elimination  | 1=Not eliminated<br>2=Winding 1<br>3=Winding 2<br>4=Winding 1 and 2                        |      |      | 1=Not eliminated | Elimination of the zero-sequence current   |
| CT ratio Cor Wnd 1 | 0.40...4.00  |      | 0.01 | 1.00             | CT ratio correction, winding 1             |
| CT ratio Cor Wnd 2 | 0.40...4.00  |      | 0.01 | 1.00             | CT ratio correction, winding 2             |

Table 378: TR2PTDF Non group settings (Advanced)

| Parameter       | Values (Range) | Unit | Step | Default | Description  |
|-----------------|----------------|------|------|---------|--|
| Min winding tap | -36...36       |      | 1    | 36      | The tap position number resulting the minimum number of effective winding turns on the side of the transformer where the tap changer is. |
| Max winding tap | -36...36       |      | 1    | 0       | The tap position number resulting the maximum number of effective winding turns on the side of   |

*Table continues on the next page*

| Parameter      | Values (Range)                             | Unit | Step | Default      | Description  |
|----------------|--|------|------|--------------|--|
|                |  |      |      |              | the transformer where the tap changer is.  |
| Tap nominal    | -36...36                                   |      | 1    | 18           | The nominal position of the tap changer resulting the default transformation ratio of the transformer (as if there was no tap changer) |
| Tapped winding | 1=Not in use<br>2=Winding 1<br>3=Winding 2 |      |      | 1=Not in use | The winding where the tap changer is connected to  |
| Step of tap    | 0.60...9.00                                | %    | 0.01 | 1.50         | The percentage change in voltage corresponding one step of the tap changer   |

3.3.1.9

**Monitored data**

**TR2PTDF Monitored data**

**Table 379: TR2PTDF Monitored data**

| Name     | Type    | Values (Range)    | Unit | Description                                 |
|----------|---------|-------------------|------|---|
| OPR_A    | BOOLEAN | 0=False<br>1=True |      | Operate phase A                             |
| OPR_B    | BOOLEAN | 0=False<br>1=True |      | Operate phase B                             |
| OPR_C    | BOOLEAN | 0=False<br>1=True |      | Operate phase C                             |
| BLKD2H_A | BOOLEAN | 0=False<br>1=True |      | 2nd harmonic restraint block phase A status |

*Table continues on the next page*

| Name         | Type    | Values (Range)    | Unit | Description   |
|--------------|---------|-------------------|------|---|
| BLKD2H_B     | BOOLEAN | 0=False<br>1=True |      | 2nd harmonic restraint block phase B status           |
| BLKD2H_C     | BOOLEAN | 0=False<br>1=True |      | 2nd harmonic restraint block phase C status           |
| BLKD5H_A     | BOOLEAN | 0=False<br>1=True |      | 5th harmonic restraint block phase A status           |
| BLKD5H_B     | BOOLEAN | 0=False<br>1=True |      | 5th harmonic restraint block phase B status           |
| BLKD5H_C     | BOOLEAN | 0=False<br>1=True |      | 5th harmonic restraint block phase C status           |
| BLKDWAV_A    | BOOLEAN | 0=False<br>1=True |      | Waveform blocking phase A status                      |
| BLKDWAV_B    | BOOLEAN | 0=False<br>1=True |      | Waveform blocking phase B status                      |
| BLKDWAV_C    | BOOLEAN | 0=False<br>1=True |      | Waveform blocking phase C status                      |
| BLKD2HPHAR   | BOOLEAN | 0=False<br>1=True |      | 2nd harmonic restraint blocking for PHAR LN, combined |
| BLKD2HPHAR_A | BOOLEAN | 0=False<br>1=True |      | 2nd harmonic restraint blocking for PHAR LN, phase A  |
| BLKD2HPHAR_B | BOOLEAN | 0=False<br>1=True |      | 2nd harmonic restraint blocking for PHAR LN, phase B  |
| BLKD2HPHAR_C | BOOLEAN | 0=False<br>1=True |      | 2nd harmonic restraint blocking for PHAR LN, phase C  |
| BLKD5HPHAR   | BOOLEAN | 0=False<br>1=True |      | 5th harmonic restraint blocking for PHAR LN, combined |
| BLKD5HPHAR_A | BOOLEAN | 0=False<br>1=True |      | 5th harmonic restraint blocking                       |

*Table continues on the next page*

| Name         | Type    | Values (Range)    | Unit | Description   |
|--------------|---------|-------------------|------|---|
|              |         |                   |      | for PHAR LN,<br>phase A   |
| BLKD5HPHAR_B | BOOLEAN | 0=False<br>1=True |      | 5th harmonic re-<br>straint blocking<br>for PHAR LN,<br>phase B   |
| BLKD5HPHAR_C | BOOLEAN | 0=False<br>1=True |      | 5th harmonic re-<br>straint blocking<br>for PHAR LN,<br>phase C   |
| I_AMPL_A1    | FLOAT32 | 0.00...40.00      | xlr  | Connection<br>group compen-<br>sated primary<br>current phase A   |
| I_AMPL_B1    | FLOAT32 | 0.00...40.00      | xlr  | Connection<br>group compen-<br>sated primary<br>current phase B   |
| I_AMPL_C1    | FLOAT32 | 0.00...40.00      | xlr  | Connection<br>group compen-<br>sated primary<br>current phase C   |
| I_AMPL_A2    | FLOAT32 | 0.00...40.00      | xlr  | Connection<br>group compen-<br>sated secondary<br>current phase A |
| I_AMPL_B2    | FLOAT32 | 0.00...40.00      | xlr  | Connection<br>group compen-<br>sated secondary<br>current phase B |
| I_AMPL_C2    | FLOAT32 | 0.00...40.00      | xlr  | Connection<br>group compen-<br>sated secondary<br>current phase C |
| ID_A         | FLOAT32 | 0.00...80.00      | xlr  | Differential Cur-<br>rent phase A                                 |
| ID_B         | FLOAT32 | 0.00...80.00      | xlr  | Differential Cur-<br>rent phase B                                 |
| ID_C         | FLOAT32 | 0.00...80.00      | xlr  | Differential Cur-<br>rent phase C                                 |
| IB_A         | FLOAT32 | 0.00...80.00      | xlr  | Biasing current<br>phase A  |
| IB_B         | FLOAT32 | 0.00...80.00      | xlr  | Biasing current<br>phase B  |
| IB_C         | FLOAT32 | 0.00...80.00      | xlr  | Biasing current<br>phase C  |

*Table continues on the next page*



| Name         | Type    | Values (Range)   | Unit | Description   |
|--------------|---------|------------------|------|---|
| I_2H_RAT_A   | FLOAT32 | 0.00...1.00      |      | Differential current second harmonic ratio, phase A       |
| I_2H_RAT_B   | FLOAT32 | 0.00...1.00      |      | Differential current second harmonic ratio, phase B       |
| I_2H_RAT_C   | FLOAT32 | 0.00...1.00      |      | Differential current second harmonic ratio, phase C       |
| I_ANGL_A1_B1 | FLOAT32 | -180.00...180.00 | deg  | Current phase angle phase A to B, winding 1               |
| I_ANGL_B1_C1 | FLOAT32 | -180.00...180.00 | deg  | Current phase angle phase B to C, winding 1               |
| I_ANGL_C1_A1 | FLOAT32 | -180.00...180.00 | deg  | Current phase angle phase C to A, winding 1               |
| I_ANGL_A2_B2 | FLOAT32 | -180.00...180.00 | deg  | Current phase angle phase A to B, winding 2               |
| I_ANGL_B2_C2 | FLOAT32 | -180.00...180.00 | deg  | Current phase angle phase B to C, winding 2               |
| I_ANGL_C2_A2 | FLOAT32 | -180.00...180.00 | deg  | Current phase angle phase C to A, winding 2               |
| I_ANGL_A1_A2 | FLOAT32 | -180.00...180.00 | deg  | Current phase angle diff between winding 1 and 2, phase A |
| I_ANGL_B1_B2 | FLOAT32 | -180.00...180.00 | deg  | Current phase angle diff between winding 1 and 2, phase B |
| I_ANGL_C1_C2 | FLOAT32 | -180.00...180.00 | deg  | Current phase angle diff between winding 1 and 2, phase C |
| I_5H_RAT_A   | FLOAT32 | 0.00...1.00      |      | Differential current fifth harmonic ratio, phase A        |

*Table continues on the next page*

| Name       | Type    | Values (Range)   | Unit | Description  |
|------------|---------|--|------|--|
| I_5H_RAT_B | FLOAT32 | 0.00...1.00  |      | Differential current fifth harmonic ratio, phase B |
| I_5H_RAT_C | FLOAT32 | 0.00...1.00  |      | Differential current fifth harmonic ratio, phase C |
| TR2PTDF    | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status   |
| IL1-diff   | FLOAT32 | 0.00...80.00   |      | Measured differential current amplitude phase IL1  |
| IL2-diff   | FLOAT32 | 0.00...80.00   |      | Measured differential current amplitude phase IL2  |
| IL3-diff   | FLOAT32 | 0.00...80.00   |      | Measured differential current amplitude phase IL3  |
| IL1-bias   | FLOAT32 | 0.00...80.00   |      | Measured bias current amplitude phase IL1          |
| IL2-bias   | FLOAT32 | 0.00...80.00   |      | Measured bias current amplitude phase IL2          |
| IL3-bias   | FLOAT32 | 0.00...80.00   |      | Measured bias current amplitude phase IL3          |

3.3.1.10

Technical data

Table 380: TR2PTDF Technical data

| Characteristic             |  | Value  |         |         |
|----------------------------|--|--|---------|---------|
| Operation accuracy         |  | Depending on the frequency of the measured current: $f_n \pm 2 \text{ Hz}$ |         |         |
|                            |  | $\pm 3.0\%$ of the set value or $\pm 0.002 \times I_n$                     |         |         |
| Start time <sup>4142</sup> |  | Minimum  | Typical | Maximum |

Table continues on the next page

| Characteristic           |            | Value   |       |       |
|--------------------------|------------|---|-------|-------|
|                          | Low stage  | 36 ms   | 41 ms | 46 ms |
|                          | High stage | 21 ms   | 22 ms | 24 ms |
| Reset time               |            | Typically 40 ms   |       |       |
| Reset ratio              |            | Typically 0.96  |       |       |
| Suppression of harmonics |            | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$ |       |       |

### 3.3.1.11 Technical revision history

Table 381: TR2PTDF Technical revision history

| Technical revision | Change   |
|--------------------|--|
| B                  | 5th harmonic and waveform blockings taken to event data set. |
| C                  | Added setting <i>Slope section 3</i> . Added input TAP_POS.  |

## 3.3.2 Numerically stabilized low-impedance restricted earth-fault protection LREFPNDF

### 3.3.2.1 Identification

| Function description   | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--|--------------------------|--------------------------|-------------------------------|
| Numerically stabilized low-impedance restricted earth-fault protection | LREFPNDF                 | dIoLo>                   | 87NL                          |

### 3.3.2.2 Function block

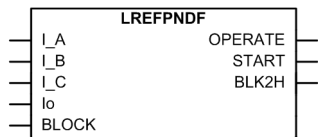


Figure 197: Function block

<sup>41</sup> Current before fault = 0.0,  $f_n = 50$  Hz, results based on statistical distribution of 1000 measurements

<sup>42</sup> Includes the delay of the output contact. When differential current =  $2 \times$  set operate value and  $f_n = 50$  Hz.

### 3.3.2.3 Functionality

The numerically stabilized low-impedance restricted earth-fault protection function LREFPNDF for a two-winding transformer is based on the numerically stabilized differential current principle. No external stabilizing resistor or non-linear resistor are required.

The fundamental components of the currents are used for calculating the residual current of the phase currents, the neutral current, differential currents and stabilizing currents. The operating characteristics are according to the definite time.

LREFPNDF contains a blocking functionality. The neutral current second harmonic is used for blocking during the transformer inrush situation. It is also possible to block function outputs, timers or the function itself, if desired.

### 3.3.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of LREFPNDF can be described using a module diagram. All the modules in the diagram are explained in the next sections.

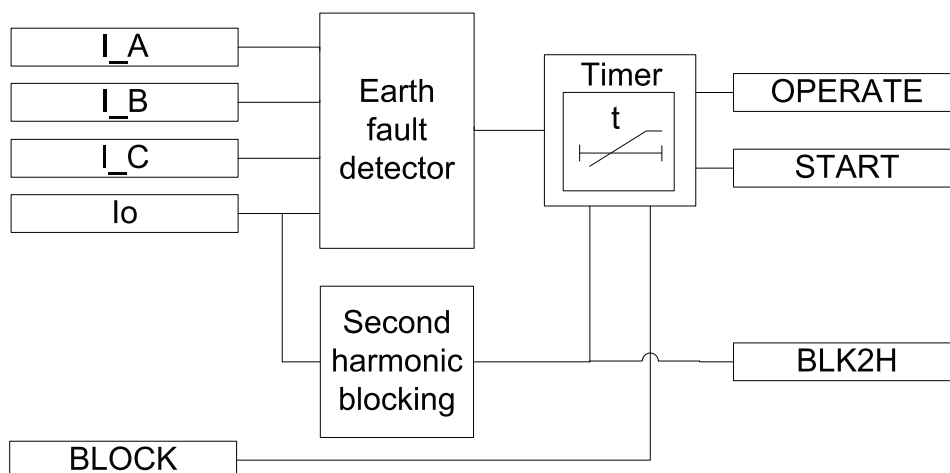


Figure 198: Functional module diagram

#### Earth-fault detector

The operation is based on comparing the amplitude and the phase difference between the sum of the fundamental frequency component of the phase currents ( $\Sigma I$ , residual current) and the fundamental frequency component of the neutral current ( $I_o$ ) flowing in the conductor between the transformer or generator's neutral point and earth. The differential current is calculated as the absolute value of the difference between the residual current, that is, the sum of the fundamental frequency components of the phase currents  $I_A$ ,  $I_B$  and  $I_C$ , and the neutral current. The directional differential current  $ID\_COSPHI$  is the product of the differential current and  $\cos\phi$ . The value is available in the monitored data view.

$$ID\_COSPHI = \left( \overline{\Sigma I} - \overline{I_o} \right) \times \cos \varphi$$

|                       |  |
|-----------------------|--|
| $\overline{\Sigma I}$ | Residual current   |
| $\varphi$             | Phase difference between the residual and neutral currents |
| $\overline{I_o}$      | Neutral current  |

An earth fault occurring in the protected area, that is, between the phase CTs and the neutral connection CT, causes a differential current. The directions, that is, the phase difference of the residual current and the neutral current, are considered in the operation criteria to maintain selectivity. A correct value for *CT connection type* is determined by the connection polarities of the current transformer.



The current transformer ratio mismatch between the phase current transformer and neutral current transformer (residual current in the analog input settings) is taken into account by the function with the properly set analog input setting values.

During an earth fault in the protected area, the currents  $\Sigma I$  and  $I_o$  are directed towards the protected area. The factor  $\cos \varphi$  is 1 when the phase difference of the residual current and the neutral current is 180 degrees, that is, when the currents are in opposite direction at the earth faults within the protected area. Similarly,  $ID\_COSPHI$  is specified to be 0 when the phase difference between the residual current and the neutral current is less than 90 degrees in situations where there is no earth fault in the protected area. Thus tripping is possible only when the phase difference between the residual current and the neutral current is above 90 degrees.

The stabilizing current  $I_B$  used by the stabilizing current principle is calculated as an average of the phase currents in the windings to be protected. The value is available in the monitored data view.

$$I_B = \frac{|I\_A| + |I\_B| + |I\_C|}{3}$$

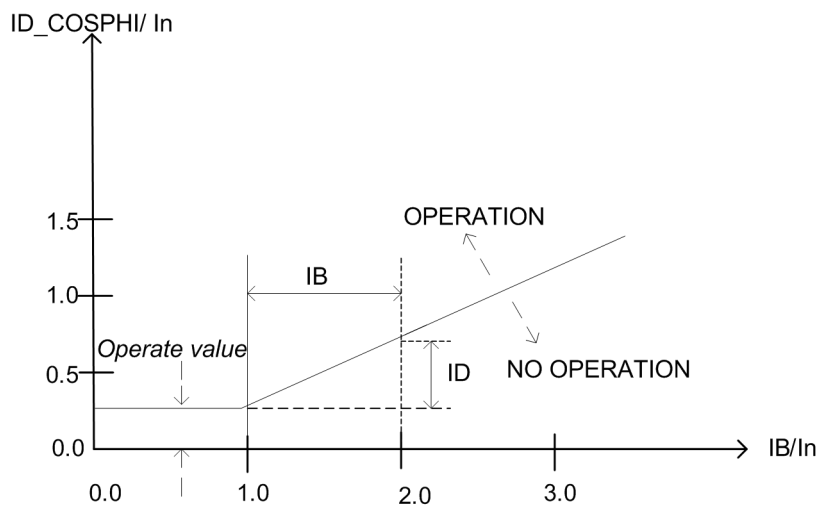


Figure 199: Operating characteristics of the stabilized earth-fault protection function

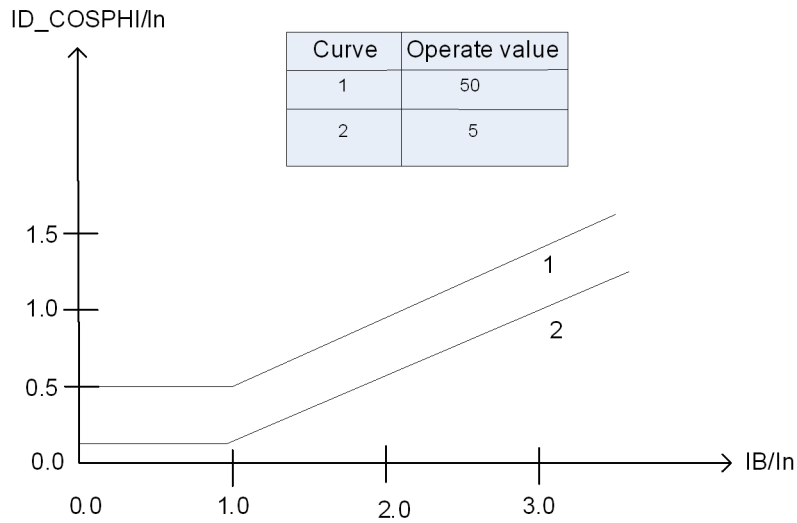


Figure 200: Setting range of the operating characteristics for the stabilized differential current principle of the earth-fault protection function

The *Operate value* setting is used for defining the characteristics of the function. The differential current value required for tripping is constant at the stabilizing current values  $0.0 < IB/In < 1.0$ , where  $In$  is the nominal current, and the  $In$  in this context refers to the nominal of the phase current inputs. When the stabilizing current is higher than 1.0, the slope of the operation characteristic ( $ID/IB$ ) is constant at 50 percent. Different operating characteristics are possible based on the *Operate value* setting.

For the protection of the trip, the measured neutral current has to be above 4 percent. When the condition has been fulfilled, the measured neutral current must stay above 2 percent, otherwise reset time is started.

To calculate the directional differential current  $ID\_COSPHI$ , the fundamental frequency amplitude of both the residual and neutral currents has to be above 4 percent of  $In$ . If neither or only one condition is fulfilled at a time, the  $\cos\phi$  term is forced to 1. After the conditions are fulfilled, both currents must stay above 2 percent of  $In$  to allow the continuous calculation of the  $\cos\phi$  term.

**Second harmonic blocking**

This module compares the ratio of the current second harmonic ( $I_{0\_2H}$ ) and  $I_0$  to the set value *Start value 2.H*. If the ratio ( $I_{0\_2H} / I_0$ ) value exceeds the set value, the  $BLK2H$  output is activated.

The blocking also prevents unwanted operation at the recovery and sympathetic magnetizing inrushes. At the recovery inrush, the magnetizing current of the transformer to be protected increases momentarily when the voltage returns to normal after the clearance of a fault outside the protected area. The sympathetic inrush is caused by the energization of a transformer running in parallel with the protected transformer connected to the network.

The second harmonic blocking is disabled when *Restraint mode* is set to "None" and enabled when set to "Harmonic2".

### Timer

Once activated, the Timer activates the `START` output. The time characteristic is according to DT. When the operation timer has reached the value set by *Minimum operate time*, the `OPERATE` output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the reset timer resets and the `START` output is deactivated.

The Timer calculates the start duration value `START_DUR` which indicates the percentage ratio of the start situation and the set operate time. The value is available through the Monitored data view.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration > System > Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value, but the `OPERATE` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the `OPERATE` output is not activated. The activation of the output of the second harmonic blocking signal `BLK2H` deactivates the `OPERATE` output.

## 3.3.2.5

### Application

An earth-fault protection using an overcurrent element does not adequately protect the transformer winding in general and the star-connected winding in particular.

The restricted earth-fault protection is mainly used as a unit protection for the transformer windings. LREFPNDF is a sensitive protection applied to protect the star-connected winding of a transformer. This protection system remains stable for all the faults outside the protected zone.

LREFPNDF provides higher sensitivity for the detection of earth faults than the overall transformer differential protection. This is a high-speed unit protection scheme applied to the star-connected winding of the transformer. LREFPNDF is normally applied when the transformer is earthed solidly or through low-impedance resistor (NER). LREFPNDF can be also applied on the delta side of the transformer if an earthing transformer (zig-zag transformer) is used there. In LREFPNDF, the difference of the fundamental component of all three phase currents and the neutral current is provided to the differential element to detect the earth fault in the transformer winding based on the numerical stabilized differential current principle.

### Connection of current transformers

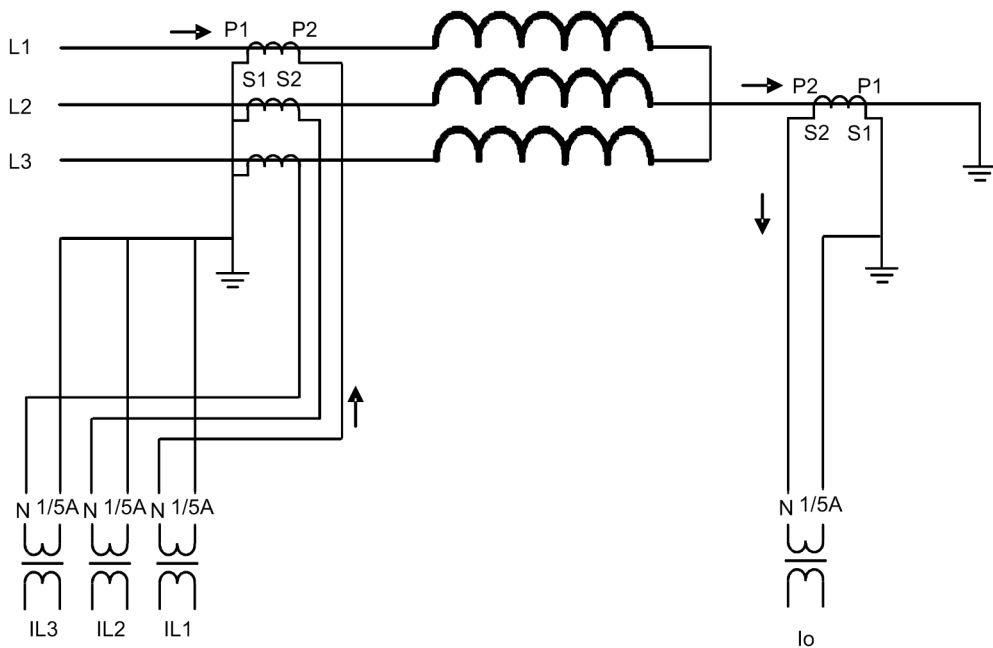
The connections of the primary current transformers are designated as "Type 1" and "Type 2".

- If the positive directions of the winding 1 and winding 2 IED currents are opposite, the *CT connection type* setting parameter is "Type 1". The connection examples of "Type 1" are as shown in [Figure 201](#) and [Figure 202](#).

- If the positive directions of the winding 1 and winding 2 IED currents equate, the *CT connection type* setting parameter is "Type 2". The connection examples of "Type 2" are as shown in [Figure 203](#) and [Figure 204](#).
- The default value of the *CT connection type* setting is "Type 1".

In case the earthings of the current transformers on the phase side and the neutral side are both either inside or outside the area to be protected, the setting parameter *CT connection type* is "Type 1".

If the earthing of the current transformers on the phase side is inside the area to be protected and the neutral side is outside the area to be protected or if the earthing on the phase side is outside the area and on the neutral side inside the area, the setting parameter *CT connection type* is "Type 2".



*Figure 201: Connection of the current transformers of Type 1. The connected phase currents and the neutral current have opposite directions at an external earth-fault situation. Both earthings are inside the area to be protected.*



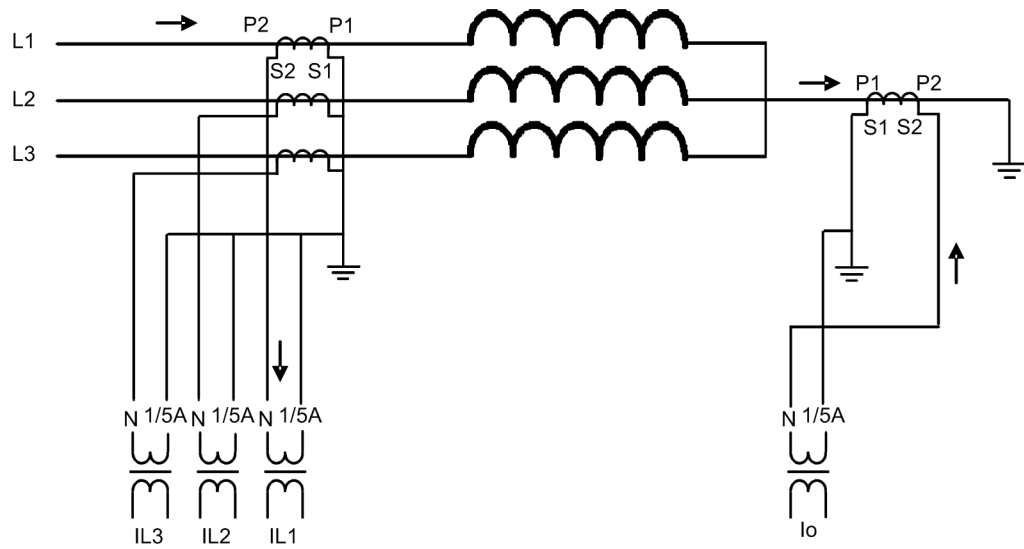


Figure 202: Connection of the current transformers of Type 1. The connected phase currents and the neutral current have opposite directions at an external earth-fault situation. Both earthing are outside the area to be protected.

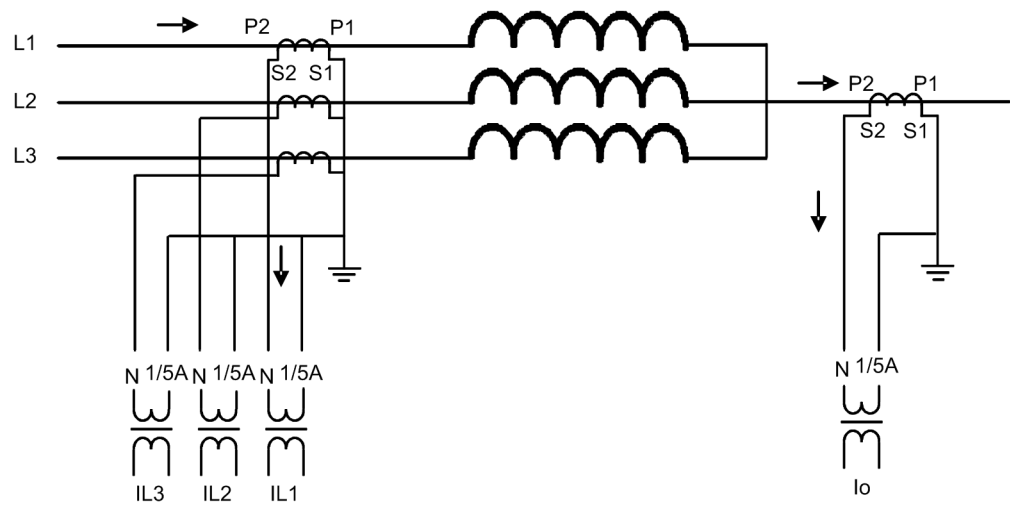


Figure 203: Connection of the current transformers of Type 2. The phase currents and the neutral current have equal directions at an external earth-fault situation. Phase earthing is inside and neutral earthing is outside the area to be protected.

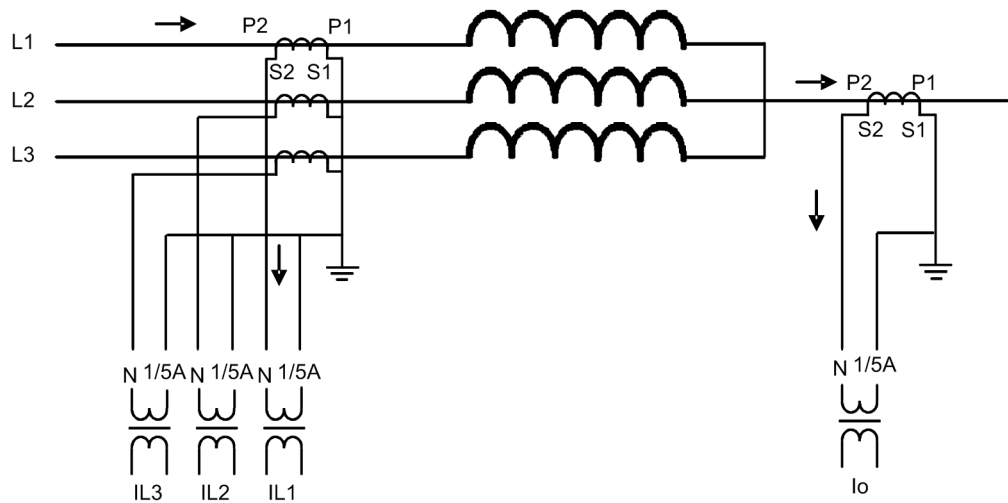


Figure 204: Connection of the current transformers of Type 2. The phase currents and the neutral current have equal directions at an external earth-fault situation. Phase earthing is outside and neutral earthing is inside the area to be protected.

**Internal and external faults**

LREFPNDF does not respond to any faults outside the protected zone. An external fault is detected by checking the phase angle difference of the neutral current and the sum of the phase currents. When the difference is less than 90 degrees, the operation is internally restrained or blocked. Hence the protection is not sensitive to an external fault.

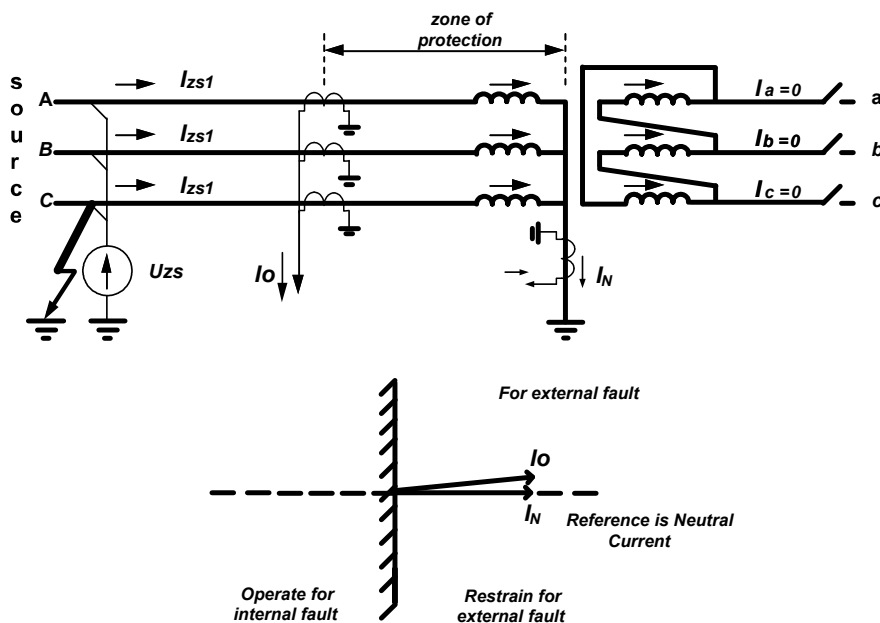


Figure 205: Current flow in all the CTs for an external fault

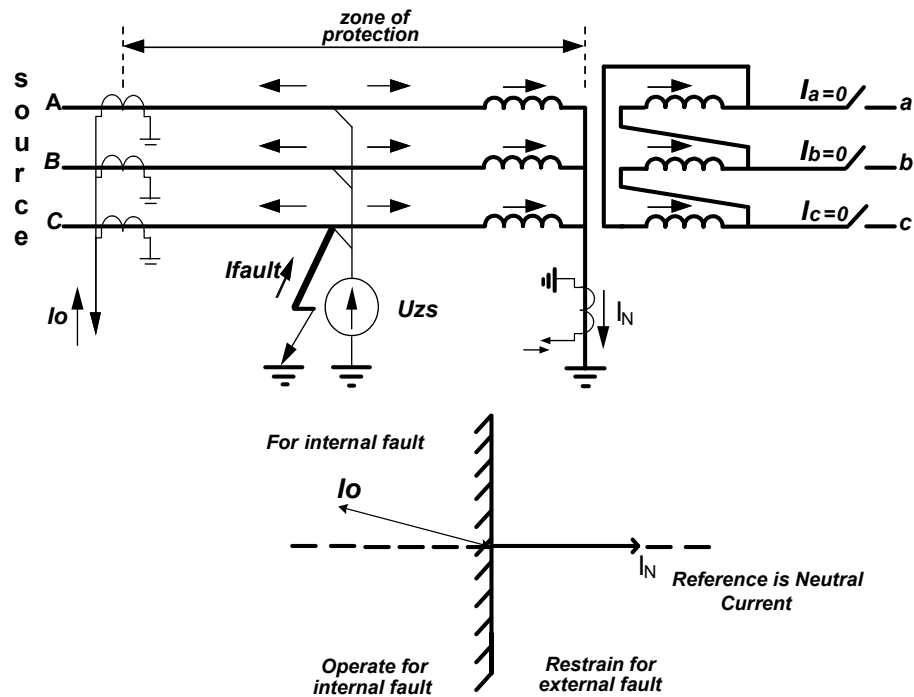


Figure 206: Current flow in all the CTs for an internal fault

LREFPNDF does not respond to phase-to-phase faults either, as in this case the fault current flows between the two line CTs and so the neutral CT does not experience this fault current.

### Blocking based on the second harmonic of the neutral current

The transformer magnetizing inrush currents occur when the transformer is energized after a period of de-energization. The inrush current can be many times the rated current, and the halving time can be up to several seconds. For the differential IED, the inrush current represents the differential current, which causes the IED to operate almost always when the transformer is connected to the network. Typically, the inrush current contains a large amount of second harmonics.

The blocking also prevents unwanted operation at the recovery and sympathetic magnetizing inrushes. At the recovery inrush, the magnetizing current of the transformer to be protected increases momentarily when the voltage returns to normal after the clearance of a fault outside the protected area. The sympathetic inrush is caused by the energization of a transformer running in parallel with the protected transformer already connected to the network.

Blocking the starting of the restricted earth-fault protection at the magnetizing inrush is based on the ratio of the second harmonic and the fundamental frequency amplitudes of the neutral current  $I_{o\_2H} / I_o$ . Typically, the second harmonic content of the neutral current at the magnetizing inrush is higher than that of the phase currents.

### 3.3.2.6 Signals

**LREFPNDF Input signals****Table 382: LREFPNDF Input signals**

| Name  | Type    | Default | Description                                   |
|-------|---------|---------|---|
| I_A   | SIGNAL  | 0       | Phase A current                               |
| I_B   | SIGNAL  | 0       | Phase B current                               |
| I_C   | SIGNAL  | 0       | Phase C current                               |
| Io    | SIGNAL  | 0       | Residual current                              |
| BLOCK | BOOLEAN | 0=False | Block signal for activating the blocking mode |

**LREFPNDF Output signals****Table 383: LREFPNDF Output signals**

| Name    | Type    | Description        |
|---------|---------|--------------------|
| OPERATE | BOOLEAN | Operate            |
| START   | BOOLEAN | Start              |
| BLK2H   | BOOLEAN | 2nd harmonic block |

**3.3.2.7****Settings****LREFPNDF Settings****Table 384: LREFPNDF Group settings (Basic)**

| Parameter     | Values (Range) | Unit | Step | Default | Description   |
|---------------|----------------|------|------|---------|---------------|
| Operate value | 5.0...50.0     | %In  | 1.0  | 5.0     | Operate value |

**Table 385: LREFPNDF Group settings (Advanced)**

| Parameter            | Values (Range)        | Unit | Step | Default | Description   |
|----------------------|-----------------------|------|------|---------|---|
| Minimum operate time | 40...300000           | ms   | 1    | 40      | Minimum operate time  |
| Restraint mode       | 1=None<br>2=Harmonic2 |      |      | 1=None  | Restraint mode  |
| Start value 2.H      | 10...50               | %    | 1    | 50      | The ratio of the 2. harmonic to fundamental component required for blocking |

**Table 386: LREFPNDF Non group settings (Basic)**

| Parameter          | Values (Range)       | Unit | Step | Default  | Description        |
|--------------------|----------------------|------|------|----------|--------------------|
| Operation          | 1=on<br>5=off        |      |      | 1=on     | Operation Off / On |
| CT connection type | 1=Type 1<br>2=Type 2 |      |      | 2=Type 2 | CT connection type |

**Table 387: LREFPNDF Non group settings (Advanced)**

| Parameter        | Values (Range) | Unit | Step | Default | Description      |
|------------------|----------------|------|------|---------|------------------|
| Reset delay time | 0..60000       | ms   | 1    | 20      | Reset delay time |

### 3.3.2.8

#### Monitored data

##### LREFPNDF Monitored data

**Table 388: LREFPNDF Monitored data**

| Name      | Type    | Values (Range)   | Unit | Description                                |
|-----------|---------|--|------|--|
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time         |
| RES2H     | BOOLEAN | 0=False<br>1=True                                      |      | 2nd harmonic restraint                     |
| ID_COSPHI | FLOAT32 | 0.00...80.00   | xIn  | Directional differential current Id cosphi |
| IB        | FLOAT32 | 0.00...80.00   | xIn  | Bias current                               |
| LREFPNDF  | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                                     |

### 3.3.2.9 Technical data

Table 389: LREFPNDF Technical data

| Characteristic                              |  | Value  |         |         |
|---|--|--|---------|---------|
| Operation accuracy                          |  | Depending on the frequency of the measured current: $f_n \pm 2$ Hz<br>$\pm 2.5\%$ of the set value or $\pm 0.002 \times I_n$ |         |         |
| Start time <sup>4344</sup>                  |  | Minimum  | Typical | Maximum |
|   | $I_{\text{Fault}} = 2.0 \times \text{set Operate value}$ | 37 ms  | 41 ms   | 45 ms   |
| Reset time                                  |  | Typically 40 ms  |         |         |
| Reset ratio                                 |  | Typically 0.96   |         |         |
| Retardation time                            |  | <35 ms   |         |         |
| Operate time accuracy in definite time mode |  | $\pm 1.0\%$ of the set value or $\pm 20$ ms  |         |         |
| Suppression of harmonics                    |  | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$  |         |         |

### 3.3.2.10 Technical revision history

Table 390: LREFPNDF Technical revision history

| Technical revision | Change   |
|--------------------|--|
| B                  | Unit for setting <i>Start value 2.H</i> changed from %In to %. |
| C                  | Internal Improvement.  |

## 3.3.3 Busbar differential protection function BBPBDF

### 3.3.3.1 Identification

Table 391: Function identification

| Function description                    | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE identification |
|---|--------------------------|--------------------------|--------------------------|
| Busbar differential protection function | BBPBDF                   | 3Id/I                    | 87BL                     |

<sup>43</sup> Current before fault = 0.0,  $f_n = 50$  Hz, results based on statistical distribution of 1000 measurements

<sup>44</sup> Includes the delay of the signal output contact

### 3.3.3.2 Function block

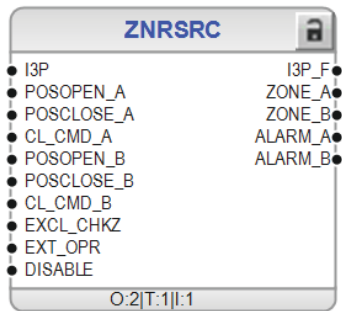


Figure 207: Function block symbol of ZNRSRC

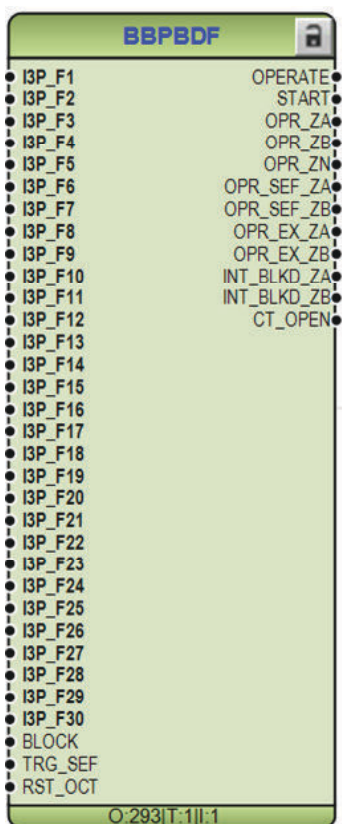


Figure 208: Function block symbol of BBPBDP

### 3.3.3.3 Functionality

Busbar differential protection function BBPBDP is used for detecting faults within the substation. Protection function consists of one or two zones depending on the substation configuration (single busbar, double busbar, one or two sections).

All bays within the substation are connected to the busbar protection function. Connection to different zones (zone A or zone B) are done with ZNMSRC function (Zone source). This function enables dynamic changes to the network configuration based on the disconnector status information.

This function contains a blocking functionality. Blocking deactivates all outputs and resets timers.

### 3.3.3.4 Operation principle

The *Operation* setting is used to enable or disable the function. When selected "On" the function is enabled and respectively "Off" means function is disabled.

The operation of BBPBDF can be described by using a module diagram (see [Figure 209](#)). All the modules in the diagram are explained in the next sections.

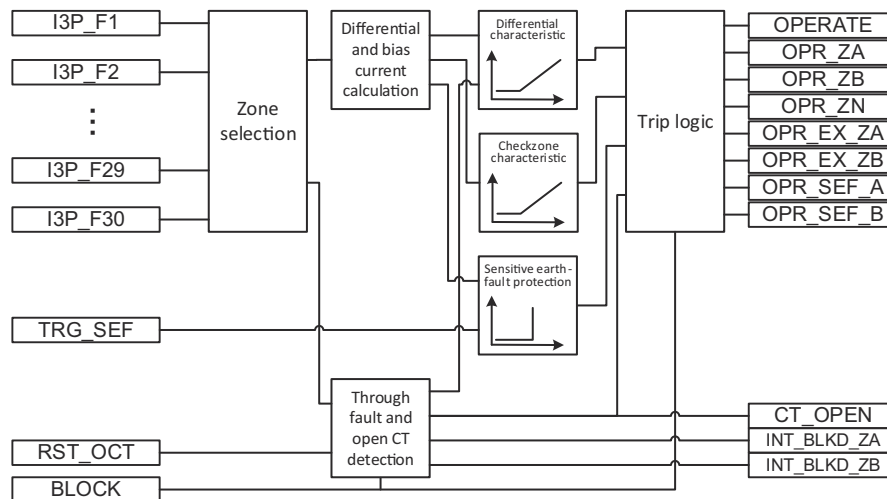


Figure 209: Functional module diagram

### 3.3.3.5 Zone selection

Busbar differential protection function can operate in single or two zone operation mode depending on the (sub)station configuration. If (sub)station has only single busbar and one section, then function operates in single zone mode. On the other hand, if substation has two busbars or single busbar with two sections, then both zones are taken into use.

Zone connection is done with the ZNRSRC function block. All protected feeders have their own zone selection function block that is used to connect measurements and breaker or disconnector status information to proper protected zone in the busbar differential protection function. ZNRSRC function block is also used to scale different CT ratios to rated current ( $x_{lr}$ ). The scaling is done with setting *CT ratio correction*.



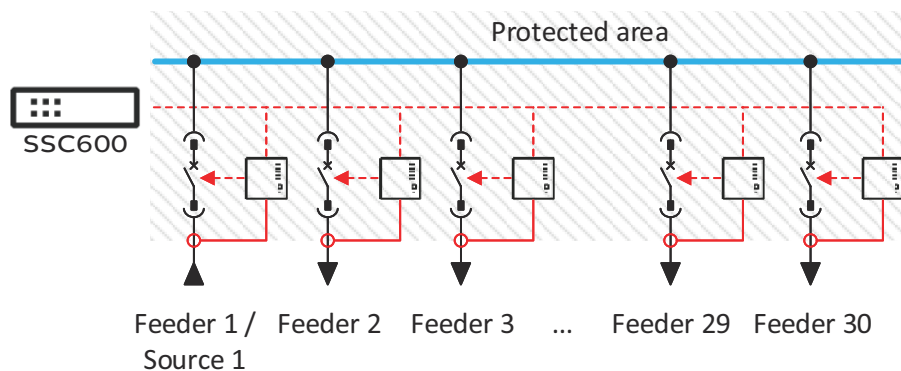


Figure 210: Example of single busbar configuration with one section

If only one zone is in use as in [Figure 210](#), the disconnector or breaker status information is connected only to POSOPEN\_A and POSCLOSE\_A inputs of ZNRSRC function block and POSOPEN\_B and POSCLOSE\_B inputs are left unconnected which activates protection for zone A for all connected feeders.

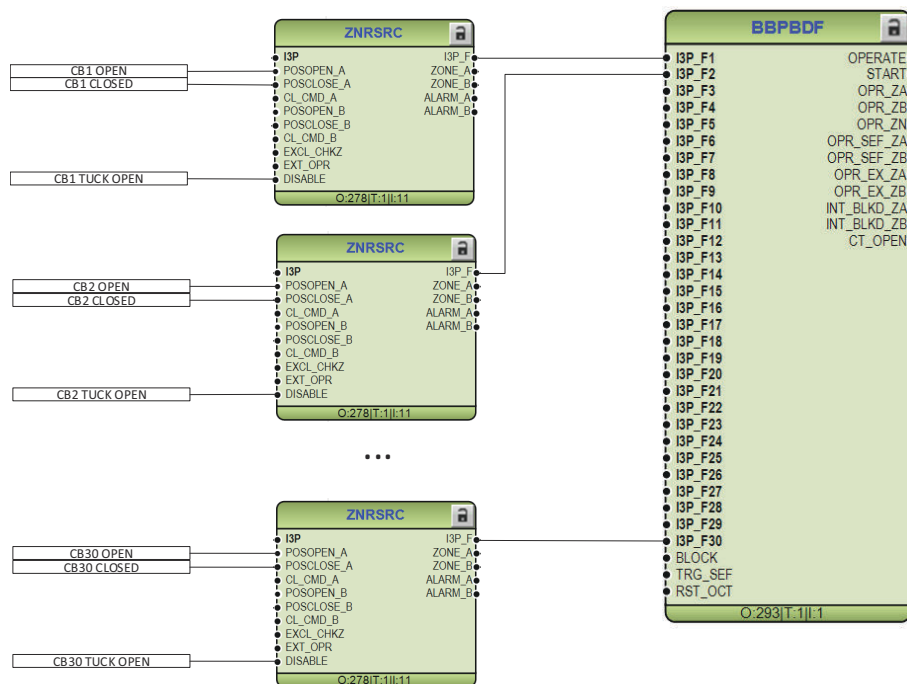


Figure 211: Configuration of ZNRSRC function blocks in case only one zone is used

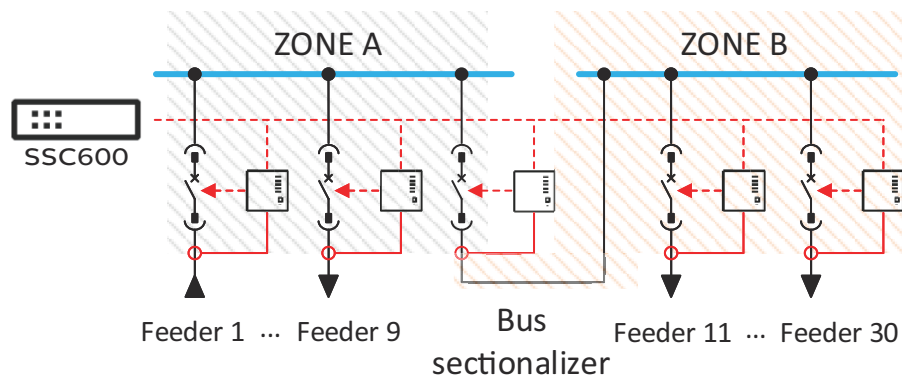


Figure 212: Example of single busbar with two sections

In the case of single busbar with two sections, the feeders connected to protection zone A connect their disconnector or breaker status information to POSOPEN\_A and POSCLOSE\_A inputs and feeders connected to zone B connect their disconnector or breaker status information to POSOPEN\_B and POSCLOSE\_B inputs (see [Figure 213](#)). The bus sectionalizer in this case is connected to both zones and needs to be connected to both zones. If bus sections are connected (bus sectionalizer is closed), then the current flowing through the bus sectionalizer needs to be considered in both zones and the current needs to be inverted for zone B (setting *Polarity reversal* in ZNRSRC- block). The current flowing through the bus sectionalizer is ignored in the check-zone calculation. This is done by setting the EXCL\_CHKZ input to TRUE in the ZNRSRC-block that is related to bus sectionalizer.

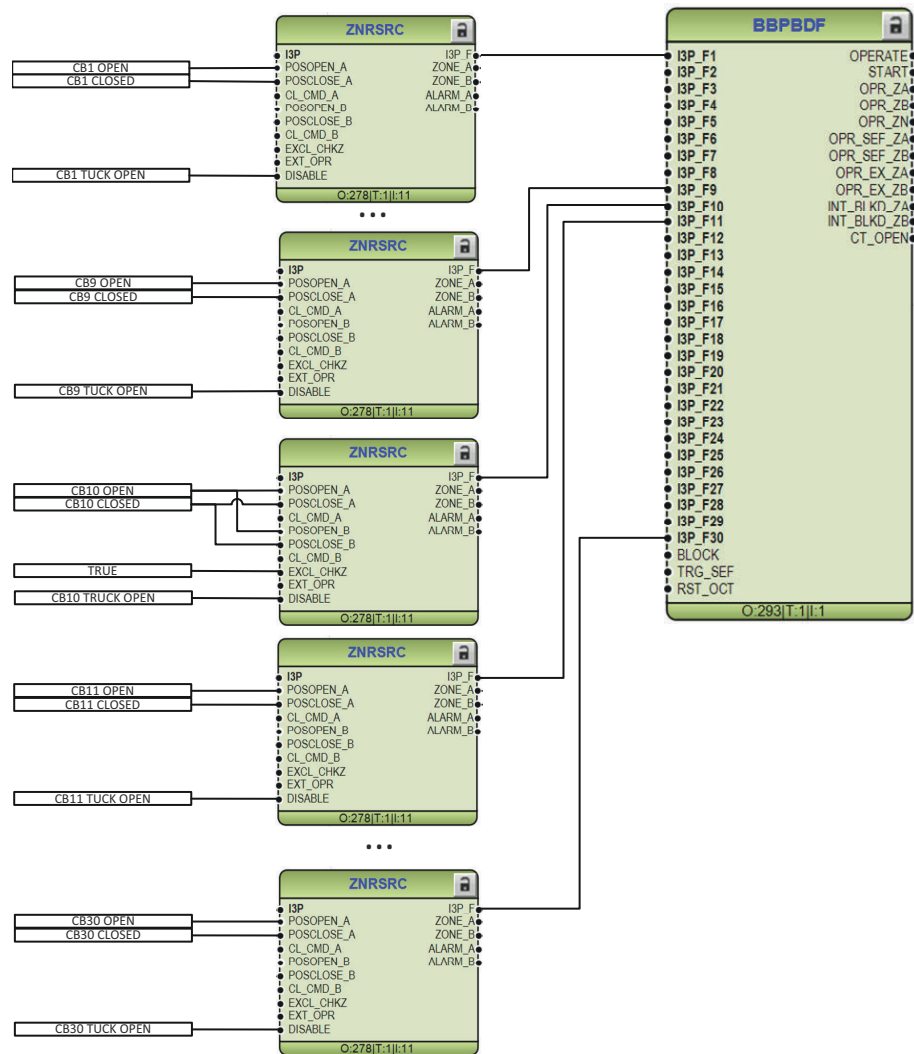


Figure 213: Configuration of ZNRSRC function blocks in single busbar with two sections configuration

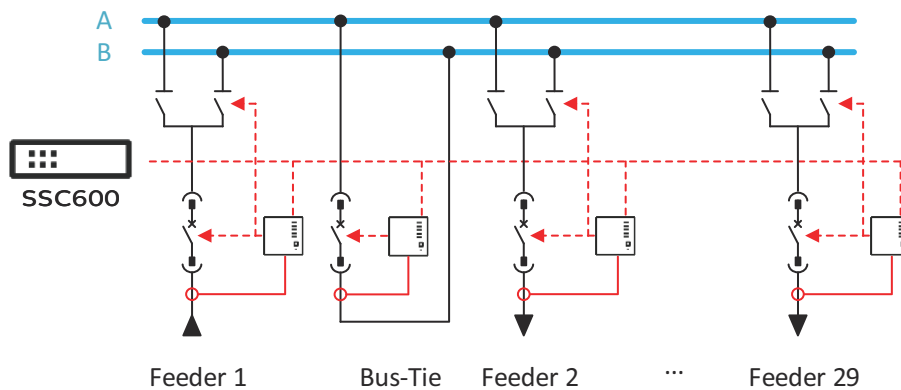


Figure 214: Example of double busbar system

In double busbar system all relevant disconnector or breaker status information must be connected to the configuration to consider dynamic load switching.

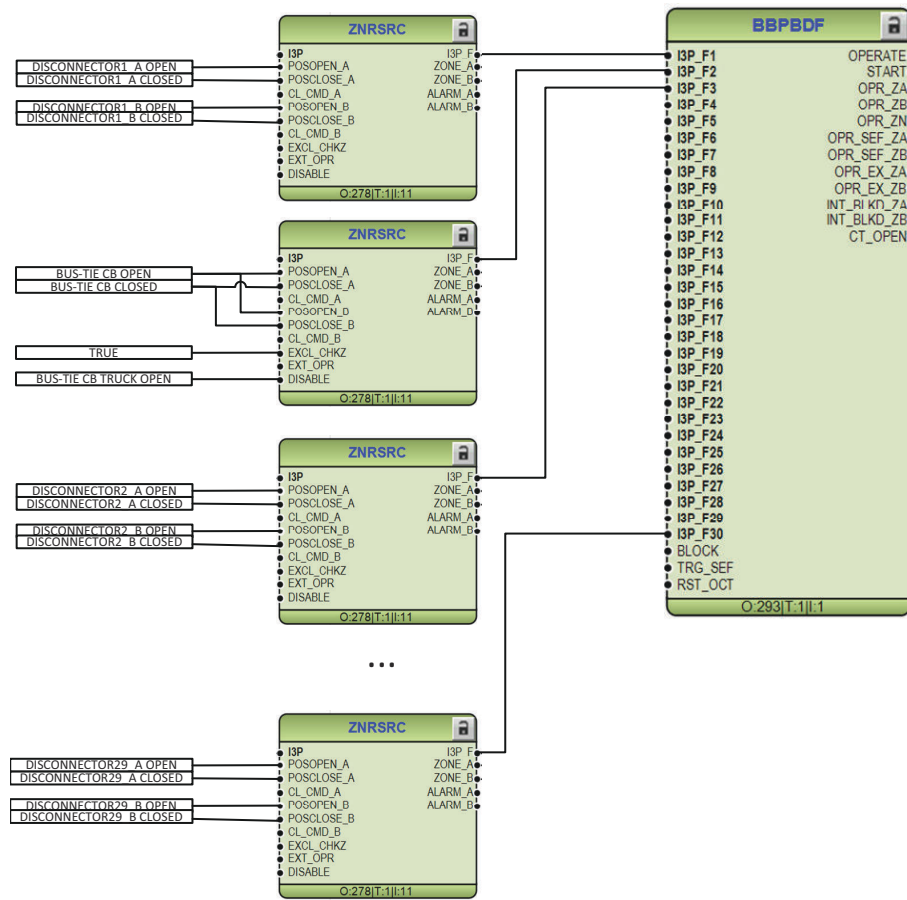


Figure 215: Configuration of ZNRSRC function blocks in double busbar system

In the case of double busbar with two sections, two instances of BBPBDf are needed. Figures [Figure 216](#) and [Figure 217](#) show an example of such system. In the example instance 1 of BBPBDf protects the section 1 and instance 2 of BBPBDf protects the section 2 of the system.

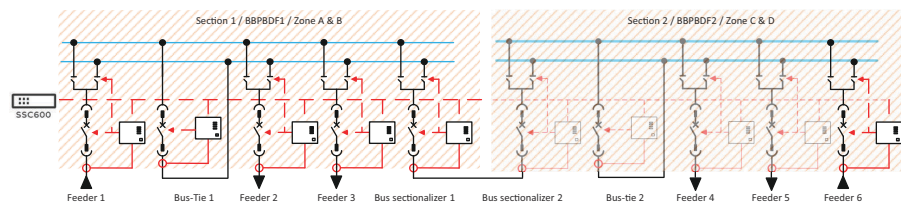


Figure 216: Example of double busbar system with two sections

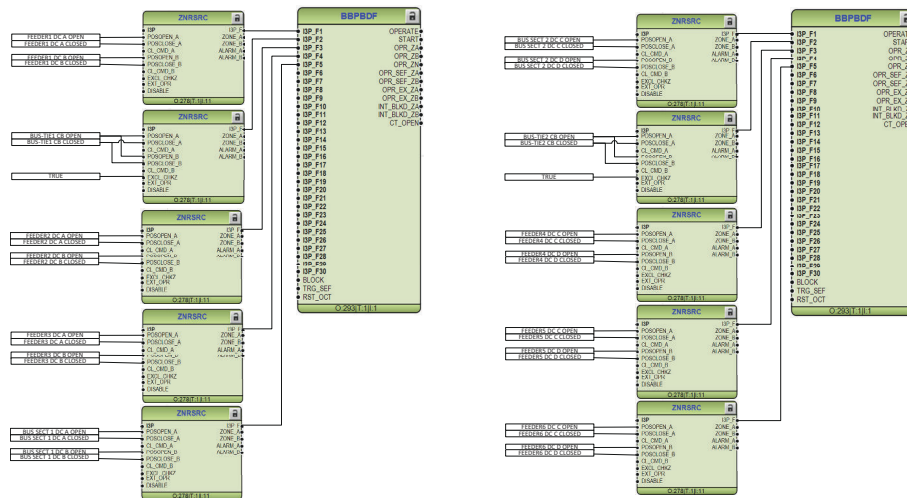


Figure 217: Configuration of ZNRSRC function blocks in double busbar and double section system

### 3.3.3.6 Differential and bias current calculation

The differential protection is based on a very simple principle of the First Kirchhoff’s law, i.e. all currents that are entering the object should also leave the object. If there is no fault at the protected object (in this case a busbar) the difference between the incoming and outgoing current (differential current  $i_d$ ) will be near zero, while in the case of a fault the difference is significant.

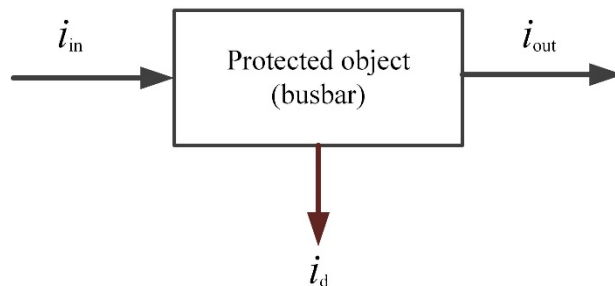


Figure 218: Basic principle of any differential protection

All calculations are completely phase-segregated, thus all following calculations are represented phase wise.

The instantaneous differential current ( $i_d$ ) is calculated as:

$$i_d = \left| \sum_{j=1}^N i_j \right| \tag{1}$$

where:

$i_d$  instantaneous differential current

$i_j$  instantaneous current of bay  $j$  ( $j = 1 \dots N$ )

$N$  total number of bays connected to the protected zone (zone A / zone B)

For check zone characteristic differential current is calculated over all connected feeder except those that are excluded from check zone calculated (input EXCL\_CHKZ in ZNMSRC function).

The currents that enter ( $i_{in}$ ) and leave ( $i_{out}$ ) the protected area are defined as:

$$i_{in} = \max(i_{pos}, i_{neg}) \quad (2)$$

$$i_{out} = \min(i_{pos}, i_{neg}) \quad (3)$$

where:

$i_{in}$  current entering the protected zone

$i_{out}$  current leaving the protected zone

$i_{pos}$  and  $i_{neg}$  are defined as:

$$i_{pos} = \sum_{j=1}^M i_j, \text{ where } i_j \geq 0 \quad (4)$$

$$i_{neg} = \sum_{j=M+1}^N |i_j|, \text{ where } i_j < 0 \quad (5)$$

where:

M number of bays that have positive instantaneous current

N total number of bays connected to protected zone

$i_j$  current sample value of feeder j

The calculated instantaneous currents are stabilized with integration over one power cycle, which results the stabilized differential current ( $I_d$ ), stabilized incoming current ( $I_{in}$ ) and stabilized outgoing current ( $I_{out}$ ).

The stabilized differential currents ( $I_d$ ) that are used in the differential characteristic are reported in the monitored data as ID\_ZA\_A, ID\_ZA\_B and ID\_ZA\_C (for zone A, phases 1,2 and 3) and ID\_ZB\_A, ID\_ZB\_B and ID\_ZB\_C (for zone B, phases 1,2 and 3).

The stabilized incoming currents ( $I_{in}$ ) are used as biasing current for differential characteristic and are reported in the monitored data as IB\_ZA\_A, IB\_ZA\_B and IB\_ZA\_C (for zone A, phases 1,2 and 3) and IB\_ZB\_A, IB\_ZB\_B and IB\_ZB\_C (for zone B, phases 1,2 and 3).

The stabilized differential currents for check zone are reported in the monitored data as ID\_ZN\_A, ID\_ZN\_B and ID\_ZN\_C (for phases 1,2 and 3).

The stabilized outgoing currents ( $I_{out}$ ) are used as biasing current for check zone characteristic and are reported in the monitored data as IB\_ZN\_A, IB\_ZN\_B and IB\_ZN\_C (for phases 1,2 and 3).

### 3.3.3.7 Differential characteristic operation

The differential characteristic compares the calculated differential current against the set operation value. The stabilized differential current ( $I_d$ ) must be greater than the set *Low operate value* and at the same time the stabilized differential current must be greater than  $Slope \cdot$  stabilized incoming current ( $I_{in}$ ). Note that differential current ( $I_d$ ) is always equal or less than incoming current ( $I_{in}$ ).

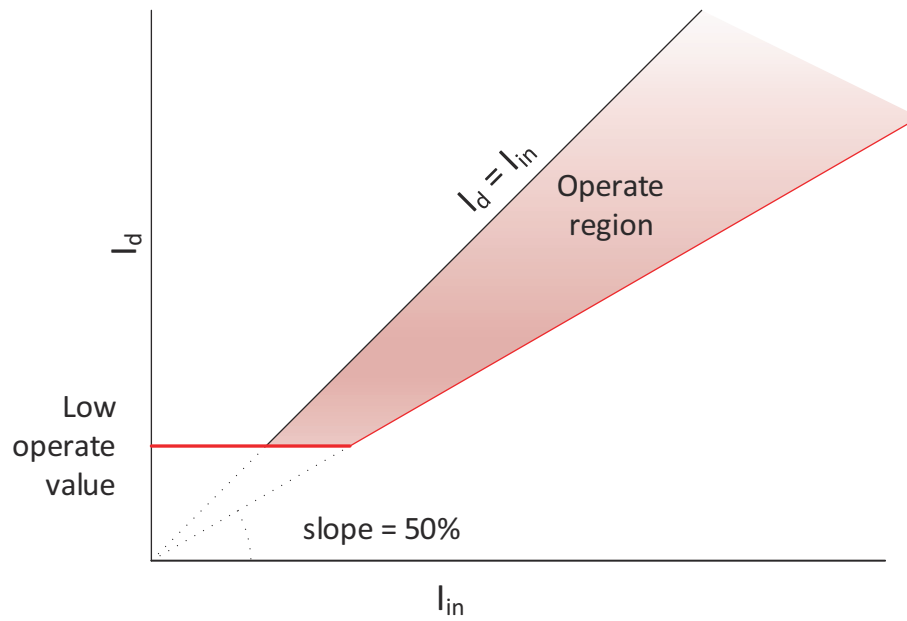


Figure 219: Differential characteristic

If differential current is in the operate region, start signal is passed on to Trip logic functionality.

### 3.3.3.8 Check zone characteristic

For busbar protection in double busbar stations when dynamic zone selection is needed, it is sometimes required to include the overall differential zone (that is, check zone). Because in the built-in check zone current measurement is not dependent on the disconnector status, this feature ensures stability of busbar differential protection even for completely wrong status indication from the busbar disconnectors.

The check zone has simple current operating algorithm, which ensures check zone operation for all internal faults regardless the fault current distribution. To achieve this, the outgoing current ( $I_{out}$ ) from the overall check zone is used as bias current. The check zone operation is enabled with setting *Enable check zone*.

Operating characteristic of the check zone is shown in [Figure 220](#).

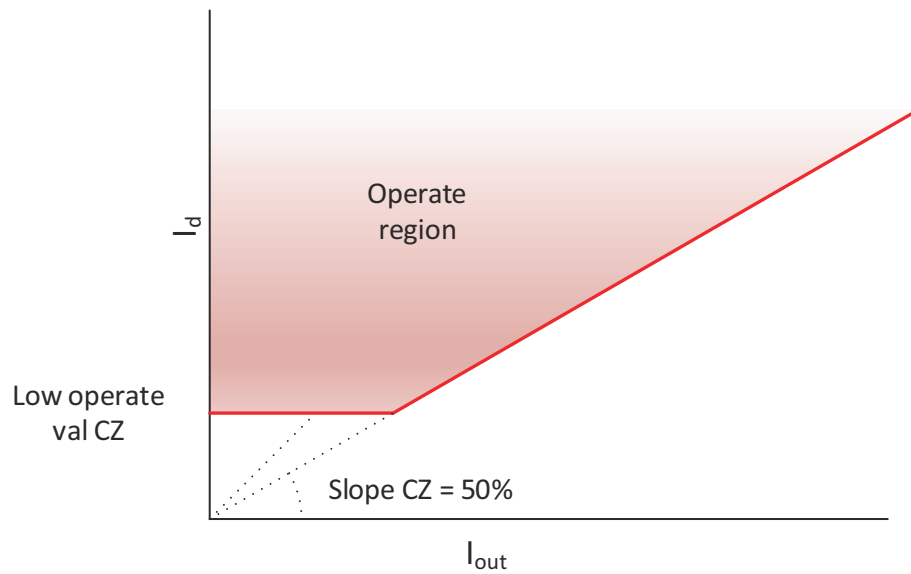


Figure 220: Check zone operation characteristic

### 3.3.3.9 Sensitive earth-fault protection

The sensitive earth-fault protection function is used for low impedance earthed power systems where earth-fault current is limited or for power systems where high sensitivity is needed.

The sensitive earth-fault protection is activated (started) with following conditions:

- sensitive earth-fault protection is enabled, setting “Enable SEF” is TRUE
- input TRG\_SEF is activated. The triggering can be done for instance with residual over-voltage protection (ROVPTOV)
- stabilized differential current ( $I_d$ ) is above “Low operate val SEF”
- stabilized input current ( $I_{in}$ ) is below “Block value SEF”
- “normal” differential protection is not active
- open CT has not been detected
- block input is not active



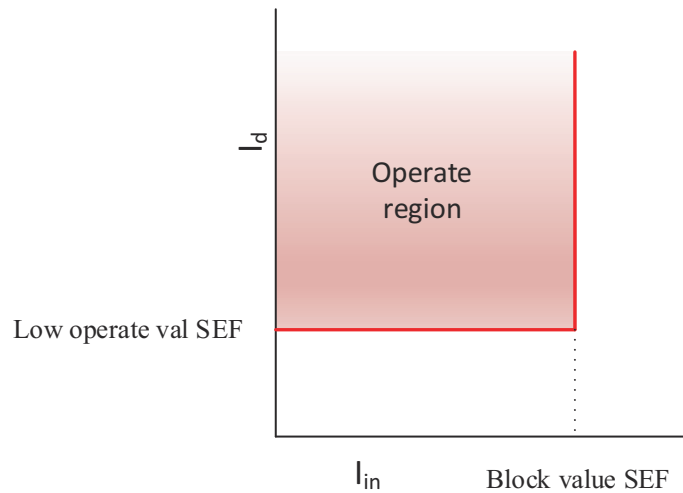


Figure 221: Sensitive earth-fault protection characteristic

When all these criteria have been fulfilled, operation timer is activated for sensitive earth-fault protection. When operate timer elapses, OPR\_SEF\_ZA or OPR\_SEF\_ZB output is activated. The time delay of the operate time is defined with parameter *Operate delay SEF*. Reset delay time for timer is defined with *Reset delay time SEF*.

### 3.3.3.10 Through fault detection and open CT detection

#### Through fault detection

Through fault detection requires following conditions:

- OPERATE output is not active
- stabilized outgoing and incoming currents in previous cycle were approximately equal, difference less than *Low operate value*
- incoming current is increasing
- outgoing current is increasing
- outgoing current is smaller than incoming current, ratio between outgoing and incoming current is less than 0.9
- outgoing current must be more than *Low operate value*

If through fault has been detected, tripping characteristic will be blocked until through fault detection resets.

Through fault is reset when:

- stabilized differential current falls below *Low operate value* after through fault has first been detected

Outputs INT\_BLKD\_ZA or INT\_BLKD\_ZB are activated when through fault detection is active.

#### Open CT detection

A CT circuit that suddenly fails, can be detected when current that previously existed, abruptly decreases to zero. A CT circuit that suddenly fails is usually characterized by the following facts:

- incoming current doesn't change more than *Start value OCT*

- outgoing current decreases more than *Start value OCT*
- differential current increases *Start value OCT*
- differential current was less than 10% setting *Low operate value* in the previous cycle
- Open CT detection must also be enabled with setting *Enable OCT*

Open CT detection logic shall only be reset when:

- Start condition from all differential characteristic is FALSE and
- manual reset signal is provided to RST\_OCT input or through communication
- or open CT detection is disabled with setting *Enable OCT*

Open CT detection is disabled in case stabilized input current is greater than 2.5xI<sub>r</sub>.

If open CT has been detected, the included zone will be blocked until Open CT detection has been reset and output CT\_OPEN is set active.

### 3.3.3.11 Trip logic

The busbar differential protection operation requires following criteria to be fulfilled before operation is allowed:

- Differential characteristic operation
  - stabilized differential current ( $I_d$ ) must be in the operate region of the differential characteristic or if sensitive earth-fault protection has been enabled, then stabilized differential current must be in the operate region of the sensitive earth-fault characteristic
  - output current must change more than 5% or output current is less than 10% of the Low operate value (no load condition)
- BLOCK input must not be active
- through fault detection is not active
- no open CT detections are made
- if check zone functionality has been enabled, check zone must also allow operation based on the check zone characteristic

OPR\_ZN output is activated when differential current is in the operate region of the check zone operate characteristic.

OPR\_ZA output is activated when stabilized differential characteristic for zone A operates or external tripping is activated for zone A.

OPR\_ZB output is activated when stabilized differential characteristic for zone B operates or external tripping is activated for zone B.

OPR\_SEF\_ZA output is activated when sensitive earth-fault protection for zone A operates.

OPR\_SEF\_ZB output is activated when sensitive earth-fault protection for zone B operates.

OPR\_EX\_ZA is activated when external operate for zone A is active.

OPR\_EX\_ZB is activated when external operate for zone A is active.

### 3.3.3.12 Application

Protection of power system busbars is one of the most critical relaying applications since a false trip disconnects numerous feeders which can cause outages to a large

number of customers. On the other hand, uncleared bus faults would generate large fault currents followed by thermal effects and dynamic forces, hence, a high-speed operation of busbar protection is required. A distance or overcurrent protection can include busbar in its protection zone, but these protections are often slow and used mostly as a backup protection. The fastest busbar protection is a differential protection. Traditionally, a high-impedance differential protection was widely used, but microprocessor-based relays utilize low-impedance differential protection as a more advanced solution.

The main principle of low-impedance busbar differential protection is shown in [Figure 222](#) and [Figure 223](#). The protection algorithm is applied to each phase independently so required current measurements for one of the phases are shown in red in [Figure 222](#).

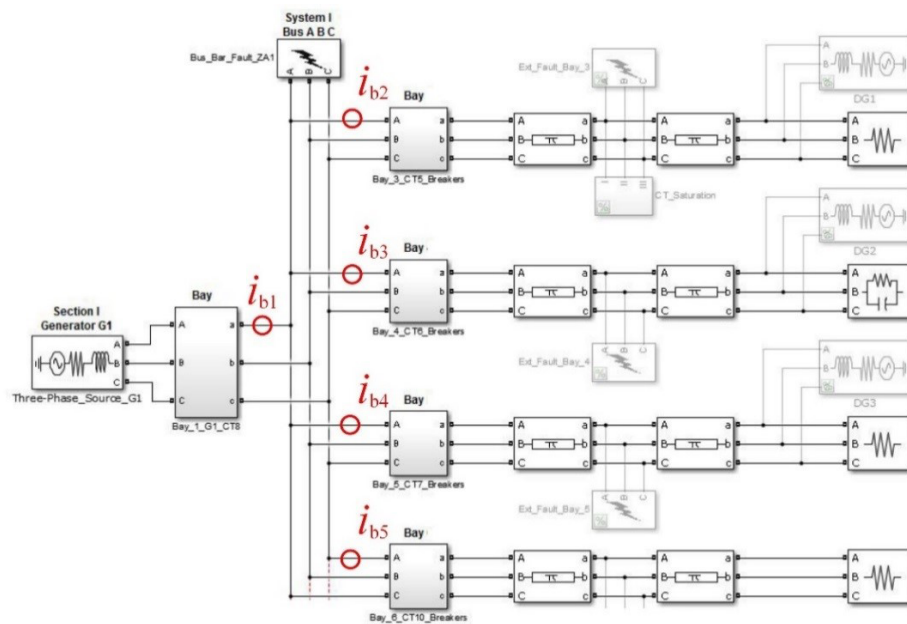


Figure 222: A MV substation consisting of a source, busbar and 4 feeders, where one phase currents measurements required for busbar protection are emphasized.

A differential protection is based on a very simple principle of the first Kirchhoff’s law, all currents that are entering an object ( $i_{in}$ ) should also leave the object ( $i_{out}$ ). If there is no fault at the protected object (in this case a busbar) the difference between the incoming and outgoing current (differential current  $i_d$ ) will be near zero, while in the case of a fault the difference is significant ( [Figure 223](#)).

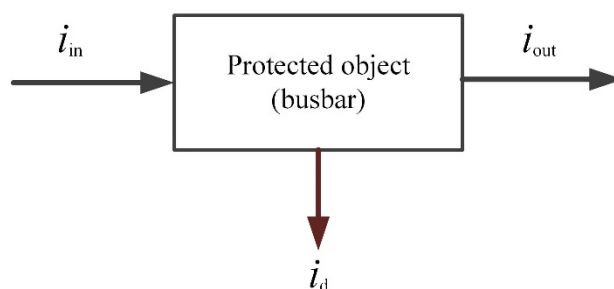
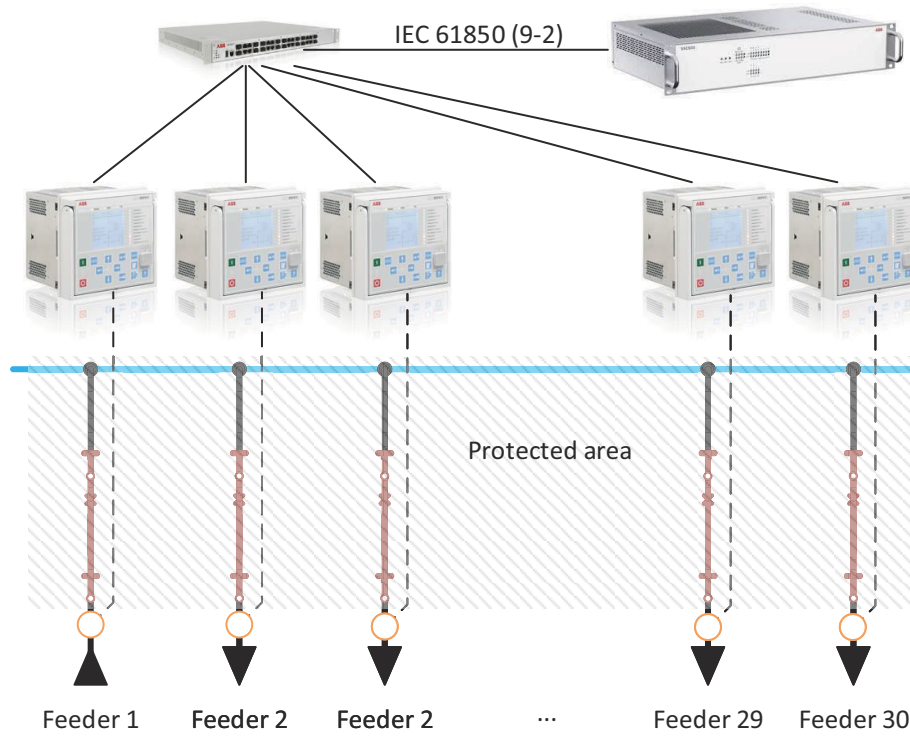


Figure 223: The basic principle of any differential protection

### 3.3.3.13 Configuration of the system

Below are some examples of the usage of SSC600 in different types of substations. The substation can consist of single busbar with one or two sections. [Figure 224](#) shows a system with single busbar with single section. With one SSC it is possible to protect up to 20 feeders.



*Figure 224: Single busbar system*

[Figure 225](#) shows a (sub)station with single busbar that has been divided into two sections. In this case with one SSC600 it is possible to protect 29 feeders with if one merging unit is connected to bus sectionalizer.

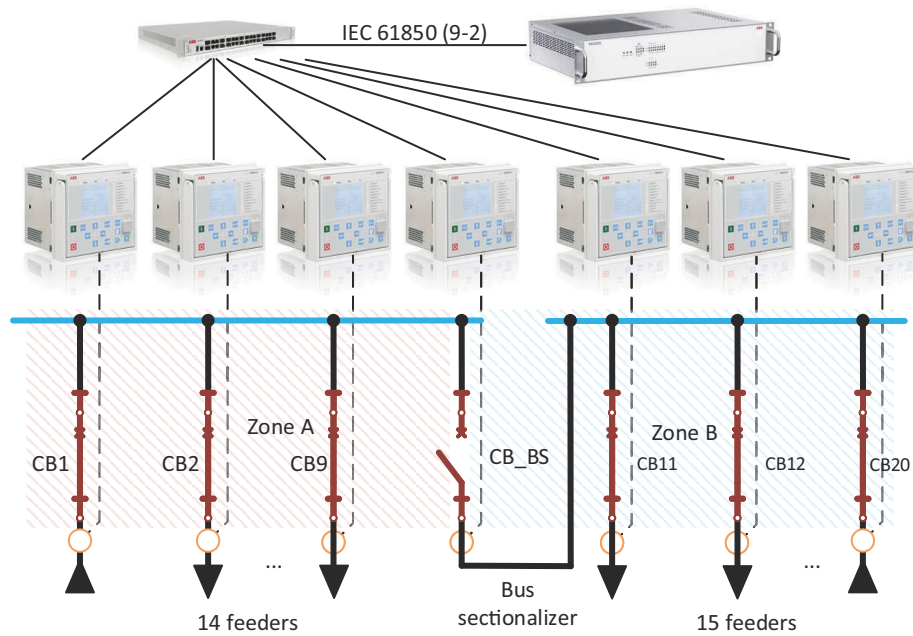


Figure 225: Single busbar system, two sections

Figure 226 shows substation with double busbar system. Both busbars in this case can have 14 feeders and two merging units are connected to buscoupler.

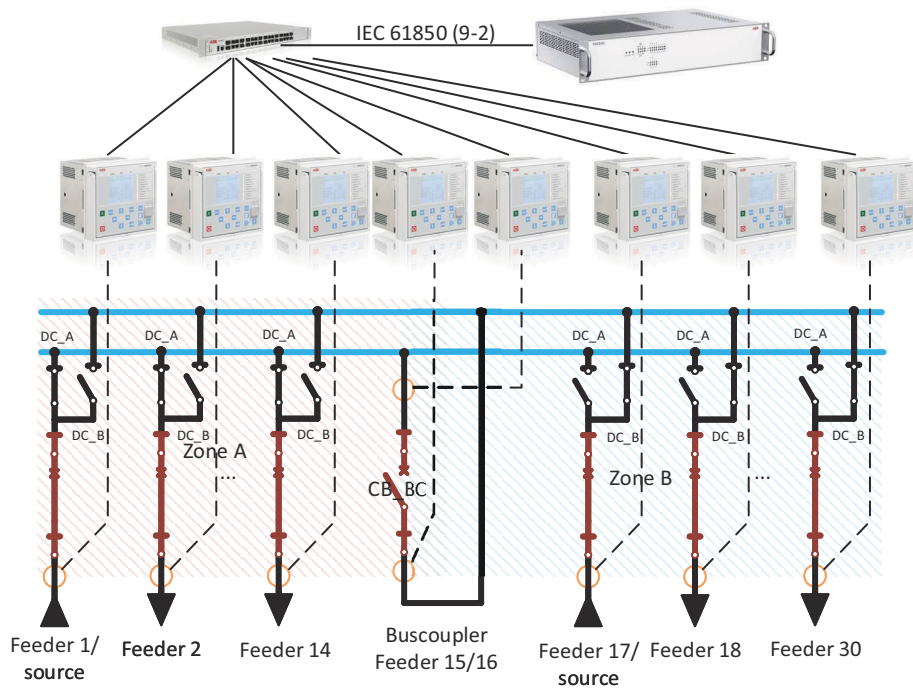


Figure 226: Double busbar system

### 3.3.3.14 BBPBDF Inputs

Table 392: BBPBDF Inputs

| IEC name | ANSI name | Type    | Default | Description  |
|----------|-----------|---------|---------|--|
| I3P_F1   | I3P_F1    | SIGNAL  |         | Three phase group signal for bay 1/<br>feeder 1 currents   |
| I3P_F2   | I3P_F2    | SIGNAL  |         | Three phase group signal for bay 2/<br>feeder 2 currents   |
| ...      | ...       | ...     |         | ...  |
| I3P_F30  | I3P_F30   | SIGNAL  |         | Three phase group signal for bay 30/<br>feeder 30 currents   |
| BLOCK    | BLOCK     | BOOLEAN | FALSE   | Signal for blocking the function   |
| TRG_SEF  | TRG_SEF   | BOOLEAN | FALSE   | Signal for enabling or triggering the<br>sensitive earth-fault protection.<br><br>Triggering function can be for in-<br>stance residual over-voltage protec-<br>tion (ROVPTOV) |
| RST_OCT  | RST_OCT   | BOOLEAN | FALSE   | Reset open CT detection logic  |

### 3.3.3.15 BBPBDF Outputs

Table 393: BBPBDF Outputs

| IEC name    | ANSI name   | Type    | Event /<br>dataset | Description   |
|-------------|-------------|---------|--------------------|---|
| OPERATE     | TRIP        | BOOLEAN | TRUE               | General operate signal  |
| OPR_ZA      | TRIP_ZA     | BOOLEAN | TRUE               | Operate signal for zone A   |
| OPR_ZB      | TRIP_ZB     | BOOLEAN | TRUE               | Operate signal for zone B   |
| OPR_ZN      | TRIP_CHK_Z  | BOOLEAN | FALSE              | Operate signal for check zone                                     |
| OPR_SEF_A   | TRIP_SEF_A  | BOOLEAN | TRUE               | Operate signal for sensitive<br>earth-fault protection for zone A |
| OPR_SEF_B   | TRIP_SEF_B  | BOOLEAN | TRUE               | Operate signal for sensitive<br>earth-fault protection for zone B |
| OPR_EX_ZA   | TRIP_EX_ZA  | BOOLEAN | TRUE               | External operate signal for zone<br>A                             |
| OPR_EX_ZB   | TRIP_EX_ZB  | BOOLEAN | TRUE               | External operate signal for zone<br>B                             |
| INT_BLKD_ZA | INT_BLKD_ZA | BOOLEAN | FALSE              | Internal block status for zone A                                  |
| INT_BLKD_ZB | INT_BLKD_ZB | BOOLEAN | FALSE              | Internal block status for zone B                                  |
| CT_OPEN     | CT_OPEN     | BOOLEAN | FALSE              | Open CT detected  |

### 3.3.3.16 BBPBDF Monitored data

**Table 394: BBPBDF Monitored data**

| IEC name | ANSI name | Type | Event / dataset | Description                                   |
|----------|-----------|------|-----------------|---|
| ID_ZA_A  | ID_ZA_A   | REAL | FALSE           | Differential current for zone A, phase A      |
| ID_ZA_B  | ID_ZA_B   | REAL | FALSE           | Differential current for zone A, phase B      |
| ID_ZA_C  | ID_ZA_C   | REAL | FALSE           | Differential current for zone A, phase C      |
| IB_ZA_A  | IB_ZA_A   | REAL | FALSE           | Stabilization current for zone A, phase A     |
| IB_ZA_B  | IB_ZA_B   | REAL | FALSE           | Stabilization current for zone A, phase B     |
| IB_ZA_C  | IB_ZA_C   | REAL | FALSE           | Stabilization current for zone A, phase C     |
| ID_ZB_A  | ID_ZB_A   | REAL | FALSE           | Differential current for zone B, phase A      |
| ID_ZB_B  | ID_ZB_B   | REAL | FALSE           | Differential current for zone B, phase B      |
| ID_ZB_C  | ID_ZB_C   | REAL | FALSE           | Differential current for zone B, phase C      |
| IB_ZB_A  | IB_ZB_A   | REAL | FALSE           | Stabilization current for zone B, phase A     |
| IB_ZB_B  | IB_ZB_B   | REAL | FALSE           | Stabilization current for zone B, phase B     |
| IB_ZB_C  | IB_ZB_C   | REAL | FALSE           | Stabilization current for zone B, phase C     |
| ID_ZN_A  | ID_ZN_A   | REAL | FALSE           | Differential current for check zone, phase A  |
| ID_ZN_B  | ID_ZN_B   | REAL | FALSE           | Differential current for check zone, phase B  |
| ID_ZN_C  | ID_ZN_C   | REAL | FALSE           | Differential current for check zone, phase C  |
| IB_ZN_A  | IB_ZN_A   | REAL | FALSE           | Stabilization current for check zone, phase A |
| IB_ZN_B  | IB_ZN_B   | REAL | FALSE           | Stabilization current for check zone, phase B |
| IB_ZN_C  | IB_ZN_C   | REAL | FALSE           | Stabilization current for check zone, phase C |

### 3.3.3.17 BBPBDF Settings and parameters

#### BBPBDF Settings

**Table 395: BBPBDF Group settings (Basic)**

| IEC name           | ANSI name          | Values (Range) | Unit | Default | Description   |
|--------------------|--------------------|----------------|------|---------|---|
| Low operate value  | Low operate value  | 5...150        | %Ir  | 20 %    | Operation threshold for differential characteristic |
| Low operate val CZ | Low operate val CZ | 5...150        | %Ir  | 20 %    | Operation threshold for check zone characteristic   |

*Table continues on the next page*

| IEC name            | ANSI name           | Values (Range) | Unit | Default | Description  |
|---------------------|---------------------|----------------|------|---------|--|
| Low operate val SEF | Low operate val SEF | 5...150        | %Ir  | 20 %    | Operation threshold for sensitive earth-fault protection |
| Operate delay SEF   | Operate delay SEF   | 20...200 000   | ms   | 50ms    | Operate delay time for sensitive earth-fault protection  |

**Table 396: BBPBDF Group settings (Advanced)**

| IEC name           | ANSI name          | Values (Range) | Unit | Default | Description                              |
|--------------------|--------------------|----------------|------|---------|--|
| Slope section 2    | Slope section 2    | 25...75        | %    | 50 %    | Slope of the differential characteristic |
| Slope section 2 CZ | Slope section 2 CZ | 25...75        | %    | 50 %    | Slope of the check zone characteristic   |

**Table 397: BBPBDF Non-group settings (Basic)**

| IEC name             | ANSI name            | Values (Range)                        | Unit | Default | Description   |
|----------------------|----------------------|---------------------------------------|------|---------|---|
| Operation            | Operation            | 1 = On<br>5 = Off                     | -    | On      | Operation Mode On / Off                               |
| Enable check zone    | Enable check zone    | FALSE = not enabled<br>TRUE = enabled | -    | TRUE    | Enable check zone functionality                       |
| Enable SEF           | Enable SEF           | FALSE = not enabled<br>TRUE = enabled | -    | TRUE    | Enable sensitive earth-fault protection               |
| Reset delay time SEF | Reset delay time SEF | 0...60 000                            | ms   | 20ms    | Reset delay time for sensitive earth-fault protection |

**Table 398: BBPBDF Non-group settings (Advanced)**

| IEC name        | ANSI name       | Values (Range)                        | Unit | Default | Description                              |
|-----------------|-----------------|---------------------------------------|------|---------|--|
| Enable OCT      | Enable OCT      | FALSE = not enabled<br>TRUE = enabled | -    | FALSE   | Enable open CT detection                 |
| Start value OCT | Start value OCT | 5...50                                | %Ir  | 5 %     | Start value for open CT detection        |
| Block value SEF | Block value SEF | 50...500                              | %Ir  | 150 %   | Sensitive earth-fault blocking threshold |



### 3.3.3.18 Technical data

**Table 399: BBPBDF Technical data**

| Characteristic                      | Value  |         |         |
|-------------------------------------|--|---------|---------|
| Operation accuracy <sup>45</sup>    | Depending on the frequency of the measured current: $f_n \pm 2$ Hz |         |         |
|                                     | 3% or $0.005 \cdot I_r$  |         |         |
| Operate time <sup>64,46,47,48</sup> | Minimum  | Typical | Maximum |
|                                     | 16 ms  | 18 ms   | 21 ms   |
| Reset time                          | Typically 40 ms  |         |         |
| Reset ratio                         | Typically 0.96   |         |         |
| Retardation time                    | < 20 ms  |         |         |
| Operate time accuracy               | $\pm 1.0\%$ of the set value or $\pm 20$ ms                        |         |         |
| Suppression of harmonics            | No suppression   |         |         |

## 3.3.4 Zone selection function ZNRCRC

### 3.3.4.1 Identification

| Function description           | IEC 61850<br>identification | IEC 60617<br>identification | ANSI/IEEE<br>identification |
|--------------------------------|-----------------------------|-----------------------------|-----------------------------|
| Busbar zone selection function | ZNRCRC                      | ZNRCRC                      | ZNRCRC                      |

<sup>45</sup> Sampled value delay 100%. Time synchronization implemented with IEE1588

<sup>46</sup> Current before fault  $0.0 \times I_n$ . Differential fault current  $2 \times$  set Start value

<sup>47</sup> Analog measurements connected to from merging unit to SSC600 via IEC 61850-9-2 LE

<sup>48</sup> Measured from IO unit static power output. Signalled with IEC 61850-8-1 GOOSE from SSC600.

### 3.3.4.2 Function block

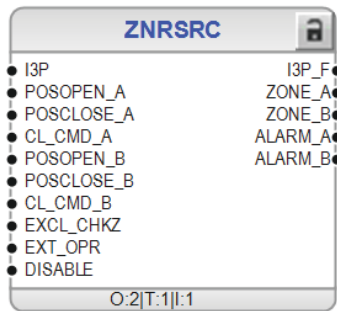


Figure 227: Function block symbol of ZNRSRC

### 3.3.4.3 Functionality

Busbar zone selection function ZNRSRC is necessary for configuring zone connections for busbar differential protection function BBPBDF. All bays within the substation are connected to the busbar protection function. ZNRSRC enables dynamic changes to the network configuration based on the disconnector or breaker status information.

Busbar protection function can operate in single or two zone operation mode depending on the (sub)station configuration. If (sub)station has only single busbar and one section, then function operates in single zone mode. On the other hand, if substation has two busbars or single busbar with two sections, then both zones are taken into use.

All bays within the substation are connected to the busbar protection function. Connection to different zones (zone A or zone B) are done with ZNRSRC function (Zone source). This function enables dynamic changes to the network configuration based on the disconnector or breaker status information.

### 3.3.4.4 Operation principle

The *Operation* setting is used to enable or disable the function. When selected "On" the function is enabled and respectively "Off" means function is disabled.

The operation of ZNRCRC can be described by using a module diagram (see [Figure 228](#)). All the modules in the diagram are explained in the next sections.

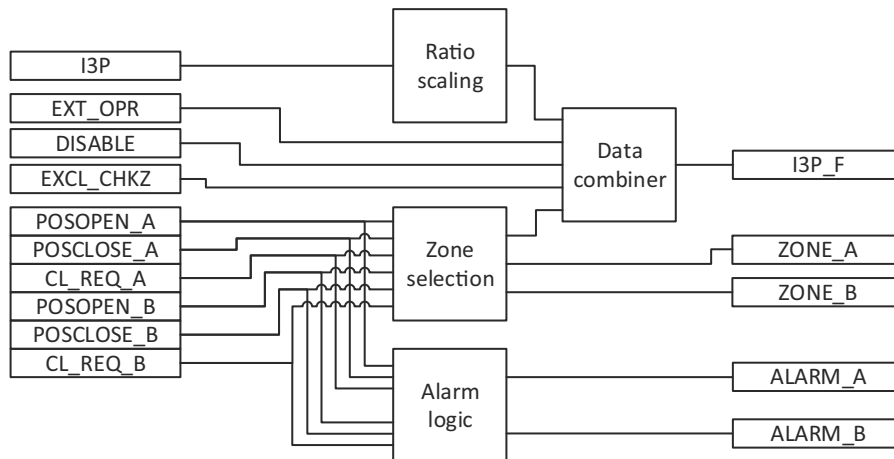


Figure 228: Functional module diagram

### 3.3.4.5 Ratio scaling

CT ratio correction-setting is used to scale all connected feeders to the same rated current level. Figure 229 shows a simple example of substation with one incoming feeder and two outgoing feeders. The busbar rated current is 1000A, so all connected feeders are scaled towards that value. CT ratio correction values are then following:

Feeder 1: CT ratio correction =  $500A / 1000A = 0.5$

Feeder 2: CT ratio correction =  $200A / 1000A = 0.2$

Feeder 3: CT ratio correction =  $200A / 1000A = 0.2$

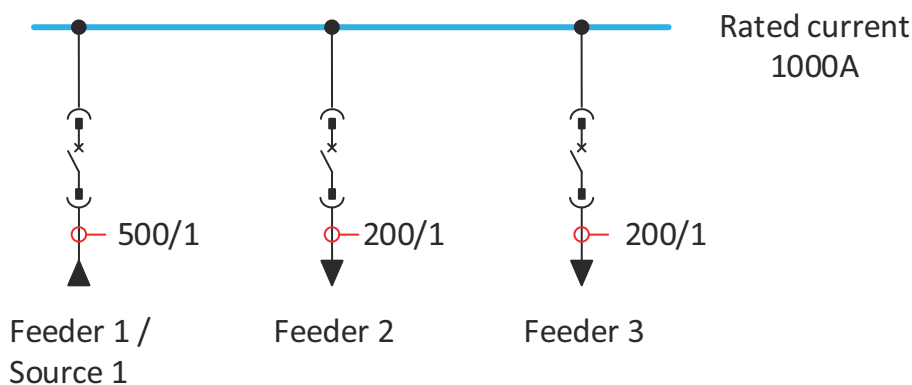


Figure 229: Example of CT ratio correction settings in simple substation

### 3.3.4.6 Zone selection

Zone selection is done based on the inputs POSOPEN\_A, POSCLOSE\_A, POSOPEN\_B and POSCLOSE\_B. The setting *Contact type* defines how the inputs configure the zone connection. Different combinations for Zone A are shown in the following tables. The Zone B behaves the same way.

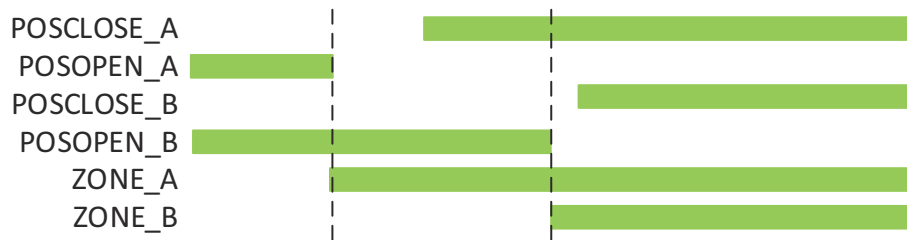
**Table 400: Connection to Zone A, Contact type “make-before-break”.**

| POSOPEN_A | POSCLOSE_A | Breaker or disconnector state | Connection to ZONE_A |
|-----------|------------|-------------------------------|----------------------|
| FALSE     | FALSE      | Intermediate                  | Yes                  |
| TRUE      | FALSE      | Open                          | No                   |
| FALSE     | TRUE       | Closed                        | Yes                  |
| TRUE      | TRUE       | Bad                           | Yes                  |

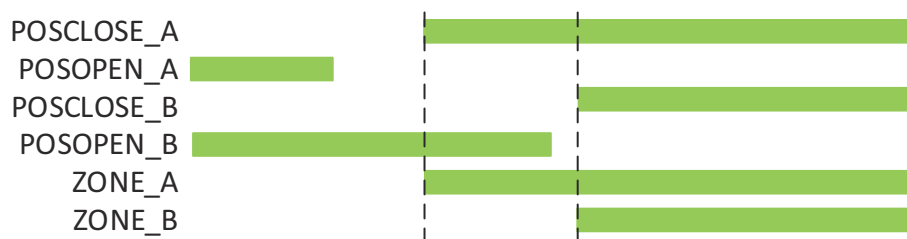
**Table 401: Connection to Zone A, Contact type “break-before-make”.**

| POSOPEN_A | POSCLOSE_A | Breaker or disconnector state | Connection to ZONE_A |
|-----------|------------|-------------------------------|----------------------|
| FALSE     | FALSE      | Intermediate                  | No                   |
| TRUE      | FALSE      | Open                          | No                   |
| FALSE     | TRUE       | Closed                        | Yes                  |
| TRUE      | TRUE       | Bad                           | Yes                  |

Outputs ZONE\_A and ZONE\_B are activated based on position information. *Figure 230* and *Figure 231* show the zone connection activation for different values of *Contact type* setting.



*Figure 230: Zone connection activation, Contact type “make-before-break”*



*Figure 231: Zone connection activation, Contact type “break-before-make”*

The close request inputs (CL\_REQ\_A and CL\_REQ\_B) can also be used to define the zone connection. If breaker or disconnector is open and close request input is activated (rising edge of the signal), connection to the zone A or zone B is made active for a time defined by setting Close timeout. The close request has only effect if the status information is “Open”.

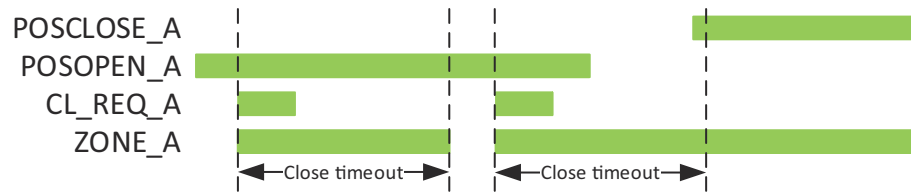


Figure 232: Connection to Zone A when *CL\_REQ\_A* input is activated.

Setting *Active zone* can be used to select active zone. If *Active zone* is set to “Zone A&B”, both zones are active and they follow the input information. If *Active zone* is set to “Zone A”, then inputs related to zone A are only considered and inputs related to Zone B are disregarded. And if *Active zone* is set to “Zone B”, then input related to zone B are only considered and input related to Zone A are disregarded.



Default value for *POSCLOSE\_A* and *POSCLOSE\_B* is FALSE and default value for *POSOPEN\_A* and *POSOPEN\_B* is TRUE. This means that if input is not connected at all in ACT, by default that zone is not active.

### 3.3.4.7

#### Alarm logic

Alarm logic gives alarm in following cases:

- breaker or disconnector status stays in “Intermediate” or “Bad” state longer than defined by setting *Event delay*.
- close request has been issued but breaker state does not change to “Closed” within time defined by setting *Close timeout*.

Alarm caused by status information “Intermediate” or “Bad” is reset when status information goes either to “Open” or “Closed”.

Alarm caused by close request is reset automatically after time defined by setting “Close timeout” or when a new command is activated or breaker status changes to “Closed” or “Open”.

### 3.3.4.8

#### Alarm logic

Setting Polarity reversal is used to invert the polarity of the measured currents connected to BBPBDf zone selection function. Polarity can be inverted to all zones or just for zone A or zone B. The default value is “no reversal” meaning polarity is not inverted.

Input *EXCL\_CHKZ* affects the check-zone calculation of the busbar-differential protection. If the *EXCL\_CHKZ*-input is active, the current connected to BBPBDf zone selection function is not used in the check-zone calculation in the busbar-differential protection.

External tripping signal can be connected to input *EXT\_OPR*.



Measured current samples (I3P), Polarity reversal and *EXT\_OPR* signal are routed to proper zone based on the zone connection information. All information is combined to *I3P\_F* output which is then connected to busbar protection function.

If *DISABLE*-input is active, the function block is disabled and data from this function is not used in the busbar differential protection. For instance the breaker truck

position can be connected to the DISABLE input to disconnect the feeder from busbar protection while breaker is maintained or tested.



DISABLE-input does not affect the check-zone current. If check-zone current is wanted to be excluded, EXCL\_CHKZ-input must be used.

### 3.3.4.9

## ZNRCRC Inputs

Table 402: ZNRSRC Inputs

| IEC name   | ANSI name  | Type    | Default | Description  |
|------------|------------|---------|---------|--|
| I3P        | I3P        | SIGNAL  |         | Three phase group signal   |
| POSOPEN_A  | POSOPEN_A  | BOOLEAN | TRUE    | Signal for open position of apparatus from I/O zone A                      |
| POSCLOSE_A | POSCLOSE_A | BOOLEAN | FALSE   | Signal for close position of apparatus from I/O zone A                     |
| CL_REQ_A   | CL_REQ     | BOOLEAN | FALSE   | Signal for close request of apparatus from I/O zone A                      |
| POSOPEN_B  | POSOPEN_B  | BOOLEAN | TRUE    | Signal for open position of apparatus from I/O zone B                      |
| POSCLOSE_B | POSCLOSE_B | BOOLEAN | FALSE   | Signal for close position of apparatus from I/O zone B                     |
| CL_REQ_B   | CL_REQ_B   | BOOLEAN | FALSE   | Signal for close request of apparatus from I/O zone B                      |
| EXCL_CHKZ  | EXCL_CHKZ  | BOOLEAN | FALSE   | Exclude from check zone  |
| EXT_OPR    | EXT_OPR    | BOOLEAN | FALSE   | External operate signal  |
| DISABLE    | DISABLE    | BOOLEAN | FALSE   | Disable function, current to busbar differential protection forced to zero |

### 3.3.4.10 ZNRSRC Outputs

**Table 403: ZNRSRC Outputs**

| IEC name | ANSI name | Type    | Event / dataset | Description   |
|----------|-----------|---------|-----------------|---|
| I3P_F    | I3P_F     | Group   |                 | Three phase group signal with disconnector status information |
| ZONE_A   | ZONE_A    | BOOLEAN | FALSE           | Measurements connected to Zone A                              |
| ZONE_B   | ZONE_B    | BOOLEAN | FALSE           | Measurements connected to Zone B                              |
| ALARM_A  | ALARM_A   | BOOLEAN | FALSE           | Apparatus state alarm from Zone A                             |
| ALARM_B  | ALARM_B   | BOOLEAN | FALSE           | Apparatus state alarm from Zone B                             |

### ZNRSRC Settings

**Table 404: ZNRSRC Non-group settings (Basic)**

| IEC name            | ANSI name           | Values (Range)   | Unit | Default         | Description                           |
|---------------------|---------------------|--|------|-----------------|---------------------------------------|
| Operation           | Operation           | 1 = On<br>5 = Off  | -    | On              | Operation Mode On / Off               |
| CT ratio correction | CT ratio correction | 0.200 ... 5.000  |      | 1.000           | Current transformer ratio correction  |
| Polarity reversal   | Polarity reversal   | 1 = No reversal<br>2 = All Zones<br>3 = Zone A<br>4 = Zone B |      | 0 = No reversal | Current measurement polarity reversal |
| Active zone         | Active zone         | 1 = Zone A<br>2 = Zone B<br>3 = Zone A&B                     |      | 3 = Zone A&B    | Active zones                          |

**Table 405: ZNRSRC Non-group settings (Advanced)**

| IEC name          | ANSI name         | Values (Range)        | Unit | Default               | Description                              |
|-------------------|-------------------|-----------------------|------|-----------------------|--|
| Event delay       | Event delay       | 0...60000             | ms   | 200                   | Event delay of the intermediate position |
| Close cmd timeout | Close cmd timeout | 10...60000            | ms   | 500                   | Close command timeout                    |
| Contact type      | Contact type      | 1 = make-before-break |      | 1 = make-before-break | Apparatus contact type                   |

| IEC name | ANSI name | Values (Range)        | Unit | Default | Description |
|----------|-----------|-----------------------|------|---------|-------------|
|          |           | 2 = break-before-make |      |         |             |

### 3.4 Unbalance protection

#### 3.4.1 Negative-sequence overcurrent protection NSPTOC

##### 3.4.1.1 Identification

| Function description                     | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--|--------------------------|--------------------------|-------------------------------|
| Negative-sequence overcurrent protection | NSPTOC                   | I2>                      | 46                            |

##### 3.4.1.2 Function block

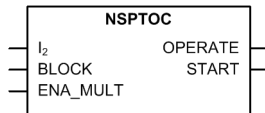


Figure 233: Function block

##### 3.4.1.3 Functionality

The negative-sequence overcurrent protection function NSPTOC is used for increasing sensitivity to detect single-phase and phase-to-phase faults or unbalanced loads due to, for example, broken conductors or unsymmetrical feeder voltages.



NSPTOC can also be used for detecting broken conductors.

The function is based on the measurement of the negative sequence current. In a fault situation, the function starts when the negative sequence current exceeds the set limit. The operate time characteristics can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.



### 3.4.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of NSPTOC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

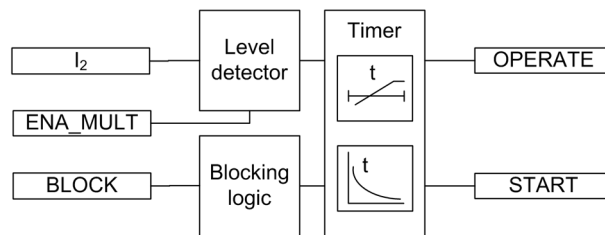


Figure 234: Functional module diagram

#### Level detector

The measured negative-sequence current is compared to the set *.Start value*. If the measured value exceeds the set *Start value*, the level detector activates the timer module. If the `ENA_MULT` input is active, the set *Start value* is multiplied by the set *Start value Mult*.



The IED does not accept the *Start value* or *Start value Mult* setting if the product of the settings exceeds the *Start value* setting range.

#### Timer

Once activated, the timer activates the `START` output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the `OPERATE` output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation happens, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation. The `START` output is deactivated when the reset timer has elapsed.



The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating

curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.



The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see [Chapter 10.2.1 IDMT curves for overcurrent protection](#) in this manual.

The timer calculates the start duration value `START_DUR`, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration > System > Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the `OPERATE` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block `OPERATE` output" mode, the function operates normally but the `OPERATE` output is not activated.

### 3.4.1.5

#### Application

Since the negative sequence current quantities are not present during normal, balanced load conditions, the negative sequence overcurrent protection elements can be set for faster and more sensitive operation than the normal phase-overcurrent protection for fault conditions occurring between two phases. The negative sequence overcurrent protection also provides a back-up protection functionality for the feeder earth-fault protection in solid and low resistance earthed networks.

The negative sequence overcurrent protection provides the back-up earth-fault protection on the high voltage side of a delta-wye connected power transformer for earth faults taking place on the wye-connected low voltage side. If an earth fault occurs on the wye-connected side of the power transformer, negative sequence current quantities appear on the delta-connected side of the power transformer.

The most common application for the negative sequence overcurrent protection is probably rotating machines, where negative sequence current quantities indicate unbalanced loading conditions (unsymmetrical voltages). Unbalanced loading normally causes extensive heating of the machine and can result in severe damages even over a relatively short time period.

Multiple time curves and time multiplier settings are also available for coordinating with other devices in the system.

### 3.4.1.6 Signals

#### NSPTOC Input signals

Table 406: NSPTOC Input signals

| Name           | Type    | Default | Description                                   |
|----------------|---------|---------|---|
| I <sub>2</sub> | SIGNAL  | 0       | Negative phase sequence current               |
| BLOCK          | BOOLEAN | 0=False | Block signal for activating the blocking mode |
| ENA_MULT       | BOOLEAN | 0=False | Enable signal for current multiplier          |

#### NSPTOC Output signals

Table 407: NSPTOC Output signals

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

### 3.4.1.7 Settings

#### NSPTOC Settings

Table 408: NSPTOC Group settings (Basic)

| Parameter            | Values (Range)  | Unit | Step | Default          | Description                             |
|----------------------|---|------|------|------------------|---|
| Start value          | 0.01...5.00   | xIn  | 0.01 | 0.30             | Start value                             |
| Start value Mult     | 0.8...10.0  |      | 0.1  | 1.0              | Multiplier for scaling the start value  |
| Time multiplier      | 0.05...15.00  |      | 0.01 | 1.00             | Time multiplier in IEC/ANSI IDMT curves |
| Operate delay time   | 40...200000   | ms   | 10   | 40               | Operate delay time                      |
| Operating curve type | 1=ANSI Ext. inv.<br>2=ANSI Very inv.<br>3=ANSI Norm. inv. |      |      | 15=IEC Def. Time | Selection of time delay curve type      |

| Parameter | Values (Range)   | Unit | Step | Default | Description |
|-----------|--|------|------|---------|-------------|
|           | 4=ANSI Mod. inv.<br>5=ANSI Def. Time<br>6=L.T.E. inv.<br>7=L.T.V. inv.<br>8=L.T. inv.<br>9=IEC Norm. inv.<br>10=IEC Very inv.<br>11=IEC inv.<br>12=IEC Ext. inv.<br>13=IEC S.T. inv.<br>14=IEC L.T. inv.<br>15=IEC Def. Time<br>17=Program-mable<br>18=RI type<br>19=RD type |      |      |         |             |

**Table 409: NSPTOC Group settings (Advanced)**

| Parameter           | Values (Range)                                       | Unit | Step | Default     | Description                   |
|---------------------|--|------|------|-------------|-------------------------------|
| Type of reset curve | 1=Immediate<br>2=Def time re-set<br>3=Inverse re-set |      |      | 1=Immediate | Selection of reset curve type |

**Table 410: NSPTOC Non group settings (Basic)**

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on           |      |      | 1=on    | Operation Off / On |

*Table continues on the next page*

| Parameter         | Values (Range)    | Unit | Step | Default | Description                                 |
|-------------------|-------------------|------|------|---------|---|
|                   | 5=off             |      |      |         |   |
| Curve parameter A | 0.0086...120.0000 |      | 1    | 28.2000 | Parameter A for customer programmable curve |
| Curve parameter B | 0.0000...0.7120   |      | 1    | 0.1217  | Parameter B for customer programmable curve |
| Curve parameter C | 0.02...2.00       |      | 1    | 2.00    | Parameter C for customer programmable curve |
| Curve parameter D | 0.46...30.00      |      | 1    | 29.10   | Parameter D for customer programmable curve |
| Curve parameter E | 0.0...1.0         |      | 1    | 1.0     | Parameter E for customer programmable curve |

Table 411: NSPTOC Non group settings (Advanced)

| Parameter            | Values (Range) | Unit | Step | Default | Description                          |
|----------------------|----------------|------|------|---------|--------------------------------------|
| Minimum operate time | 20...60000     | ms   | 1    | 20      | Minimum operate time for IDMT curves |
| Reset delay time     | 0...60000      | ms   | 1    | 20      | Reset delay time                     |

### 3.4.1.8

## Monitored data

### NSPTOC Monitored data

Table 412: NSPTOC Monitored data

| Name      | Type    | Values (Range)              | Unit | Description                        |
|-----------|---------|-----------------------------|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00               | %    | Ratio of start time / operate time |
| NSPTOC    | Enum    | 1=on<br>2=blocked<br>3=test |      | Status                             |

| Name | Type | Values (Range)          | Unit | Description |
|------|------|-------------------------|------|-------------|
|      |      | 4=test/blocked<br>5=off |      |             |

### 3.4.1.9 Technical data

Table 413: NSPTOC Technical data

| Characteristic                              |  | Value   |                |                |
|---|--|---|----------------|----------------|
| Operation accuracy                          |  | Depending on the frequency of the measured current: $f_n$<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$ |                |                |
| Start time <sup>50</sup>                    |  | Minimum   | Typical        | Maximum        |
|   | $I_{\text{Fault}} = 2 \times \text{set Start value}$ | 24 ms<br>15 ms  | 27 ms<br>18 ms | 29 ms<br>20 ms |
|   |  | $I_{\text{Fault}} = 10 \times \text{set Start value}$   |                |                |
| Reset time                                  |  | Typically 40 ms   |                |                |
| Reset ratio                                 |  | Typically 0.96  |                |                |
| Retardation time                            |  | <35 ms  |                |                |
| Operate time accuracy in definite time mode |  | $\pm 1.0\%$ of the set value or $\pm 20$ ms   |                |                |
| Operate time accuracy in inverse time mode  |  | $\pm 5.0\%$ of the theoretical value or $\pm 20$ ms <sup>51</sup>   |                |                |
| Suppression of harmonics                    |  | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$   |                |                |

### 3.4.1.10 Technical revision history

Table 414: NSPTOC Technical revision history

| Technical revision | Change  |
|--------------------|---|
| B                  | Minimum and default values changed to 40 ms for the <i>Operate delay time</i> setting |
| C                  | Step value changed from 0.05 to 0.01 for the <i>Time multiplier</i> setting           |
| D                  | Internal improvement.   |
| E                  | Internal Improvements.  |

<sup>49</sup> Negative sequence current before fault = 0.0,  $f_n = 50$  Hz, results based on statistical distribution of 1000 measurements

<sup>50</sup> Includes the delay of the signal output contact

<sup>51</sup> Maximum *Start value* =  $2.5 \times I_n$ , *Start value* multiples in range of 1.5...20

### 3.4.2 Phase discontinuity protection PDNSPTOC

#### 3.4.2.1 Identification

| Function description           | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--------------------------------|--------------------------|--------------------------|-------------------------------|
| Phase discontinuity protection | PDNSPTOC                 | I2/I1>                   | 46PD                          |

#### 3.4.2.2 Function block

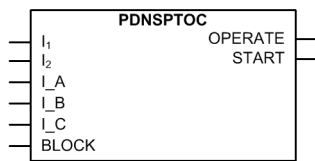


Figure 235: Function block

#### 3.4.2.3 Functionality

The phase discontinuity protection function PDNSPTOC is used for detecting unbalance situations caused by broken conductors.

The function starts and operates when the unbalance current  $I_2/I_1$  exceeds the set limit. To prevent faulty operation at least one phase current needs to be above the minimum level. PDNSPTOC operates with DT characteristic.

The function contains a blocking functionality. It is possible to block the function output, timer or the function itself, if desired.

#### 3.4.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PDNSPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

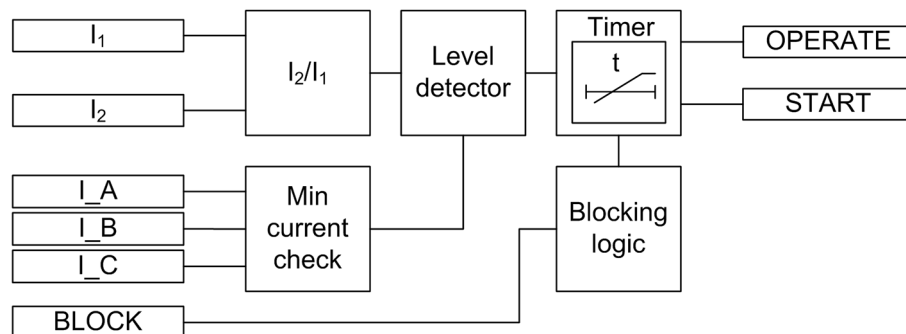


Figure 236: Functional module diagram

## I<sub>2</sub>/I<sub>1</sub>

The I<sub>2</sub>/I<sub>1</sub> module calculates the ratio of the negative and positive sequence current. It reports the calculated value to the level detector.

### Level detector

The level detector compares the calculated ratio of the negative- and positive-sequence currents to the set *Start value*. If the calculated value exceeds the set *Start value* and the min current check module has exceeded the value of *Min phase current*, the level detector reports the exceeding of the value to the timer.

### Min current check

The min current check module checks whether the measured phase currents are above the set *Min phase current*. At least one of the phase currents needs to be above the set limit to enable the level detector module.

### Timer

Once activated, the timer activates the `START` output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the `OPERATE` output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the `START` output is deactivated.

The timer calculates the start duration value `START_DUR`, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration > System > Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the `OPERATE` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block `OPERATE` output" mode, the function operates normally but the `OPERATE` output is not activated.

## 3.4.2.5

### Application

In three-phase distribution and subtransmission network applications the phase discontinuity in one phase can cause an increase of zero-sequence voltage and short overvoltage peaks and also oscillation in the corresponding phase.

PDNSPTOC is a three-phase protection with DT characteristic, designed for detecting broken conductors in distribution and subtransmission networks. The function is applicable for both overhead lines and underground cables.

The operation of PDNSPTOC is based on the ratio of the positive-sequence and negative-sequence currents. This gives a better sensitivity and stability



compared to plain negative-sequence current protection since the calculated ratio of positive-sequence and negative-sequence currents is relatively constant during load variations.

The unbalance of the network is detected by monitoring the negative-sequence and positive-sequence current ratio, where the negative-sequence current value is  $I_2$  and  $I_1$  is the positive-sequence current value. The unbalance is calculated with the equation.

$$I_{ratio} = \frac{I_2}{I_1}$$

Broken conductor fault situation can occur in phase A in a feeder.

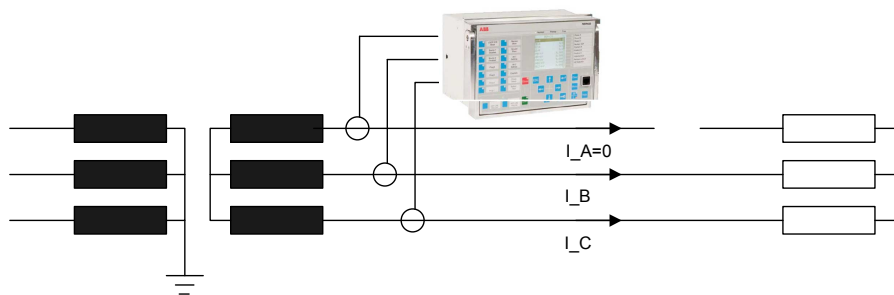


Figure 237: Broken conductor fault situation in phase A in a distribution or subtransmission feeder

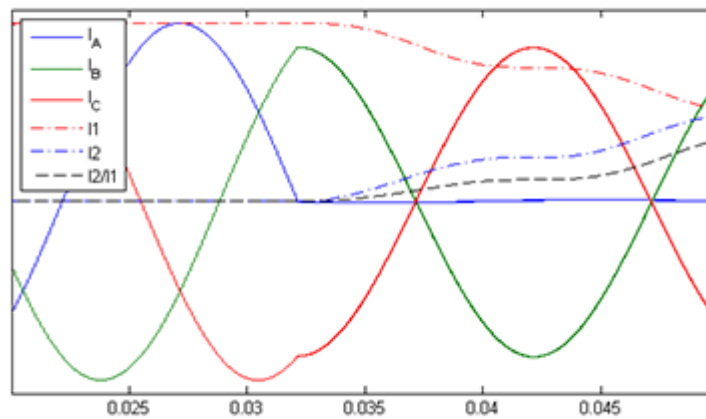


Figure 238: Three-phase current quantities during the broken conductor fault in phase A with the ratio of negative-sequence and positive-sequence currents

### 3.4.2.6 Signals

**PDNSPTOC Input signals****Table 415: PDNSPTOC Input signals**

| Name           | Type    | Default | Description                                   |
|----------------|---------|---------|---|
| I <sub>1</sub> | SIGNAL  | 0       | Positive sequence current                     |
| I <sub>2</sub> | SIGNAL  | 0       | Negative sequence current                     |
| I_A            | SIGNAL  | 0       | Phase A current                               |
| I_B            | SIGNAL  | 0       | Phase B current                               |
| I_C            | SIGNAL  | 0       | Phase C current                               |
| BLOCK          | BOOLEAN | 0=False | Block signal for activating the blocking mode |

**PDNSPTOC Output signals****Table 416: PDNSPTOC Output signals**

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

**3.4.2.7****Settings****PDNSPTOC Settings****Table 417: PDNSPTOC Group settings (Basic)**

| Parameter          | Values (Range) | Unit | Step | Default | Description        |
|--------------------|----------------|------|------|---------|--------------------|
| Start value        | 10...100       | %    | 1    | 10      | Start value        |
| Operate delay time | 100...30000    | ms   | 1    | 100     | Operate delay time |

**Table 418: PDNSPTOC Non group settings (Basic)**

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

**Table 419: PDNSPTOC Non group settings (Advanced)**

| Parameter         | Values (Range) | Unit | Step | Default | Description           |
|-------------------|----------------|------|------|---------|-----------------------|
| Reset delay time  | 0...60000      | ms   | 1    | 20      | Reset delay time      |
| Min phase current | 0.05...0.30    | xIn  | 0.01 | 0.10    | Minimum phase current |

**3.4.2.8****Monitored data****PDNSPTOC Monitored data****Table 420: PDNSPTOC Monitored data**

| Name        | Type    | Values (Range)   | Unit | Description                        |
|-------------|---------|--|------|------------------------------------|
| START_DUR   | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time |
| RATIO_I2_I1 | FLOAT32 | 0.00...999.99  | %    | Measured current ratio I2 / I1     |
| PDNSPTOC    | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                             |

**3.4.2.9****Technical data****Table 421: PDNSPTOC Technical data**

| Characteristic                              | Value  |
|---|--|
| Operation accuracy                          | Depending on the frequency of the measured current: $f_n \pm 2$ Hz<br>$\pm 2\%$ of the set value |
| Start time                                  | <70 ms   |
| Reset time                                  | Typically 40 ms  |
| Reset ratio                                 | Typically 0.96   |
| Retardation time                            | <35 ms   |
| Operate time accuracy in definite time mode | $\pm 1.0\%$ of the set value or $\pm 20$ ms  |
| Suppression of harmonics                    | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$                                |

### 3.4.2.10 Technical revision history

Table 422: PDNSPTOC Technical revision history

| Technical revision | Change                |
|--------------------|-----------------------|
| B                  | Internal improvement. |
| C                  | Internal improvement. |
| D                  | Internal improvement. |

## 3.4.3 Phase reversal protection PREVPTOC

### 3.4.3.1 Identification

| Function description      | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---------------------------|--------------------------|--------------------------|-------------------------------|
| Phase reversal protection | PREVPTOC                 | I2>>                     | 46R                           |

### 3.4.3.2 Function block

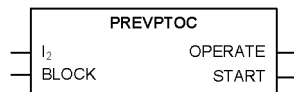


Figure 239: Function block

### 3.4.3.3 Functionality

The phase reversal protection function PREVPTOC is used to detect the reversed connection of the phases to a three-phase motor by monitoring the negative phase sequence current I<sub>2</sub> of the motor.

PREVPTOC starts and operates when I<sub>2</sub> exceeds the set limit. PREVPTOC operates on definite time (DT) characteristics. PREVPTOC is based on the calculated I<sub>2</sub>, and the function detects too high I<sub>2</sub> values during the motor startup. The excessive I<sub>2</sub> values are caused by incorrectly connected phases, which in turn makes the motor rotate in the opposite direction.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

### 3.4.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PREVPTOC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

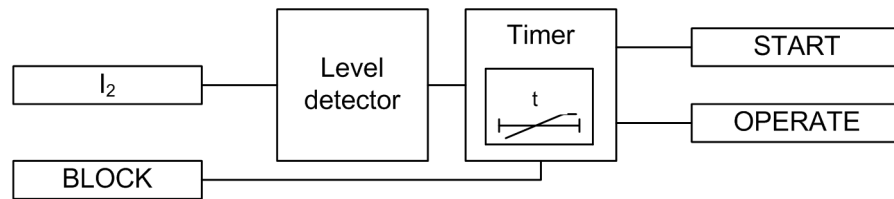


Figure 240: Functional module diagram

### Level detector

The level detector compares the negative-sequence current to the set *Start value*. If the  $I_2$  value exceeds the set *Start value*, the level detector sends an enabling signal to the timer module.

### Timer

Once activated, the timer activates the *START* output. When the operation timer has reached the set *Operate delay time* value, the *OPERATE* output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value of 200 ms, the operation timer resets and the *START* output is deactivated.

The timer calculates the start duration value *START\_DUR*, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

## 3.4.3.5 PREVPTOC application

The rotation of a motor in the reverse direction is not a desirable operating condition. When the motor drives fans and pumps, for example, and the rotation direction is reversed due to a wrong phase sequence, the driven process can be disturbed and the flow of the cooling air of the motor can become reversed too. With a motor designed only for a particular rotation direction, the reversed rotation direction can lead to an inefficient cooling of the motor due to the fan design.

In a motor, the value of the negative-sequence component of the phase currents is very negligible when compared to the positive-sequence component of the current during a healthy operating condition of the motor. But when the motor is started with the phase connections in the reverse order, the magnitude of  $I_2$  is very high. So whenever the value of  $I_2$  exceeds the start value, the function detects the reverse rotation direction and provides an operating signal that disconnects the motor from the supply.

## 3.4.3.6 Signals

**PREVPTOC Input signals****Table 423: PREVPTOC Input signals**

| Name           | Type    | Default | Description                                   |
|----------------|---------|---------|---|
| I <sub>2</sub> | SIGNAL  | 0       | Negative sequence current                     |
| BLOCK          | BOOLEAN | 0=False | Block signal for activating the blocking mode |

**PREVPTOC Output signals****Table 424: PREVPTOC Output signals**

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

**3.4.3.7****Settings****PREVPTOC Settings****Table 425: PREVPTOC Group settings (Basic)**

| Parameter          | Values (Range) | Unit | Step | Default | Description        |
|--------------------|----------------|------|------|---------|--------------------|
| Start value        | 0.05...1.00    | xIn  | 0.01 | 0.75    | Start value        |
| Operate delay time | 100...60000    | ms   | 10   | 100     | Operate delay time |

**Table 426: PREVPTOC Non group settings (Basic)**

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

**3.4.3.8****Monitored data**

**PREVPTOC Monitored data****Table 427: PREVPTOC Monitored data**

| Name      | Type    | Values (Range)   | Unit | Description                        |
|-----------|---------|--|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time |
| PREVPTOC  | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                             |

**3.4.3.9****Technical data****Table 428: PREVPTOC Technical data**

| Characteristic                              |   | Value  |         |         |
|---|---|--|---------|---------|
| Operation accuracy                          |   | Depending on the frequency of the measured current: $f_n \pm 2$ Hz |         |         |
|   |   | $\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$             |         |         |
| Start time <sup>5253</sup>                  |   | Minimum  | Typical | Maximum |
|   | $I_{Fault} = 2.0 \times \text{set Start value}$ | 24 ms  | 25 ms   | 28 ms   |
| Reset time                                  |   | Typically 40 ms  |         |         |
| Reset ratio                                 |   | Typically 0.96   |         |         |
| Retardation time                            |   | <35 ms   |         |         |
| Operate time accuracy in definite time mode |   | $\pm 1.0\%$ of the set value or $\pm 20$ ms                        |         |         |
| Suppression of harmonics                    |   | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$  |         |         |

**3.4.3.10****Technical revision history****Table 429: PREVPTOC Technical revision history**

| Technical revision | Change                |
|--------------------|-----------------------|
| B                  | Internal improvement. |

<sup>52</sup> Negative-sequence current before = 0.0,  $f_n = 50$  Hz, results based on statistical distribution of 1000 measurements

<sup>53</sup> Includes the delay of the signal output contact

### 3.4.4 Negative-sequence overcurrent protection for machines MNSPTOC

#### 3.4.4.1 Identification

| Function description                                  | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|--------------------------|--------------------------|-------------------------------|
| Negative-sequence overcurrent protection for machines | MNSPTOC                  | I2>M                     | 46M                           |

#### 3.4.4.2 Function block

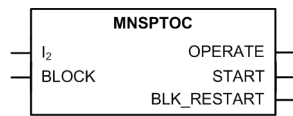


Figure 241: Function block

#### 3.4.4.3 Functionality

The negative-sequence overcurrent protection for machines function MNSPTOC protects electric motors from phase unbalance. A small voltage unbalance can produce a large negative-sequence current flow in the motor. For example, a 5 percent voltage unbalance produces a stator negative-sequence current of 30 percent of the full load current, which can severely heat the motor. MNSPTOC detects the large negative-sequence current and disconnects the motor.

The function contains a blocking functionality. It is possible to block the function outputs, timers or the function itself, if desired.

#### 3.4.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of MNSPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

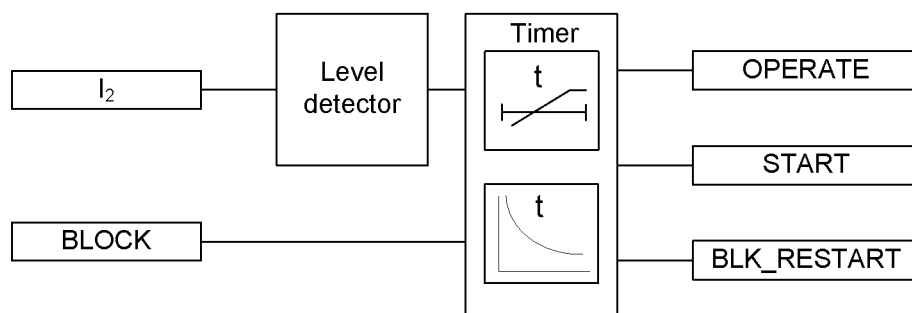


Figure 242: Functional module diagram



### Level detector

The calculated negative-sequence current is compared to the *Start value* setting. If the measured value exceeds the *Start value* setting, the function activates the timer module.

### Timer

Once activated, the timer activates the `START` output. Depending on the value of the set *Operating curve type*, the time characteristics are according to DT or IDMT. When the operation timer has reached the value set by *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the `OPERATE` output is activated.

In a drop-off situation, that is, when the value of the negative-sequence current drops below the *Start value* setting, the reset timer is activated and the `START` output resets after the time delay of *Reset delay time* for the DT characteristics. For IDMT, the reset time depends on the curve type selected.

For the IDMT curves, it is possible to define minimum and maximum operate times with the *Minimum operate time* and *Maximum operate time* settings. The *Machine time Mult* setting parameter corresponds to the machine constant, equal to the  $I_2^2t$  constant of the machine, as stated by the machine manufacturer. In case there is a mismatch between the used CT and the protected motor's nominal current values, it is possible to fit the IDMT curves for the protected motor using the *Current reference* setting.

The activation of the `OPERATE` output activates the `BLK_RESTART` output. The deactivation of the `OPERATE` output activates the cooling timer. The timer is set to the value entered in the *Cooling time* setting. The `BLK_RESTART` output is kept active until the cooling timer is exceeded. If the negative-sequence current increases above the set value during this period, the `OPERATE` output is activated immediately.

The `T_ENARESTART` output indicates the duration for which the `BLK_RESTART` output remains active, that is, it indicates the remaining time of the cooling timer. The value is available in the monitored data view.

The timer calculates the start duration value `START_DUR`, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

### 3.4.4.5

#### Timer characteristics

MNSPTOC supports both DT and IDMT characteristics. The DT timer characteristics can be selected with "ANSI Def. Time" or "IEC Def. Time" in the *Operating curve type* setting. The functionality is identical in both cases. When the DT characteristics are selected, the functionality is only affected by the *Operate delay time* and *Reset delay time* settings.

The IED provides two user-programmable IDMT characteristics curves, "Inv. curve A" and "Inv. curve B".

#### Current-based inverse definite minimum time curve (IDMT)

In inverse-time modes, the operate time depends on the momentary value of the current: the higher the current, the shorter the operate time. The operate time calculation or integration starts immediately when the current exceeds the set *Start value* and the `START` output is activated.

The OPERATE output of the component is activated when the cumulative sum of the integrator calculating the overcurrent situation exceeds the value set by the inverse time mode. The set value depends on the selected curve type and the setting values used.

The *Minimum operate time* and *Maximum operate time* settings define the minimum operate time and maximum operate time possible for the IDMT mode. For setting these parameters, a careful study of the particular IDMT curves is recommended.

#### Inv. curve A

The inverse time equation for curve type A is:

$$t[s] = \frac{k}{\left(\frac{I_2}{I_r}\right)^2}$$

|                |                              |
|----------------|------------------------------|
| t[s]           | Operate time in seconds      |
| k              | Set <i>Machine time Mult</i> |
| I <sub>2</sub> | Negative-sequence current    |
| I <sub>r</sub> | Set <i>Rated current</i>     |

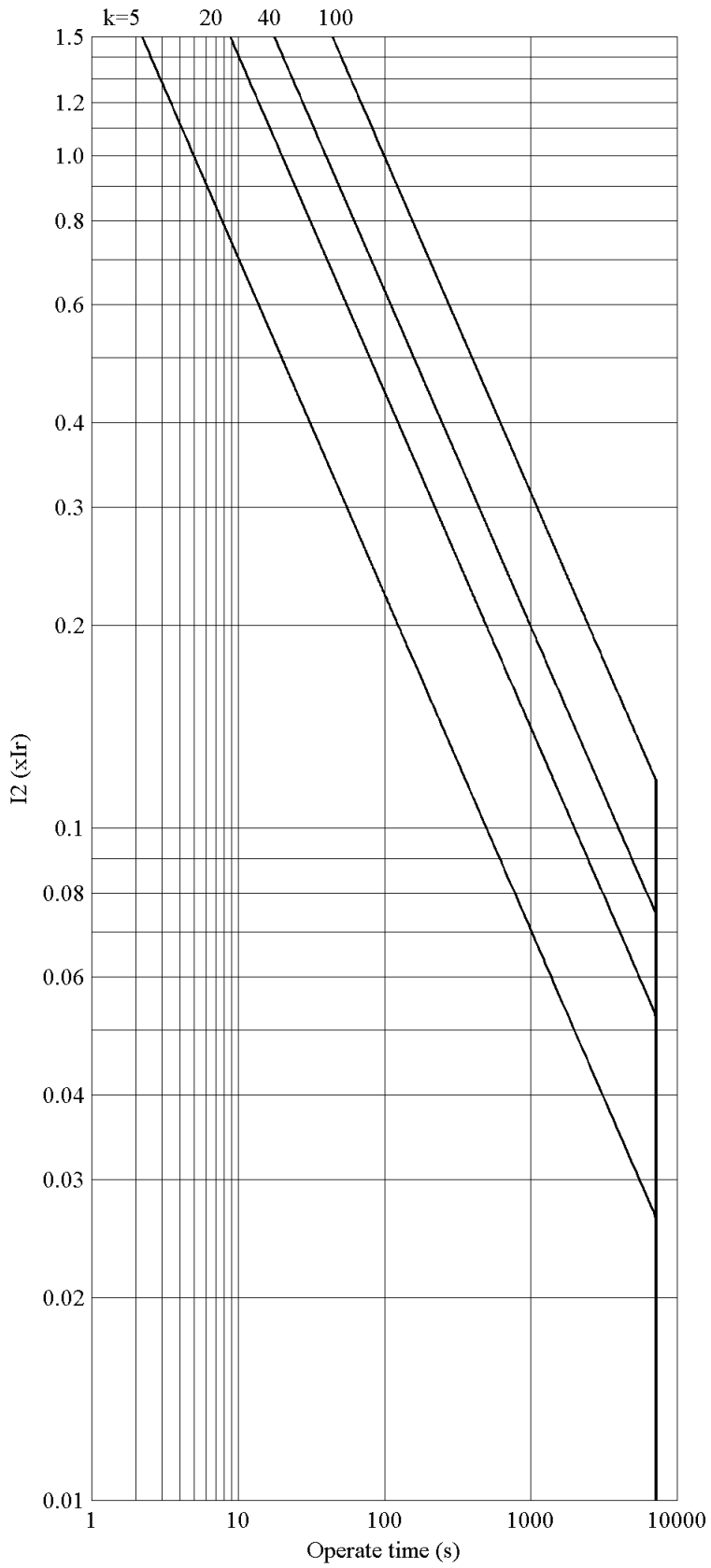


Figure 243: MNSPTOC Inverse Curve A

If the negative sequence current drops below the *Start value* setting, the reset time is defined as:

$$t[s] = a \times \left( \frac{b}{100} \right)$$

|      |   |
|------|---|
| t[s] | Reset time in seconds                       |
| a    | Set <i>Cooling time</i>                     |
| b    | Percentage of start time elapse (START_DUR) |

When the reset period is initiated, the time for which START has been active is saved. If the fault reoccurs, that is, the negative-sequence current rises above the set value during the reset period, the operate calculations are continued using the saved values. If the reset period elapses without a fault being detected, the operate timer is reset and the saved values of start time and integration are cleared.

#### Inv. curve B

The inverse time equation for curve type B is:

$$t[s] = \frac{k}{\left( \frac{I_2}{I_r} \right)^2 - \left( \frac{I_S}{I_r} \right)^2}$$

|                |                           |
|----------------|---------------------------|
| t[s]           | Operate time in seconds   |
| k              | <i>Machine time Mult</i>  |
| I <sub>2</sub> | Negative-sequence current |
| I <sub>S</sub> | Set <i>Start value</i>    |
| I <sub>r</sub> | Set <i>Rated current</i>  |

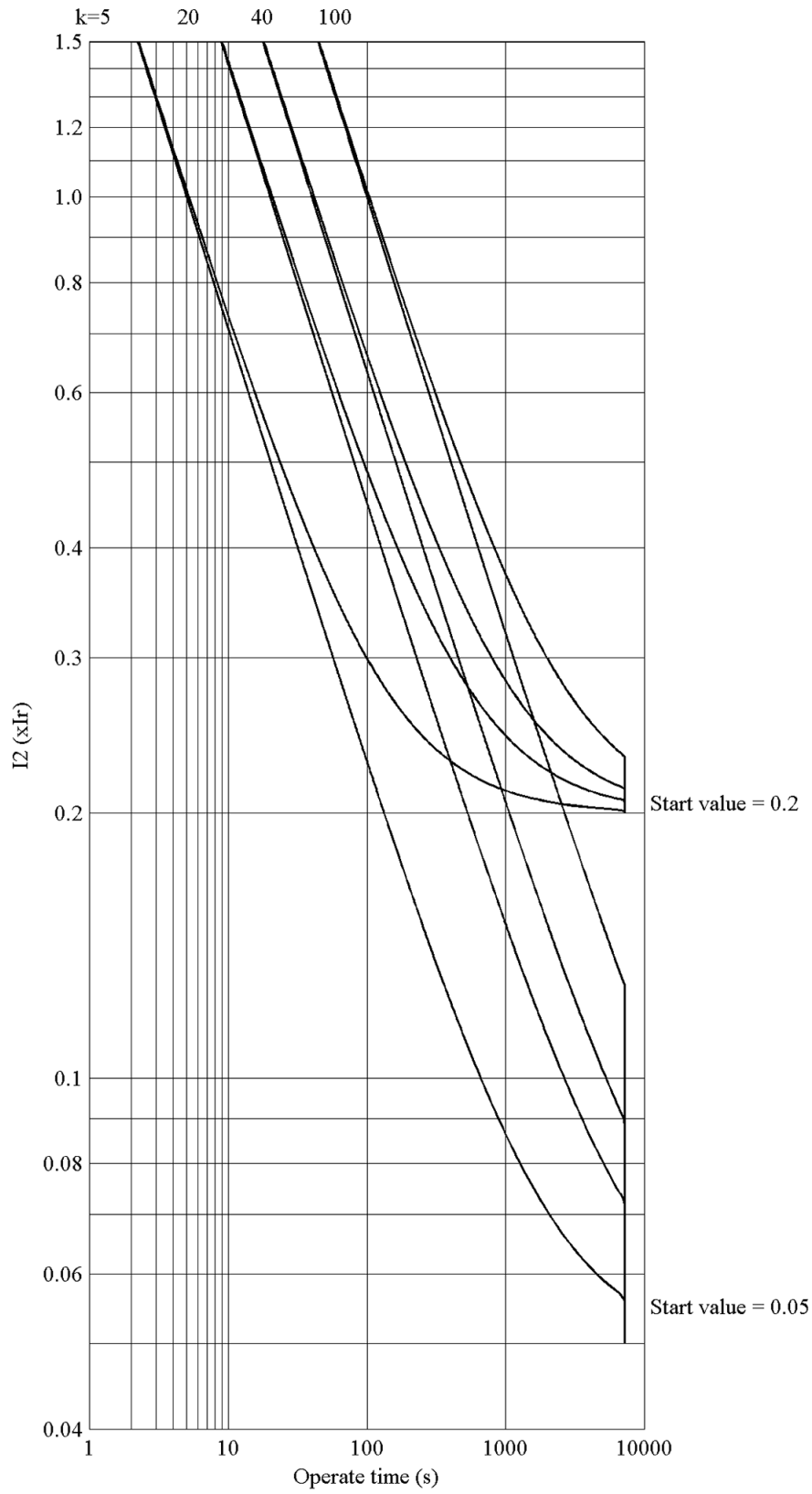


Figure 244: MNSPTOC Inverse Curve B

If the fault disappears, the negative-sequence current drops below the *Start value* setting and the *START* output is deactivated. The function does not reset instantaneously. Resetting depends on the equation or the *Cooling time* setting.

The timer is reset in two ways:

- When the negative sequence current drops below start value the subtraction in the denominator becomes negative and the cumulative sum starts to decrease. The decrease in the sum indicates the cooling of the machine and the cooling speed depends on the value of the negative-sequence current. If the sum reaches zero without a fault being detected, the accumulation stops and the timer is reset.
- If the reset time set through the *Cooling time* setting elapses without a fault being detected, the timer is reset.

The reset period thus continues for a time equal to the *Cooling time* setting or until the operate time decreases to zero, whichever is less.

#### 3.4.4.6 Application

In a three-phase motor, the conditions that can lead to unbalance are single phasing, voltage unbalance from the supply and single-phase fault. The negative sequence current damages the motor during the unbalanced voltage condition, and therefore the negative sequence current is monitored to check the unbalance condition.

When the voltages supplied to an operating motor become unbalanced, the positive-sequence current remains substantially unchanged, but the negative-sequence current flows due to the unbalance. For example, if the unbalance is caused by an open circuit in any phase, a negative-sequence current flows and it is equal and opposite to the previous load current in a healthy phase. The combination of positive and negative-sequence currents produces phase currents approximately 1.7 times the previous load in each healthy phase and zero current in the open phase.

The negative-sequence currents flow through the stator windings inducing negative-sequence voltage in the rotor windings. This can result in a high rotor current that damages the rotor winding. The frequency of the induced current is approximately twice the supply frequency. Due to skin effect, the induced current with a frequency double the supply frequency encounters high rotor resistance which leads to excessive heating even with phase currents with value less than the rated current of the motor.

The negative-sequence impedance of induction or a synchronous motor is approximately equal to the locked rotor impedance, which is approximately one-sixth of the normal motor impedance, considering that the motor has a locked-rotor current of six times the rated current. Therefore, even a three percent voltage unbalance can lead to 18 percent stator negative sequence current in windings. The severity of this is indicated by a 30-40 percent increase in the motor temperature due to the extra current.

#### 3.4.4.7 Signals

**MNSPTOC Input signals****Table 430: MNSPTOC Input signals**

| Name           | Type    | Default | Description                                   |
|----------------|---------|---------|---|
| I <sub>2</sub> | SIGNAL  | 0       | Negative sequence current                     |
| BLOCK          | BOOLEAN | 0=False | Block signal for activating the blocking mode |

**MNSPTOC Output signals****Table 431: MNSPTOC Output signals**

| Name        | Type    | Description                              |
|-------------|---------|--|
| OPERATE     | BOOLEAN | Operate                                  |
| START       | BOOLEAN | Start                                    |
| BLK_RESTART | BOOLEAN | Overheated machine reconnection blocking |

**3.4.4.8****Settings****MNSPTOC Settings****Table 432: MNSPTOC Group settings (Basic)**

| Parameter            | Values (Range)   | Unit | Step | Default          | Description                        |
|----------------------|--|------|------|------------------|------------------------------------|
| Start value          | 0.01...0.50  | xIn  | 0.01 | 0.20             | Start value                        |
| Operating curve type | 5=ANSI Def. Time<br>15=IEC Def. Time<br>17=Inv. Curve A<br>18=Inv. Curve B |      |      | 15=IEC Def. Time | Selection of time delay curve type |
| Machine time Mult    | 5.0...100.0  |      | 0.1  | 5.0              | Machine related time constant      |
| Operate delay time   | 100...120000   | ms   | 10   | 1000             | Operate delay time                 |

**Table 433: MNSPTOC Non group settings (Basic)**

| Parameter            | Values (Range)  | Unit | Step | Default | Description   |
|----------------------|-----------------|------|------|---------|---|
| Operation            | 1=on<br>5=off   |      |      | 1=on    | Operation Off / On  |
| Maximum operate time | 500000...720000 | ms   | 1000 | 1000000 | Max operate time regardless of the inverse characteristic |
| Minimum operate time | 100...120000    | ms   | 1    | 100     | Minimum operate time for IDMT curves                      |
| Cooling time         | 5...7200        | s    | 1    | 50      | Time required to cool the machine                         |

**Table 434: MNSPTOC Non group settings (Advanced)**

| Parameter         | Values (Range) | Unit | Step | Default | Description   |
|-------------------|----------------|------|------|---------|---|
| Current reference | 0.30...2.00    | xIn  | 0.01 | 1.00    | Rated current (Ir) of the machine (used only in the IDMT) |
| Reset delay time  | 0...60000      | ms   | 1    | 20      | Reset delay time  |

### 3.4.4.9

## Monitored data

### MNSPTOC Monitored data

**Table 435: MNSPTOC Monitored data**

| Name         | Type    | Values (Range)                                | Unit | Description                              |
|--------------|---------|---|------|--|
| START_DUR    | FLOAT32 | 0.00...100.00                                 | %    | Ratio of start time / operate time       |
| T_ENARESTART | INT32   | 0...10000                                     | s    | Estimated time to reset of block restart |
| MNSPTOC      | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked |      | Status                                   |



| Name | Type | Values (Range) | Unit | Description |
|------|------|----------------|------|-------------|
|      |      | 5=off          |      |             |

### 3.4.4.10 Technical data

Table 436: MNSPTOC Technical data

| Characteristic                              |  | Value   |         |         |
|---|--|---|---------|---------|
| Operation accuracy                          |  | Depending on the frequency of the measured current: $f_n$         |         |         |
|   |  | $\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$            |         |         |
| Start time <sup>5455</sup>                  |  | Minimum   | Typical | Maximum |
|   | $I_{\text{Fault}} = 2.0 \times \text{set } \textit{Start value}$ | 23  | 25 ms   | 28 ms   |
| Reset time                                  |  | Typically 40 ms   |         |         |
| Reset ratio                                 |  | Typically 0.96  |         |         |
| Retardation time                            |  | <35 ms  |         |         |
| Operate time accuracy in definite time mode |  | $\pm 1.0\%$ of the set value or $\pm 20$ ms                       |         |         |
| Operate time accuracy in inverse time mode  |  | $\pm 5.0\%$ of the theoretical value or $\pm 20$ ms <sup>56</sup> |         |         |
| Suppression of harmonics                    |  | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$ |         |         |

### 3.4.4.11 Technical revision history

Table 437: MNSPTOC Technical revision history

| Technical revision | Change                |
|--------------------|-----------------------|
| B                  | Internal improvement. |
| C                  | Internal improvement. |

## 3.5 Voltage protection

### 3.5.1 Three-phase overvoltage protection PHPTOV

<sup>54</sup> Negative-sequence current before = 0.0,  $f_n = 50$  Hz, results based on statistical distribution of 1000 measurements

<sup>55</sup> Includes the delay of the signal output contact

<sup>56</sup> *Start value* multiples in range of 1.10...5.00

### 3.5.1.1 Identification

| Function description               | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|------------------------------------|--------------------------|--------------------------|-------------------------------|
| Three-phase overvoltage protection | PHPTOV                   | 3U>                      | 59                            |

### 3.5.1.2 Function block

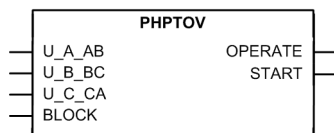


Figure 245: Function block

### 3.5.1.3 Functionality

The three-phase overvoltage protection function PHPTOV is applied on power system elements, such as generators, transformers, motors and power lines, to protect the system from excessive voltages that could damage the insulation and cause insulation breakdown. The three-phase overvoltage function includes a settable value for the detection of overvoltage either in a single phase, two phases or three phases.

PHPTOV includes both definite time (DT) and inverse definite minimum time (IDMT) characteristics for the delay of the trip.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

### 3.5.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PHPTOV can be described using a module diagram. All the modules in the diagram are explained in the next sections.

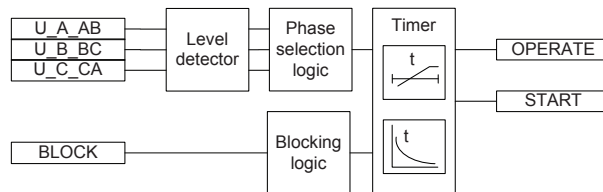


Figure 246: Functional module diagram

#### Level detector

The fundamental frequency component of the measured three-phase voltages are compared phase-wise to the set value of the *Start value* setting. If the measured

value is higher than the set value of the *Start value* setting, the level detector enables the phase selection logic module. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly differs from the *Start value* setting. After leaving the hysteresis area, the start condition has to be fulfilled again and it is not sufficient for the signal to only return to the hysteresis area.

The *Voltage selection* setting is used for selecting phase-to-earth or phase-to-phase voltages for protection.

For the voltage IDMT operation mode, the used IDMT curve equations contain discontinuity characteristics. The *Curve Sat relative* setting is used for preventing undesired operation.



For a more detailed description of the IDMT curves and the use of the *Curve Sat Relative* setting, see [Chapter 10.2.1 IDMT curves for overcurrent protection](#) in this manual.

### Phase selection logic

If the fault criteria are fulfilled in the level detector, the phase selection logic detects the phase or phases in which the fault level is detected. If the number of faulty phases match with the set *Num of start phases*, the phase selection logic activates the Timer.

### Timer

Once activated, the Timer activates the `START` output. Depending on the value of the set *Operating curve type*, the time characteristics are selected according to DT or IDMT.



For a detailed description of the voltage IDMT curves, see [Chapter 10.2.1 IDMT curves for overcurrent protection](#) in this manual.

When the operation timer has reached the value set by *Operate delay time* in the DT mode or the maximum value defined by the IDMT, the `OPERATE` output is activated.

When the user-programmable IDMT curve is selected, the operate time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation occurs, that is, a fault suddenly disappears before the operate delay is exceeded, the reset state is activated. The behavior in the drop-off situation depends on the selected operate time characteristics. If the DT characteristics are selected, the reset timer runs until the set *Reset delay time* value is exceeded. If the drop-off situation exceeds the set *Reset delay time*, the Timer is reset and the `START` output is deactivated.

When the IDMT operate time curve is selected, the functionality of the Timer in the drop-off state depends on the combination of the *Type of reset curve*, *Type of time reset* and *Reset delay time* settings.

**Table 438: Reset time functionality when IDMT operation time curve selected**

| Reset functionality |  | Setting Type of reset curve | Setting Type of time reset | Setting Reset delay time   |
|---------------------|--|-----------------------------|----------------------------|--|
| Instantaneous reset | Operation timer is "Reset instantaneously" when drop-off occurs        | "Immediate"                 | Setting has no effect      | Setting has no effect  |
| Frozen timer        | Operation timer is frozen during drop-off                              | "Def time reset"            | "Freeze Op timer"          | Operate timer is reset after the set <i>Reset delay time</i> has elapsed |
| Linear decrease     | Operation timer value linearly decreases during the drop-off situation | "Def time reset"            | "Decrease Op timer"        | Operate timer is reset after the set <i>Reset delay time</i> has elapsed |

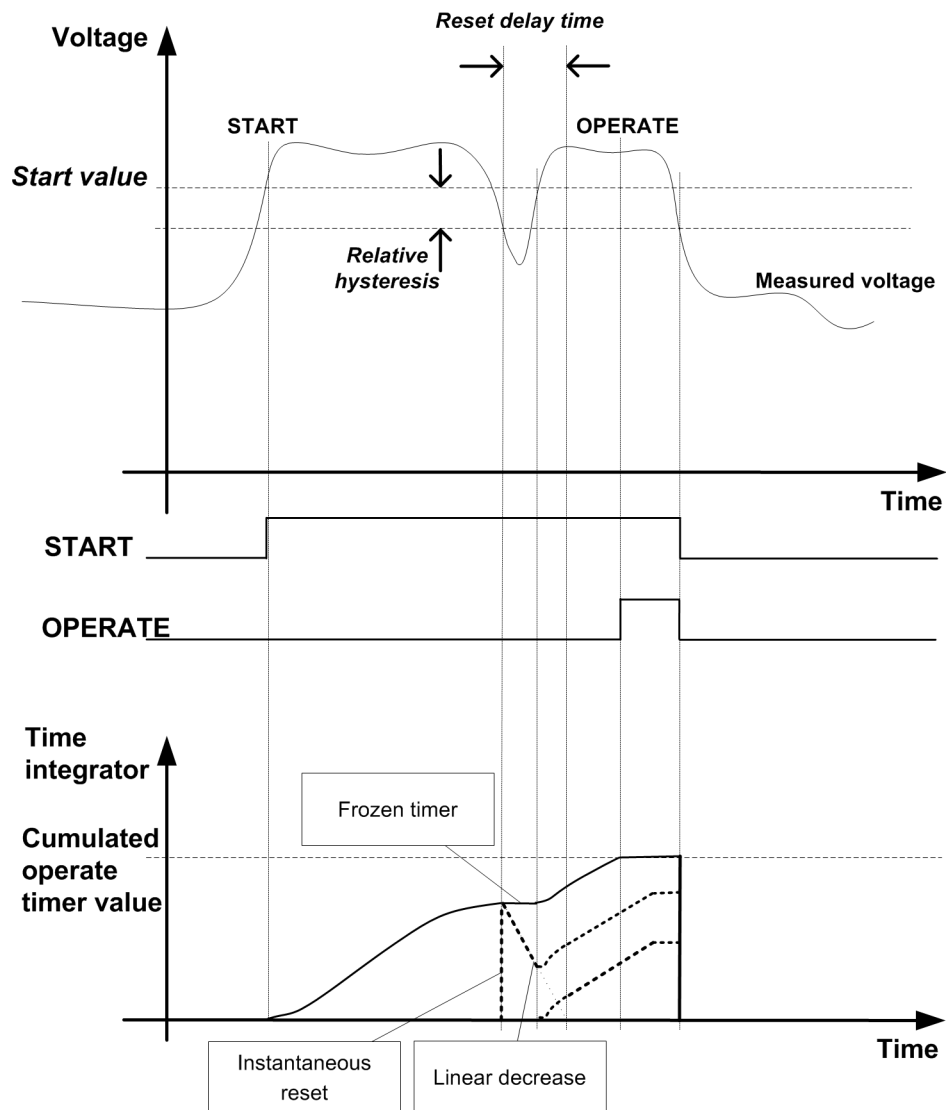


Figure 247: Behavior of different IDMT reset modes. Operate signal is based on settings *Type of reset curve* = "Def time reset" and *Type of time reset* = "Freeze Op timer". The effect of other reset modes is also presented

The *Time multiplier* setting is used for scaling the IDMT operate times.

The *Minimum operate time* setting parameter defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.



The *Minimum operate time* setting should be used with care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see [Chapter 10.2.1 IDMT curves for overcurrent protection](#) in this manual.

The Timer calculates the start duration value `START_DUR`, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the Monitored data view.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration > System > Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED's program. The influence of the `BLOCK` input signal activation is preselected with the global *Blocking mode* setting.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the `OPERATE` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the Timers are reset. In the "Block OPERATE output" mode, the function operates normally but the `OPERATE` output is not activated.



The "Freeze timers" mode of blocking has no effect during the inverse reset mode.

#### 3.5.1.5

### Timer characteristics

The operating curve types supported by PHPTOV are:

**Table 439: Timer characteristics supported by IDMT operate curve types**

| Operating curve type |
|----------------------|
| (5) ANSI Def. Time   |
| (15) IEC Def. Time   |
| (17) Inv. Curve A    |
| (18) Inv. Curve B    |
| (19) Inv. Curve C    |
| (20) Programmable    |

#### 3.5.1.6

### Application

Overvoltage in a network occurs either due to the transient surges on the network or due to prolonged power frequency overvoltages. Surge arresters are used to protect the network against the transient overvoltages, but the relay's protection function is used to protect against power frequency overvoltages.

The power frequency overvoltage may occur in the network due to contingencies such as:

- The defective operation of the automatic voltage regulator when the generator is in isolated operation.
- Operation under manual control with the voltage regulator out of service. A sudden variation of load, in particular the reactive power component, gives rise to a substantial change in voltage because of the inherent large voltage regulation of a typical alternator.
- Sudden loss of load due to the tripping of outgoing feeders, leaving the generator isolated or feeding a very small load. This causes a sudden rise in the terminal voltage due to the trapped field flux and overspeed.

If a load sensitive to overvoltage remains connected, it leads to equipment damage.

It is essential to provide power frequency overvoltage protection, in the form of time delayed element, either IDMT or DT to prevent equipment damage.

### 3.5.1.7 Signals

#### PHPTOV Input signals

Table 440: PHPTOV Input signals

| Name   | Type    | Default | Description   |
|--------|---------|---------|---|
| U_A_AB | SIGNAL  | 0       | Phase to earth voltage A or phase to phase voltage AB |
| U_B_BC | SIGNAL  | 0       | Phase to earth voltage B or phase to phase voltage BC |
| U_C_CA | SIGNAL  | 0       | Phase to earth voltage C or phase to phase voltage CA |
| BLOCK  | BOOLEAN | 0=False | Block signal for activating the blocking mode         |

#### PHPTOV Output signals

Table 441: PHPTOV Output signals

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

### 3.5.1.8 Settings

#### PHPTOV Settings

Table 442: PHPTOV Group settings (Basic)

| Parameter            | Values (Range)   | Unit | Step | Default          | Description                             |
|----------------------|------------------|------|------|------------------|---|
| Start value          | 0.05...1.60      | xUn  | 0.01 | 1.10             | Start value                             |
| Time multiplier      | 0.05...15.00     |      | 0.01 | 1.00             | Time multiplier in IEC/ANSI IDMT curves |
| Operate delay time   | 40...300000      | ms   | 10   | 40               | Operate delay time                      |
| Operating curve type | 5=ANSI Def. Time |      |      | 15=IEC Def. Time | Selection of time delay curve type      |

| Parameter | Values (Range)   | Unit | Step | Default | Description |
|-----------|--|------|------|---------|-------------|
|           | 15=IEC Def. Time<br>17=Inv. Curve A<br>18=Inv. Curve B<br>19=Inv. Curve C<br>20=Programmable |      |      |         |             |

Table 443: PHPTOV Group settings (Advanced)

| Parameter           | Values (Range)                           | Unit | Step | Default           | Description                   |
|---------------------|--|------|------|-------------------|-------------------------------|
| Type of reset curve | 1=Immediate<br>2=Def time reset          |      |      | 1=Immediate       | Selection of reset curve type |
| Type of time reset  | 1=Freeze Op timer<br>2=Decrease Op timer |      |      | 1=Freeze Op timer | Selection of time reset       |

Table 444: PHPTOV Non group settings (Basic)

| Parameter           | Values (Range)                               | Unit | Step | Default      | Description                                      |
|---------------------|--|------|------|--------------|--|
| Operation           | 1=on<br>5=off                                |      |      | 1=on         | Operation Off / On                               |
| Num of start phases | 1=1 out of 3<br>2=2 out of 3<br>3=3 out of 3 |      |      | 1=1 out of 3 | Number of phases required for operate activation |
| Curve parameter A   | 0.005...200.00<br>0                          |      | 1    | 1.000        | Parameter A for customer programmable curve      |
| Curve parameter B   | 0.50...100.00                                |      | 1    | 1.00         | Parameter B for customer programmable curve      |

*Table continues on the next page*



| Parameter         | Values (Range)                       | Unit | Step | Default          | Description  |
|-------------------|--------------------------------------|------|------|------------------|--|
| Curve parameter C | 0.0...1.0                            |      | 1    | 0.0              | Parameter C for customer programmable curve          |
| Curve parameter D | 0.000...60.000                       |      | 1    | 0.000            | Parameter D for customer programmable curve          |
| Curve parameter E | 0.000...3.000                        |      | 1    | 1.000            | Parameter E for customer programmable curve          |
| Voltage selection | 1=phase-to-earth<br>2=phase-to-phase |      |      | 2=phase-to-phase | Parameter to select phase or phase-to-phase voltages |

**Table 445: PHPTOV Non group settings (Advanced)**

| Parameter            | Values (Range) | Unit | Step | Default | Description                                     |
|----------------------|----------------|------|------|---------|---|
| Minimum operate time | 40...60000     | ms   | 1    | 40      | Minimum operate time for IDMT curves            |
| Reset delay time     | 0...60000      | ms   | 1    | 20      | Reset delay time                                |
| Curve Sat Relative   | 0.0...10.0     |      | 0.1  | 0.0     | Tuning parameter to avoid curve discontinuities |
| Relative hysteresis  | 1.0...5.0      | %    | 0.1  | 4.0     | Relative hysteresis for operation               |

### 3.5.1.9

## Monitored data

### PHPTOV Monitored data

**Table 446: PHPTOV Monitored data**

| Name      | Type    | Values (Range) | Unit | Description                        |
|-----------|---------|----------------|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time |
| PHPTOV    | Enum    | 1=on           |      | Status                             |

| Name | Type | Values (Range)                                 | Unit | Description |
|------|------|--|------|-------------|
|      |      | 2=blocked<br>3=test<br>4=test/blocked<br>5=off |      |             |

### 3.5.1.10 Technical data

Table 447: PHPTOV Technical data

| Characteristic                              | Value  |         |         |         |
|---|--|---------|---------|---------|
| Operation accuracy                          | Depending on the frequency of the measured voltage: $f_n \pm 2$ Hz<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times U_n$ |         |         |         |
| Start time <sup>5758</sup>                  |  | Minimum | Typical | Maximum |
|   | $U_{\text{Fault}} = 1.1 \times \text{set Start value}$   | 23 ms   | 27 ms   | 31 ms   |
| Reset time                                  | Typically 40 ms  |         |         |         |
| Reset ratio                                 | Depends on the set <i>Relative hysteresis</i>  |         |         |         |
| Retardation time                            | <35 ms   |         |         |         |
| Operate time accuracy in definite time mode | $\pm 1.0\%$ of the set value or $\pm 20$ ms  |         |         |         |
| Operate time accuracy in inverse time mode  | $\pm 5.0\%$ of the theoretical value or $\pm 20$ ms <sup>59</sup>  |         |         |         |
| Suppression of harmonics                    | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$  |         |         |         |

### 3.5.1.11 Technical revision history

Table 448: PHPTOV Technical revision history

| Technical revision | Change   |
|--------------------|--|
| B                  | Step value changed from 0.05 to 0.01 for the <i>Time multiplier</i> setting.                         |
| C                  | Curve Sat relative max range widened from 3.0 to 10.0 % and default value changed from 2.0 to 0.0 %. |
| D                  | Added setting <i>Type of time reset</i> .  |

<sup>57</sup> *Start value* =  $1.0 \times U_n$ , Voltage before fault =  $0.9 \times U_n$ ,  $f_n = 50$  Hz, overvoltage in one phase-to-phase with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements

<sup>58</sup> Includes the delay of the signal output contact

<sup>59</sup> Maximum *Start value* =  $1.20 \times U_n$ , *Start value* multiples in range of 1.10...2.00

## 3.5.2 Three-phase undervoltage protection PHPTUV

### 3.5.2.1 Identification

| Function description                | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|-------------------------------------|--------------------------|--------------------------|-------------------------------|
| Three-phase undervoltage protection | PHPTUV                   | 3U<                      | 27                            |

### 3.5.2.2 Function block

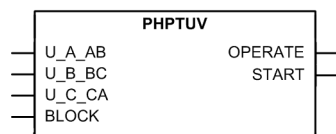


Figure 248: Function block

### 3.5.2.3 Functionality

The three-phase undervoltage protection function PHPTUV is used to disconnect from the network devices, for example electric motors, which are damaged when subjected to service under low voltage conditions. PHPTUV includes a settable value for the detection of undervoltage either in a single phase, two phases or three phases.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

### 3.5.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PHPTUV can be described using a module diagram. All the modules in the diagram are explained in the next sections.

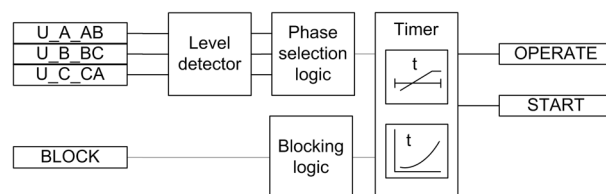


Figure 249: Functional module diagram

#### Level detector

The fundamental frequency component of the measured three phase voltages are compared phase-wise to the set *Start value*. If the measured value is lower than

the set value of the *Start value* setting, the level detector enables the phase selection logic module. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly varies above or below the *Start value* setting. After leaving the hysteresis area, the start condition has to be fulfilled again and it is not sufficient for the signal to only return back to the hysteresis area.

The *Voltage selection* setting is used for selecting the phase-to-earth or phase-to-phase voltages for protection.

For the voltage IDMT mode of operation, the used IDMT curve equations contain discontinuity characteristics. The *Curve Sat relative* setting is used for preventing unwanted operation.



For more detailed description on IDMT curves and usage of *Curve Sat Relative* setting, see [Chapter 10.2.1 IDMT curves for overcurrent protection](#) in this manual.

The level detector contains a low-level blocking functionality for cases where one of the measured voltages is below the desired level. This feature is useful when unnecessary starts and operates are wanted to avoid during, for example, an autoreclose sequence. The low-level blocking is activated by default (*Enable block value* is set to "True") and the blocking level can be set with the *Voltage block value* setting.

### Phase selection logic

If the fault criteria are fulfilled in the level detector, the phase selection logic detects the phase or phases in which the fault level is detected. If the number of faulty phases match with the set *Num of start phases*, the phase selection logic activates the Timer.

### Timer

Once activated, the Timer activates the *START* output. Depending on the value of the set *Operating curve type*, the time characteristics are selected according to DT or IDMT.



For a detailed description of the voltage IDMT curves, see [Chapter 10.2.1 IDMT curves for overcurrent protection](#) in this manual.

When the operation timer has reached the value set by *Operate delay time* in the DT mode or the maximum value defined by the IDMT, the *OPERATE* output is activated.

When the user-programmable IDMT curve is selected, the operate time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation occurs, that is, a fault suddenly disappears before the operate delay is exceeded, the reset state is activated. The behavior in the drop-off situation depends on the selected operate time characteristics. If the DT characteristics are selected, the reset timer runs until the set *Reset delay time* value is exceeded. If the drop-off situation exceeds the set *Reset delay time*, the Timer is reset and the *START* output is deactivated.

When the IDMT operate time curve is selected, the functionality of the Timer in the drop-off state depends on the combination of the *Type of reset curve*, *Type of time reset* and *Reset delay time* settings.

**Table 449: Reset time functionality when IDMT operation time curve selected**

| Reset functionality |  | Setting Type of reset curve | Setting Type of time reset | Setting Reset delay time   |
|---------------------|--|-----------------------------|----------------------------|--|
| Instantaneous reset | Operation timer is "Reset instantaneously" when drop-off occurs        | "Immediate"                 | Setting has no effect      | Setting has no effect  |
| Frozen timer        | Operation timer is frozen during drop-off                              | "Def time reset"            | "Freeze Op timer"          | Operate timer is reset after the set <i>Reset delay time</i> has elapsed |
| Linear decrease     | Operation timer value linearly decreases during the drop-off situation | "Def time reset"            | "Decrease Op timer"        | Operate timer is reset after the set <i>Reset delay time</i> has elapsed |

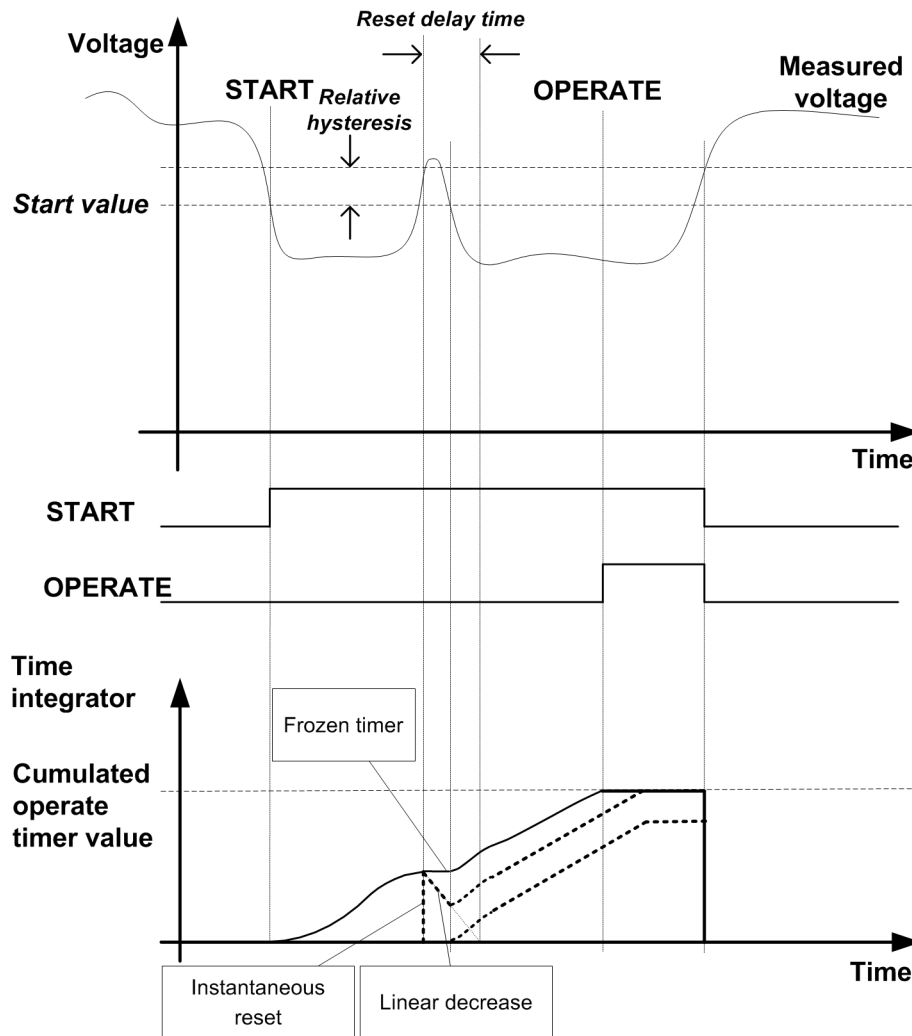


Figure 250: Behavior of different IDMT reset modes. Operate signal is based on settings *Type of reset curve* = “Def time reset” and *Type of time reset*= “Freeze Op timer”. The effect of other reset modes is also presented

The *Time multiplier* setting is used for scaling the IDMT operate times.

The *Minimum operate time* setting parameter defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.



The *Minimum operate time* setting should be used with care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see [Chapter 10.2.1 IDMT curves for overcurrent protection](#) in this manual.

The Timer calculates the start duration value START\_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the Monitored data view.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration > System > Blocking mode** which selects the blocking mode. The BLOCK input can be controlled

by a binary input, a horizontal communication input or an internal signal of the IED's program. The influence of the `BLOCK` input signal activation is preselected with the global *Blocking mode* setting.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the `OPERATE` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the Timers are reset. In the "Block `OPERATE` output" mode, the function operates normally but the `OPERATE` output is not activated.



The "Freeze timers" mode of blocking has no effect during the "Inverse reset" mode.

### 3.5.2.5

#### Timer characteristics

The operating curve types supported by PHPTUV are:

**Table 450: Supported IDMT operate curve types**

| Operating curve type |
|----------------------|
| (5) ANSI Def. Time   |
| (15) IEC Def. Time   |
| (21) Inv. Curve A    |
| (22) Inv. Curve B    |
| (23) Programmable    |

### 3.5.2.6

#### Application

PHPTUV is applied to power system elements, such as generators, transformers, motors and power lines, to detect low voltage conditions. Low voltage conditions are caused by abnormal operation or a fault in the power system. PHPTUV can be used in combination with overcurrent protections. Other applications are the detection of a no-voltage condition, for example before the energization of a high voltage line, or an automatic breaker trip in case of a blackout. PHPTUV is also used to initiate voltage correction measures, such as insertion of shunt capacitor banks, to compensate for a reactive load and thereby to increase the voltage.

PHPTUV can be used to disconnect from the network devices, such as electric motors, which are damaged when subjected to service under low voltage conditions. PHPTUV deals with low voltage conditions at power system frequency. Low voltage conditions can be caused by:

- Malfunctioning of a voltage regulator or incorrect settings under manual control (symmetrical voltage decrease)
- Overload (symmetrical voltage decrease)
- Short circuits, often as phase-to-earth faults (unsymmetrical voltage increase).

PHPTUV prevents sensitive equipment from running under conditions that could cause overheating and thus shorten their life time expectancy. In many cases, PHPTUV is a useful function in circuits for local or remote automation processes in the power system.

### 3.5.2.7 Signals

#### PHPTUV Input signals

Table 451: PHPTUV Input signals

| Name   | Type    | Default | Description   |
|--------|---------|---------|---|
| U_A_AB | SIGNAL  | 0       | Phase to earth voltage A or phase to phase voltage AB |
| U_B_BC | SIGNAL  | 0       | Phase to earth voltage B or phase to phase voltage BC |
| U_C_CA | SIGNAL  | 0       | Phase to earth voltage C or phase to phase voltage CA |
| BLOCK  | BOOLEAN | 0=False | Block signal for activating the blocking mode         |

#### PHPTUV Output signals

Table 452: PHPTUV Output signals

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

### 3.5.2.8 Settings

#### PHPTUV Settings

Table 453: PHPTUV Group settings (Basic)

| Parameter            | Values (Range)  | Unit | Step | Default          | Description                             |
|----------------------|---|------|------|------------------|---|
| Start value          | 0.05...1.20   | xUn  | 0.01 | 0.90             | Start value                             |
| Time multiplier      | 0.05...15.00  |      | 0.01 | 1.00             | Time multiplier in IEC/ANSI IDMT curves |
| Operate delay time   | 60...300000   | ms   | 10   | 60               | Operate delay time                      |
| Operating curve type | 5=ANSI Def. Time<br>15=IEC Def. Time<br>21=Inv. Curve A |      |      | 15=IEC Def. Time | Selection of time delay curve type      |



| Parameter | Values (Range)                     | Unit | Step | Default | Description |
|-----------|------------------------------------|------|------|---------|-------------|
|           | 22=Inv. Curve B<br>23=Programmable |      |      |         |             |

**Table 454: PHPTUV Group settings (Advanced)**

| Parameter           | Values (Range)                           | Unit | Step | Default           | Description                   |
|---------------------|--|------|------|-------------------|-------------------------------|
| Type of reset curve | 1=Immediate<br>2=Def time reset          |      |      | 1=Immediate       | Selection of reset curve type |
| Type of time reset  | 1=Freeze Op timer<br>2=Decrease Op timer |      |      | 1=Freeze Op timer | Selection of time reset       |

**Table 455: PHPTUV Non group settings (Basic)**

| Parameter           | Values (Range)                               | Unit | Step | Default      | Description                                      |
|---------------------|--|------|------|--------------|--|
| Operation           | 1=on<br>5=off                                |      |      | 1=on         | Operation Off / On                               |
| Num of start phases | 1=1 out of 3<br>2=2 out of 3<br>3=3 out of 3 |      |      | 1=1 out of 3 | Number of phases required for operate activation |
| Curve parameter A   | 0.005...200.00<br>0                          |      | 1    | 1.000        | Parameter A for customer programmable curve      |
| Curve parameter B   | 0.50...100.00                                |      | 1    | 1.00         | Parameter B for customer programmable curve      |
| Curve parameter C   | 0.0...1.0                                    |      | 1    | 0.0          | Parameter C for customer programmable curve      |
| Curve parameter D   | 0.000...60.000                               |      | 1    | 0.000        | Parameter D for customer programmable curve      |

*Table continues on the next page*

| Parameter         | Values (Range)                       | Unit | Step | Default          | Description  |
|-------------------|--------------------------------------|------|------|------------------|--|
| Curve parameter E | 0.000...3.000                        |      | 1    | 1.000            | Parameter E for customer programmable curve          |
| Voltage selection | 1=phase-to-earth<br>2=phase-to-phase |      |      | 2=phase-to-phase | Parameter to select phase or phase-to-phase voltages |

**Table 456: PHPTUV Non group settings (Advanced)**

| Parameter            | Values (Range)    | Unit | Step | Default | Description                                     |
|----------------------|-------------------|------|------|---------|---|
| Minimum operate time | 60...60000        | ms   | 1    | 60      | Minimum operate time for IDMT curves            |
| Reset delay time     | 0...60000         | ms   | 1    | 20      | Reset delay time                                |
| Curve Sat Relative   | 0.0...10.0        |      | 0.1  | 0.0     | Tuning parameter to avoid curve discontinuities |
| Voltage block value  | 0.05...1.00       | xUn  | 0.01 | 0.20    | Low level blocking for undervoltage mode        |
| Enable block value   | 0=False<br>1=True |      |      | 1=True  | Enable internal blocking                        |
| Relative hysteresis  | 1.0...5.0         | %    | 0.1  | 4.0     | Relative hysteresis for operation               |

### 3.5.2.9

## Monitored data

### PHPTUV Monitored data

**Table 457: PHPTUV Monitored data**

| Name      | Type    | Values (Range)    | Unit | Description                        |
|-----------|---------|-------------------|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00     | %    | Ratio of start time / operate time |
| PHPTUV    | Enum    | 1=on<br>2=blocked |      | Status                             |

| Name | Type | Values (Range)                    | Unit | Description |
|------|------|-----------------------------------|------|-------------|
|      |      | 3=test<br>4=test/blocked<br>5=off |      |             |

### 3.5.2.10 Technical data

Table 458: PHPTUV Technical data

| Characteristic                              |  | Value  |         |         |
|---|--|--|---------|---------|
| Operation accuracy                          |  | Depending on the frequency of the voltage measured: $f_n \pm 2$ Hz |         |         |
|   |  | $\pm 1.5\%$ of the set value or $\pm 0.002 \times U_n$             |         |         |
| Start time <sup>6061</sup>                  |  | Minimum  | Typical | Maximum |
|   | $U_{\text{Fault}} = 0.9 \times \text{set Start value}$ | 62 ms  | 66 ms   | 70 ms   |
| Reset time                                  |  | Typically 40 ms  |         |         |
| Reset ratio                                 |  | Depends on the set <i>Relative hysteresis</i>                      |         |         |
| Retardation time                            |  | <35 ms   |         |         |
| Operate time accuracy in definite time mode |  | $\pm 1.0\%$ of the set value or $\pm 20$ ms                        |         |         |
| Operate time accuracy in inverse time mode  |  | $\pm 5.0\%$ of the theoretical value or $\pm 20$ ms <sup>62</sup>  |         |         |
| Suppression of harmonics                    |  | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$  |         |         |

### 3.5.2.11 Technical revision history

Table 459: PHPTUV Technical revision history

| Technical revision | Change   |
|--------------------|--|
| B                  | Step value changed from 0.05 to 0.01 for the <i>Time multiplier</i> setting.                         |
| C                  | Curve Sat relative max range widened from 3.0 to 10.0 % and default value changed from 2.0 to 0.0 %. |
| D                  | Added setting <i>Type of time reset</i> .  |

## 3.5.3 Residual overvoltage protection ROVPTOV

<sup>60</sup> *Start value* =  $1.0 \times U_n$ , Voltage before fault =  $1.1 \times U_n$ ,  $f_n = 50$  Hz, undervoltage in one phase-to-phase with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements

<sup>61</sup> Includes the delay of the signal output contact

<sup>62</sup> Minimum *Start value* = 0.50, *Start value* multiples in range of 0.90...0.20

### 3.5.3.1 Identification

| Function description            | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---------------------------------|--------------------------|--------------------------|-------------------------------|
| Residual overvoltage protection | ROVPTOV                  | U <sub>0</sub> >         | 59G                           |

### 3.5.3.2 Function block



Figure 251: Function block

### 3.5.3.3 Functionality

The residual overvoltage protection function ROVPTOV is used in distribution networks where the residual overvoltage can reach non-acceptable levels in, for example, high impedance earthing.

The function starts when the residual voltage exceeds the set limit. ROVPTOV operates with the definite time (DT) characteristic.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

### 3.5.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of ROVPTOV can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

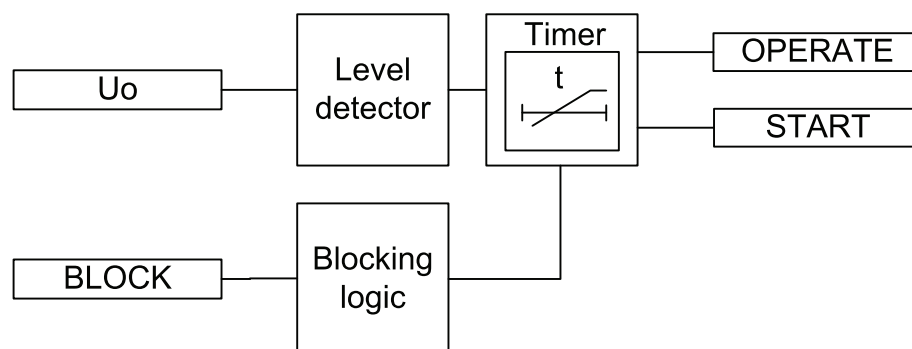


Figure 252: Functional module diagram

#### Level detector

The residual voltage is compared to the set *Start value*. If the value exceeds the set *Start value*, the level detector sends an enable signal to the timer. The operating quantity (residual voltage) can be selected within the ACT configuration. The

options are "Measured Uo" and "Calculated Uo". Measured Uo is selected when URES input of the corresponding SMVRECEIVE function is connected to Uo input of the function. Similarly Calculated Uo is selected, when URES\_CALC input is connected. VT ratios need to be defined in the parameters of the SMVRECEIVE function.

**Example 1:** Uo is measured from the open-delta connected VTs (20/sqrt(3) kV : 100/sqrt(3) V : 100/3 V). In this case, "Measured Uo" is selected. The nominal values for residual voltage is obtained from the VT ratios entered in Residual voltage Uo: SMVRECEIVE function settings: 11.547 kV:100 V. The residual voltage start value of  $1.0 \times U_n$  corresponds to  $1.0 \times 11.547 \text{ kV} = 11.547 \text{ kV}$  in the primary.

**Example 2:** Uo is calculated from the phase quantities. The phase VT-ratio is 20/sqrt(3) kV : 100/sqrt(3) V. In this case, "Calculated Uo" is selected. The nominal value for residual voltage is obtained from the VT ratios entered in Residual voltage Uo: SMVRECEIVE function settings: 20.000kV : 100V. The residual voltage start value of  $1.0 \times U_n$  corresponds to  $1.0 \times 20.000 \text{ kV} = 20.000 \text{ kV}$  in the primary.



If "Calculated Uo" is selected, the nominal value of residual voltage is always phase-to-phase voltage. Thus, the valid maximum setting for residual voltage *Start value* is  $0.577 \times U_n$ . The calculated Uo requires that all three phase-to-earth voltages are connected to the IED. Uo cannot be calculated from the phase-to-phase voltages.

### Timer

Once activated, the timer activates the START output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the OPERATE output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the START output is deactivated.

The timer calculates the start duration value START\_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration > System > Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

### 3.5.3.5

### Application

ROVPTOV is designed to be used for earth-fault protection in isolated neutral, resistance earthed or reactance earthed systems. In compensated networks, starting of the function can be used to control the switching device of the neutral resistor. The function can also be used for the back-up protection of feeders for busbar protection when a more dedicated busbar protection would not be justified.

In compensated and isolated neutral systems, the system neutral voltage, that is, the residual voltage, increases in case of any fault connected to earth. Depending on the type of the fault and the fault resistance, the residual voltage reaches different values. The highest residual voltage, equal to the phase-to-earth voltage, is achieved for a single-phase earth fault. The residual voltage increases approximately the same amount in the whole system and does not provide any guidance in finding the faulty component. Therefore, this function is often used as a backup protection or as a release signal for the feeder earth-fault protection.

The protection can also be used for the earth-fault protection of generators and motors and for the unbalance protection of capacitor banks.

The residual voltage can be calculated internally based on the measurement of the three-phase voltage. This voltage can also be measured by a single-phase voltage transformer, located between a transformer star point and earth, or by using an open-delta connection of three single-phase voltage transformers.

### 3.5.3.6 Signals

#### ROVPTOV Input signals

Table 460: ROVPTOV Input signals

| Name  | Type    | Default | Description                                   |
|-------|---------|---------|---|
| Uo    | SIGNAL  | 0       | Residual voltage                              |
| BLOCK | BOOLEAN | 0=False | Block signal for activating the blocking mode |

#### ROVPTOV Output signals

Table 461: ROVPTOV Output signals

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

### 3.5.3.7 Settings

#### ROVPTOV Settings

Table 462: ROVPTOV Group settings (Basic)

| Parameter          | Values (Range) | Unit | Step  | Default | Description                       |
|--------------------|----------------|------|-------|---------|-----------------------------------|
| Start value        | 0.010...1.000  | xUn  | 0.001 | 0.030   | Residual over-voltage start value |
| Operate delay time | 40...300000    | ms   | 1     | 40      | Operate delay time                |

**Table 463: ROVPTOV Non group settings (Basic)**

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

**Table 464: ROVPTOV Non group settings (Advanced)**

| Parameter        | Values (Range) | Unit | Step | Default | Description      |
|------------------|----------------|------|------|---------|------------------|
| Reset delay time | 0...60000      | ms   | 1    | 20      | Reset delay time |

### 3.5.3.8

#### Monitored data

##### ROVPTOV Monitored data

**Table 465: ROVPTOV Monitored data**

| Name      | Type    | Values (Range)   | Unit | Description                        |
|-----------|---------|--|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time |
| ROVPTOV   | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                             |

### 3.5.3.9

#### Technical data

**Table 466: ROVPTOV Technical data**

| Characteristic              |   | Value   |         |         |
|-----------------------------|---|---|---------|---------|
| Operation accuracy          |   | Depending on the frequency of the measured voltage:<br>$f_n \pm 2$ Hz<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times U_n$ |         |         |
| Start time <sup>63,64</sup> | $U_{Fault} = 2 \times \text{set Start value}$ | Minimum   | Typical | Maximum |
|                             |   | 48 ms   | 51 ms   | 54 ms   |

*Table continues on the next page*

<sup>63</sup> Residual voltage before fault =  $0.0 \times U_n$ ,  $f_n = 50$  Hz, residual voltage with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements

<sup>64</sup> Includes the delay of the signal output contact

| Characteristic                              | Value   |
|---|---|
| Reset time                                  | Typically 40 ms   |
| Reset ratio                                 | Typically 0.96  |
| Retardation time                            | <35 ms  |
| Operate time accuracy in definite time mode | ±1.0% of the set value or ±20 ms                                  |
| Suppression of harmonics                    | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$ |

### 3.5.3.10 Technical revision history

Table 467: ROVPTOV Technical revision history

| Technical revision | Change   |
|--------------------|--|
| B                  | Added a setting parameter for the "Measured Uo" or "Calculated Uo" selection |
| C                  | Internal improvement.  |
| D                  | Internal improvement.  |
| E                  | Modified for SSC600  |

## 3.5.4 Negative-sequence overvoltage protection NSPTOV

### 3.5.4.1 Identification

| Function description                     | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--|--------------------------|--------------------------|-------------------------------|
| Negative-sequence overvoltage protection | NSPTOV                   | U2>                      | 470-                          |

### 3.5.4.2 Function block

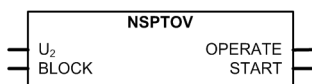


Figure 253: Function block

### 3.5.4.3 Functionality

The negative-sequence overvoltage protection function NSPTOV is used to detect negative sequence overvoltage conditions. NSPTOV is used for the protection of machines.

The function starts when the negative sequence voltage exceeds the set limit. NSPTOV operates with the definite time (DT) characteristics.



The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

### 3.5.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of NSPTOV can be described using a module diagram. All the modules in the diagram are explained in the next sections.

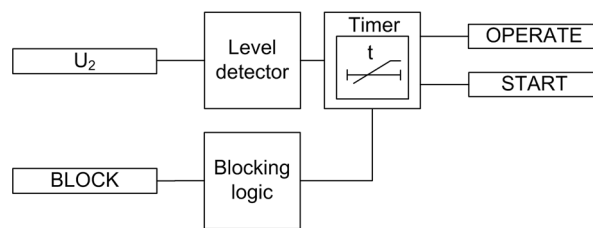


Figure 254: Functional module diagram

#### Level detector

The calculated negative-sequence voltage is compared to the set *Start value* setting. If the value exceeds the set *Start value*, the level detector enables the timer.

#### Timer

Once activated, the timer activates the `START` output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the `OPERATE` output is activated if the overvoltage condition persists. If the negative-sequence voltage normalizes before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the `START` output is deactivated.

The timer calculates the start duration value `START_DUR`, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

#### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration > System > Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the `OPERATE` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block `OPERATE` output" mode, the function operates normally but the `OPERATE` output is not activated.

### 3.5.4.5 Application

A continuous or temporary voltage unbalance can appear in the network for various reasons. The voltage unbalance mainly occurs due to broken conductors or asymmetrical loads and is characterized by the appearance of a negative-sequence component of the voltage. In rotating machines, the voltage unbalance results in a current unbalance, which heats the rotors of the machines. The rotating machines, therefore, do not tolerate a continuous negative-sequence voltage higher than typically 1-2 percent  $\times U_n$ .

The negative-sequence component current  $I_2$ , drawn by an asynchronous or a synchronous machine, is linearly proportional to the negative-sequence component voltage  $U_2$ . When  $U_2$  is P% of  $U_n$ ,  $I_2$  is typically about  $5 \times P\% \times I_n$ .

The negative-sequence overcurrent NSPTOC blocks are used to accomplish a selective protection against the voltage and current unbalance for each machine separately. Alternatively, the protection can be implemented with the NSPTOV function, monitoring the voltage unbalance of the busbar.

If the machines have an unbalance protection of their own, the NSPTOV operation can be applied as a backup protection or it can be used as an alarm. The latter can be applied when it is not required to trip loads tolerating voltage unbalance better than the rotating machines.

If there is a considerable degree of voltage unbalance in the network, the rotating machines should not be connected to the network at all. This logic can be implemented by inhibiting the closure of the circuit breaker if the NSPTOV operation has started. This scheme also prevents connecting the machine to the network if the phase sequence of the network is not correct.

An appropriate value for the setting parameter *Voltage start value* is approximately 3 percent of  $U_n$ . A suitable value for the setting parameter *Operate delay time* depends on the application. If the NSPTOV operation is used as backup protection, the operate time should be set in accordance with the operate time of NSPTOC used as main protection. If the NSPTOV operation is used as main protection, the operate time should be approximately one second.

### 3.5.4.6 Signals

#### NSPTOV Input signals

Table 468: NSPTOV Input signals

| Name  | Type    | Default | Description                                   |
|-------|---------|---------|---|
| $U_2$ | SIGNAL  | 0       | Negative phase sequence voltage               |
| BLOCK | BOOLEAN | 0=False | Block signal for activating the blocking mode |

**NSPTOV Output signals****Table 469: NSPTOV Output signals**

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

**3.5.4.7****Settings****NSPTOV Settings****Table 470: NSPTOV Group settings (Basic)**

| Parameter          | Values (Range) | Unit | Step  | Default | Description        |
|--------------------|----------------|------|-------|---------|--------------------|
| Start value        | 0.010...1.000  | xUn  | 0.001 | 0.030   | Start value        |
| Operate delay time | 40...120000    | ms   | 1     | 40      | Operate delay time |

**Table 471: NSPTOV Non group settings (Basic)**

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

**Table 472: NSPTOV Non group settings (Advanced)**

| Parameter        | Values (Range) | Unit | Step | Default | Description      |
|------------------|----------------|------|------|---------|------------------|
| Reset delay time | 0...60000      | ms   | 1    | 20      | Reset delay time |

**3.5.4.8****Monitored data****NSPTOV Monitored data****Table 473: NSPTOV Monitored data**

| Name      | Type    | Values (Range)              | Unit | Description                        |
|-----------|---------|-----------------------------|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00               | %    | Ratio of start time / operate time |
| NSPTOV    | Enum    | 1=on<br>2=blocked<br>3=test |      | Status                             |

| Name | Type | Values (Range)          | Unit | Description |
|------|------|-------------------------|------|-------------|
|      |      | 4=test/blocked<br>5=off |      |             |

### 3.5.4.9 Technical data

Table 474: NSPTOV Technical data

| Characteristic                              |  | Value   |                |                |
|---|--|---|----------------|----------------|
| Operation accuracy                          |  | Depending on the frequency of the voltage measured: $f_n$<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times U_n$ |                |                |
| Start time <sup>6566</sup>                  |  | Minimum   | Typical        | Maximum        |
|   | $U_{\text{Fault}} = 1.1 \times \text{set Start value}$ | 33 ms<br>24 ms  | 35 ms<br>26 ms | 37 ms<br>28 ms |
|   |  | $U_{\text{Fault}} = 2.0 \times \text{set Start value}$  |                |                |
| Reset time                                  |  | Typically 40 ms   |                |                |
| Reset ratio                                 |  | Typically 0.96  |                |                |
| Retardation time                            |  | <35 ms  |                |                |
| Operate time accuracy in definite time mode |  | $\pm 1.0\%$ of the set value or $\pm 20$ ms   |                |                |
| Suppression of harmonics                    |  | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$   |                |                |

### 3.5.4.10 Technical revision history

Table 475: NSPTOV Technical revision history

| Technical revision | Change                |
|--------------------|-----------------------|
| B                  | Internal change       |
| C                  | Internal improvement. |
| D                  | Internal improvement. |

## 3.5.5 Positive-sequence undervoltage protection PSPTUV

<sup>65</sup> Negative-sequence voltage before fault =  $0.0 \times U_n$ ,  $f_n = 50$  Hz, negative-sequence overvoltage with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements

<sup>66</sup> Includes the delay of the signal output contact

### 3.5.5.1 Identification

| Function description                      | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|--------------------------|--------------------------|-------------------------------|
| Positive-sequence undervoltage protection | PSPTUV                   | U1<                      | 47U+                          |

### 3.5.5.2 Function block

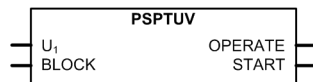


Figure 255: Function block

### 3.5.5.3 Functionality

The positive-sequence undervoltage protection function PSPTUV is used to detect positive-sequence undervoltage conditions. PSPTUV is used for the protection of small power generation plants. The function helps in isolating an embedded plant from a fault line when the fault current fed by the plant is too low to start an overcurrent function but high enough to maintain the arc. Fast isolation of all the fault current sources is necessary for a successful autoreclosure from the network-end circuit breaker.

The function starts when the positive-sequence voltage drops below the set limit. PSPTUV operates with the definite time (DT) characteristics.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

### 3.5.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PSPTUV can be described using a module diagram. The operation of 27PS can be described using a module diagram. All the modules in the diagram are explained in the next sections.

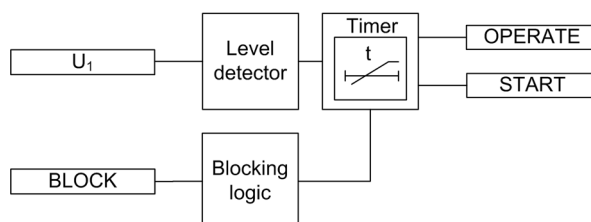


Figure 256: Functional module diagram.  $U_1$  is used for representing positive phase sequence voltage.

### Level detector

The calculated positive-sequence voltage is compared to the set *Start value* setting. If the value drops below the set *Start value*, the level detector enables the timer. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly varies from the *Start value* setting. After leaving the hysteresis area, the start condition has to be fulfilled again and it is not sufficient for the signal to only return to the hysteresis area.

### Timer

Once activated, the timer activates the `START` output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the `OPERATE` output is activated if the undervoltage condition persists. If the positive-sequence voltage normalizes before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the `START` output is deactivated.

The timer calculates the start duration value `START_DUR`, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration > System > Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the `OPERATE` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block `OPERATE` output" mode, the function operates normally but the `OPERATE` output is not activated.

## 3.5.5.5

### Application

PSPTUV can be applied for protecting a power station used for embedded generation when network faults like short circuits or phase-to-earth faults in a transmission or a distribution line cause a potentially dangerous situations for the power station. A network fault can be dangerous for the power station for various reasons. The operation of the protection can cause an islanding condition, also called a loss-of-mains condition, in which a part of the network, that is, an island fed by the power station, is isolated from the rest of the network. There is then a risk of an autoreclosure taking place when the voltages of different parts of the network do not synchronize, which is a straining incident for the power station. Another risk is that the generator can lose synchronism during the network fault. A sufficiently fast trip of the utility circuit breaker of the power station can avoid these risks.

The lower the three-phase symmetrical voltage of the network is, the higher is the probability that the generator loses the synchronism. The positive-sequence voltage is also available during asymmetrical faults. It is a more appropriate criterion for detecting the risk of loss of synchronism than, for example, the lowest phase-to-phase voltage.

Analyzing the loss of synchronism of a generator is rather complicated and requires a model of the generator with its prime mover and controllers. The generator can be able to operate synchronously even if the voltage drops by a few tens of percent for some hundreds of milliseconds. The setting of PSPTUV is thus determined by the need to protect the power station from the risks of the islanding conditions since that requires a higher setting value.

The loss of synchronism of a generator means that the generator is unable to operate as a generator with the network frequency but enters into an unstable condition in which it operates by turns as a generator and a motor. Such a condition stresses the generator thermally and mechanically. This kind of loss of synchronism should not be mixed with the one between an island and the utility network. In the islanding situation, the condition of the generator itself is normal but the phase angle and the frequency of the phase-to-phase voltage can be different from the corresponding voltage in the rest of the network. The island can have a frequency of its own relatively fast when fed by a small power station with a low inertia.

PSPTUV complements other loss-of-grid protection principles based on the frequency and voltage operation.

Motor stalling and failure to start can lead to a continuous undervoltage. The positive-sequence undervoltage is used as a backup protection against the motor stall condition.

### 3.5.5.6 Signals

#### PSPTUV Input signals

**Table 476: PSPTUV Input signals**

| Name           | Type    | Default | Description                                   |
|----------------|---------|---------|---|
| U <sub>1</sub> | SIGNAL  | 0       | Positive phase sequence voltage               |
| BLOCK          | BOOLEAN | 0=False | Block signal for activating the blocking mode |

#### PSPTUV Output signals

**Table 477: PSPTUV Output signals**

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

### 3.5.5.7 Settings

**PSPTUV Settings****Table 478: PSPTUV Group settings (Basic)**

| Parameter          | Values (Range) | Unit | Step  | Default | Description        |
|--------------------|----------------|------|-------|---------|--------------------|
| Start value        | 0.010...1.200  | xUn  | 0.001 | 0.500   | Start value        |
| Operate delay time | 40...120000    | ms   | 10    | 40      | Operate delay time |

**Table 479: PSPTUV Group settings (Advanced)**

| Parameter           | Values (Range)    | Unit | Step | Default | Description              |
|---------------------|-------------------|------|------|---------|--------------------------|
| Voltage block value | 0.01...1.00       | xUn  | 0.01 | 0.20    | Internal blocking level  |
| Enable block value  | 0=False<br>1=True |      |      | 1=True  | Enable Internal Blocking |

**Table 480: PSPTUV Non group settings (Basic)**

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

**Table 481: PSPTUV Non group settings (Advanced)**

| Parameter           | Values (Range) | Unit | Step | Default | Description                       |
|---------------------|----------------|------|------|---------|-----------------------------------|
| Reset delay time    | 0...60000      | ms   | 1    | 20      | Reset delay time                  |
| Relative hysteresis | 1.0...5.0      | %    | 0.1  | 4.0     | Relative hysteresis for operation |

**3.5.5.8****Monitored data****PSPTUV Monitored data****Table 482: PSPTUV Monitored data**

| Name      | Type    | Values (Range) | Unit | Description                        |
|-----------|---------|----------------|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time |
| PSPTUV    | Enum    | 1=on           |      | Status                             |



| Name | Type | Values (Range)                                 | Unit | Description |
|------|------|--|------|-------------|
|      |      | 2=blocked<br>3=test<br>4=test/blocked<br>5=off |      |             |

### 3.5.5.9 Technical data

Table 483: PSPTUV Technical data

| Characteristic                              |   | Value  |                |                |
|---|---|--|----------------|----------------|
| Operation accuracy                          |   | Depending on the frequency of the measured voltage: $f_n \pm 2$ Hz |                |                |
|   |   | $\pm 1.5\%$ of the set value or $\pm 0.002 \times U_n$             |                |                |
| Start time <sup>6768</sup>                  |   | Minimum  | Typical        | Maximum        |
|   | $U_{\text{Fault}} = 0.99 \times \text{set Start value}$ | 52 ms<br>44 ms   | 55 ms<br>47 ms | 58 ms<br>50 ms |
|   |   | $U_{\text{Fault}} = 0.9 \times \text{set Start value}$             |                |                |
| Reset time                                  |   | Typically 40 ms  |                |                |
| Reset ratio                                 |   | Depends on the set <i>Relative hysteresis</i>                      |                |                |
| Retardation time                            |   | <35 ms   |                |                |
| Operate time accuracy in definite time mode |   | $\pm 1.0\%$ of the set value or $\pm 20$ ms                        |                |                |
| Suppression of harmonics                    |   | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$  |                |                |

### 3.5.5.10 Technical revision history

Table 484: PSPTUV Technical revision history

| Technical revision | Change                |
|--------------------|-----------------------|
| B                  | -                     |
| C                  | Internal improvement. |
| D                  | Internal improvement. |

## 3.5.6 Low-voltage ride-through protection LVRTPTUV

<sup>67</sup> *Start value* =  $1.0 \times U_n$ , positive-sequence voltage before fault =  $1.1 \times U_n$ ,  $f_n = 50$  Hz, positive sequence undervoltage with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements

<sup>68</sup> Includes the delay of the signal output contact

### 3.5.6.1 Identification

| Function description                | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|-------------------------------------|--------------------------|--------------------------|-------------------------------|
| Low-voltage ride-through protection | LVRTPTUV                 | U<RT                     | 27RT                          |

### 3.5.6.2 Function block

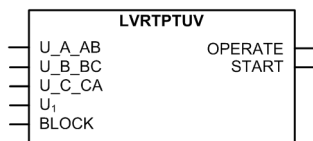


Figure 257: Function block

### 3.5.6.3 Functionality

The low-voltage ride-through protection function LVRTPTUV is principally a three-phase undervoltage protection. It differs from the traditional three-phase undervoltage protection PHPTUV by allowing the grid operators to define its own Low-Voltage Ride-Through (LVRT) curve for generators, as defined by local or national grid codes. The LVRT curve can be defined accurately according to the requirements by setting the appropriate time-voltage coordinates.

This function contains a blocking functionality. LVRTPTUV can be blocked with the BLOCK input. Blocking resets timers and outputs.

### 3.5.6.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of LVRTPTUV is described using a module diagram. All modules in the diagram are explained in the next sections.

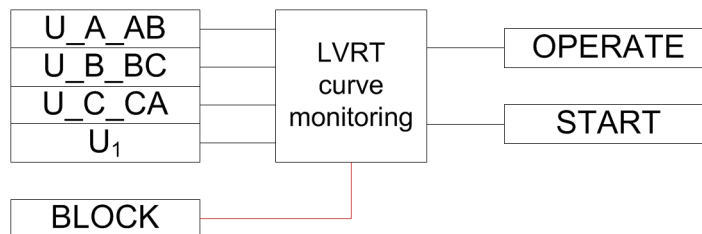


Figure 258: Functional module diagram

#### LVRT curve monitoring

LVRT curve monitoring starts with detection of undervoltage. Undervoltage detection depends on *Voltage selection* setting. All selectable options are based on fundamental frequency components.

Function uses phase-to-earth voltages when *Voltage selection* is set to “Highest Ph-to-E” or “Lowest Ph-to-E” and phase-to-phase voltages when *Voltage selection* is set to “Highest Ph-to-Ph” or “Lowest Ph-to-Ph”.

When the *Voltage selection* setting is set to “Highest Ph-to-E”, “Lowest Ph-to-E”, “Highest Ph-to-Ph” or “Lowest Ph-to-Ph”, the measured three-phase voltages are compared phase-wise to the set *Voltage start value*. If the measured value is lower than the set *Voltage start value* setting in number of phases equal to that set *Num of start phases*, the *START* output is activated.

The setting options available for *Num of start phases* are “Exactly 1 of 3”, “Exactly 2 of 3”, and “Exactly 3 of 3”, which are different from conventional setting options available in other functions. For example, *Num of start phases* is set to “Exactly 2 of 3”, any two voltages should drop below *Voltage start value* within one cycle network for the *START* output to activate. Even if more than two voltages drop below *Voltage start value*, *START* output is not activated.

When the *Voltage selection* setting is “Positive Seq”, the positive-sequence component is compared with the set *Voltage start value*. If it is lower than the set *Voltage start value*, the *START* output is activated.

Once *START* is activated, the function monitors the behavior of the voltage defined by *Voltage selection setting* with the defined LVRT curve. When defined voltage enters the operating area, the *OPERATE* output is activated instantaneously. The pulse length of *OPERATE* is fixed to 100 ms. *START* also deactivates along with *OPERATE*.

If a drop-off situation occurs, that is, voltage restores above *Voltage start value*, before *OPERATE* is activated, the function does not reset until maximum recovery time under consideration has elapsed, that is, *START* output remains active.

LVRT curve is defined using time-voltage settings coordinates. The settings available are *Recovery time 1...Recovery time 10* and *Voltage level 1...Voltage level 10*. The number of coordinates required to define a LVRT curve is set by *Active coordinate settings*.



When *Recovery time 1* is set to non-zero value, it results into horizontal characteristics from point of fault till *Recovery time 1*.

Two examples of LVRT curve are defined in [Figure 259](#) and [Figure 260](#) with corresponding settings in [Table 485](#).



It is necessary to set the coordinate points correctly in order to avoid maloperation. For example, setting for *Recovery time 2* should be greater than *Recovery time 1*. *Recovery time 1...Recovery time 10* are the respective time setting from the point of fault.

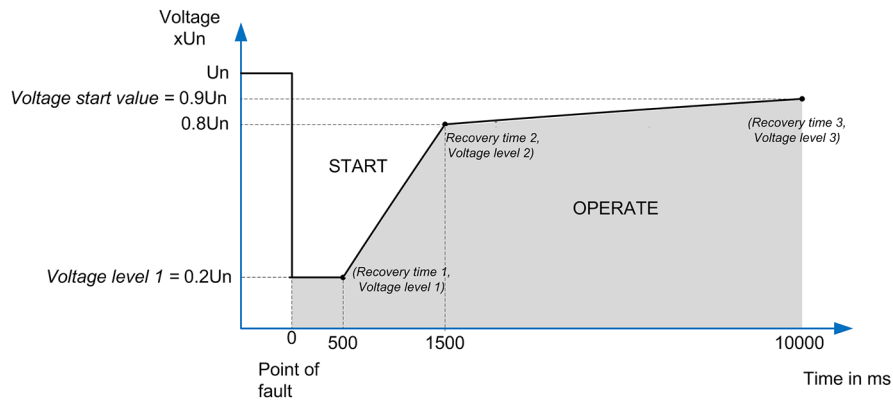


Figure 259: Low voltage ride through example curve A

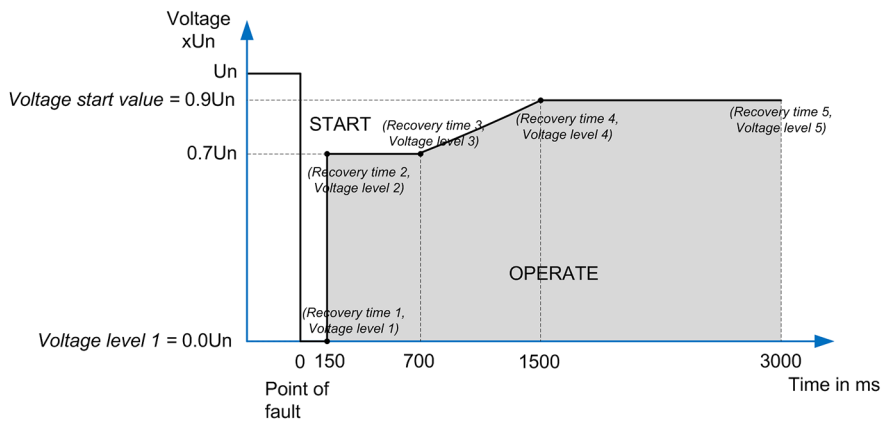


Figure 260: Low voltage ride through example curve B

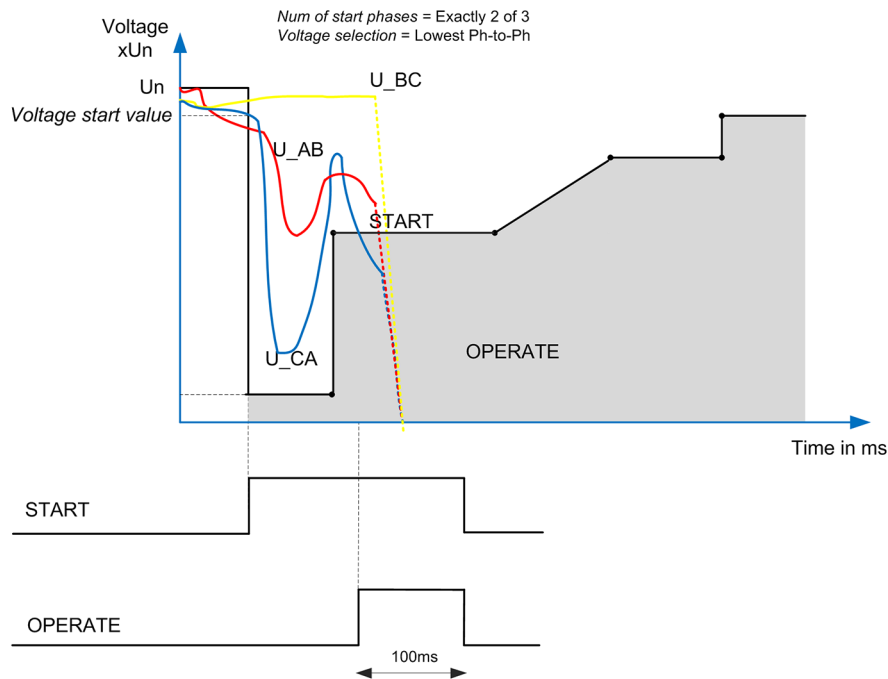
Table 485: Settings for example A and B

| Settings            | Curve A         | Curve B         |
|---------------------|-----------------|-----------------|
| Voltage start value | $0.9 \cdot U_n$ | $0.9 \cdot U_n$ |
| Active coordinates  | 3               | 5               |
| Voltage level 1     | $0.2 \cdot U_n$ | $0 \cdot U_n$   |
| Recovery time 1     | 500 ms          | 150 ms          |
| Voltage level 2     | $0.8 \cdot U_n$ | $0.7 \cdot U_n$ |
| Recovery time 2     | 1000 ms         | 150 ms          |
| Voltage level 3     | $0.9 \cdot U_n$ | $0.7 \cdot U_n$ |
| Recovery time 3     | 10000 ms        | 700 ms          |
| Voltage level 4     | -               | $0.9 \cdot U_n$ |
| Recovery time 4     | -               | 1500 ms         |
| Voltage level 5     | -               | $0.9 \cdot U_n$ |
| Recovery time 5     | -               | 3000 ms         |



It is necessary that the last active *Voltage level X* setting is set greater than or equal to *Voltage start value*. Settings are not accepted if the last active *Voltage level X* setting is not set greater than or equal to *Voltage start value*.

*Figure 261* describes an example of operation of LVRTPTUV protection function set to operate with *Num of start phases* set to “Exactly 2 of 3” and *Voltage selection* as “Lowest Ph-to-Ph” voltage.



*Figure 261: Typical example of operation of LVRTPTUV function*

Activation of the `BLOCK` input resets the timers and deactivates the function outputs.

### 3.5.6.5

#### Application

Distributed generation, mainly wind and solar farms, are rapidly increasing due to liberalized markets (deregulation) and the global trend to use more renewable sources of energy. These farms are directly connected to grids, and due to their large size may influence the behavior of the grid. These farms are now required to comply with stringent grid connection requirement, which was previously mandatory only for high capacity power plants. These requirements include helping grid in maintaining system stability, reactive power support, transient recovery and voltage-frequency regulation. These requirements make it necessary for the wind and solar farms to remain in operation in the event of network disturbances.

Many grid codes now demand that the distributed generation connected to HV grids must withstand voltage dips to a certain percentage of nominal voltage (down to 0% in some cases) and for a specific duration. Such requirements are known as Low-Voltage Ride-Through (LVRT) or Fault-Ride-Through (FRT) and are described by a voltage versus time characteristics.

Typical LVRT behavior of a distributed generation can be divided into three areas according to the variation in voltage over time.

- At the time of system faults, the magnitude of the voltage may dip to *Voltage level 1* for time defined by *Recovery time 1*. The generating unit has to remain connected to the network during such condition. This boundary defines area A.
- Area B defines the linear growth recovery voltage level from *Voltage level 1* to *Voltage level 2* in a time period from *Recovery time 1* to *Recovery time 2*.
- Area C is the zone where voltage stabilizes. *Voltage level 3* is defined to same value as *Voltage level 2*. The system should remain above this voltage in a time period from *Recovery time 2* to *Recovery time 3*.

The system restores to a normal state and function resets when the voltage is equal or greater than *Voltage level 4* after *Recovery time 4* time period.

When the voltage at the point of common coupling is above the LVRT curve, the generation unit must remain connected, and must be disconnected only if the voltage takes values below the curve.

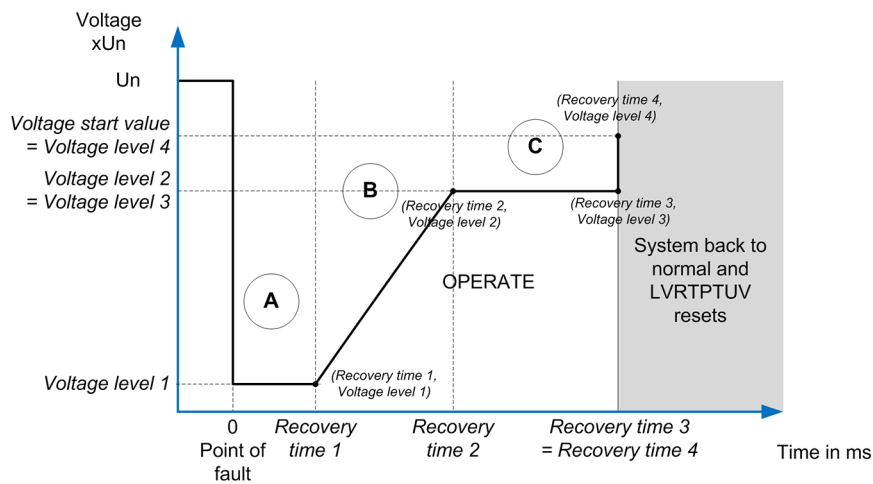


Figure 262: A typical required ride-through voltage capability of generating unit

The LVRT requirement depends on the power system characteristics and the protection employed, varying significantly from each other. The requirement also differs from country to country. LVRTPTUV function incorporates four types of LVRT curves which satisfy most of the power system needs. Grid operators can fine-tune the LVRT curve by setting the parameters as per their requirement, making the use simpler in comparison with different conventional undervoltage protection with different operate time setting and logics.

**3.5.6.6 Signals**

**LVRTPTUV Input signals****Table 486: LVRTPTUV Input signals**

| Name           | Type    | Default | Description   |
|----------------|---------|---------|---|
| U_A_AB         | SIGNAL  | 0       | Phase-to-earth voltage A or phase-to-phase voltage AB |
| U_A_BC         | SIGNAL  | 0       | Phase-to-earth voltage B or phase-to-phase voltage BC |
| U_A_CA         | SIGNAL  | 0       | Phase-to-earth voltage C or phase-to-phase voltage CA |
| U <sub>1</sub> | SIGNAL  | 0       | Positive phase sequence voltage                       |
| BLOCK          | BOOLEAN | 0=False | Block signal for activating the blocking mode         |

**LVRTPTUV Output signals****Table 487: LVRTPTUV Output signals**

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

**3.5.6.7****Settings****LVRTPTUV Settings****Table 488: LVRTPTUV Group settings (Basic)**

| Parameter           | Values (Range) | Unit | Step | Default | Description                               |
|---------------------|----------------|------|------|---------|---|
| Voltage start value | 0.05...1.20    | xUn  | 0.01 | 0.90    | Voltage value below which function starts |

**Table 489: LVRTPTUV Non group settings (Basic)**

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on           |      |      | 1=on    | Operation Off / On |

*Table continues on the next page*

| Parameter           | Values (Range)   | Unit | Step | Default           | Description                                      |
|---------------------|--|------|------|-------------------|--|
|                     | 5=off  |      |      |                   |  |
| Num of start phases | 4=Exactly 1 of 3<br>5=Exactly 2 of 3<br>6=Exactly 3 of 3   |      |      | 4=Exactly 1 of 3  | Number of faulty phases                          |
| Voltage selection   | 1=Highest Ph-to-E<br>2=Lowest Ph-to-E<br>3=Highest Ph-to-Ph<br>4=Lowest Ph-to-Ph<br>5=Positive Seq |      |      | 4=Lowest Ph-to-Ph | Parameter to select voltage for curve monitoring |
| Active coordinates  | 1...10   |      | 1    | 3                 | Coordinates used for defining LVRT curve         |
| Voltage level 1     | 0.00...1.20  | xUn  | 0.01 | 0.20              | 1st voltage coordinate for defining LVRT curve   |
| Voltage level 2     | 0.00...1.20  | xUn  | 0.01 | 0.80              | 2nd voltage coordinate for defining LVRT curve   |
| Voltage level 3     | 0.00...1.20  | xUn  | 0.01 | 0.90              | 3rd voltage coordinate for defining LVRT curve   |
| Voltage level 4     | 0.00...1.20  | xUn  | 0.01 | 0.90              | 4th voltage coordinate for defining LVRT curve   |
| Voltage level 5     | 0.00...1.20  | xUn  | 0.01 | 0.90              | 5th voltage coordinate for defining LVRT curve   |
| Voltage level 6     | 0.00...1.20  | xUn  | 0.01 | 0.90              | 6th voltage coordinate for                       |

*Table continues on the next page*



| Parameter        | Values (Range) | Unit | Step | Default | Description                                     |
|------------------|----------------|------|------|---------|---|
|                  |                |      |      |         | defining LVRT curve                             |
| Voltage level 7  | 0.00...1.20    | xUn  | 0.01 | 0.90    | 7th voltage coordinate for defining LVRT curve  |
| Voltage level 8  | 0.00...1.20    | xUn  | 0.01 | 0.90    | 8th voltage coordinate for defining LVRT curve  |
| Voltage level 9  | 0.00...1.20    | xUn  | 0.01 | 0.90    | 9th voltage coordinate for defining LVRT curve  |
| Voltage level 10 | 0.00...1.20    | xUn  | 0.01 | 0.90    | 10th voltage coordinate for defining LVRT curve |
| Recovery time 1  | 0...300000     | ms   | 1    | 500     | 1st time coordinate for defining LVRT curve     |
| Recovery time 2  | 0...300000     | ms   | 1    | 1000    | 2nd time coordinate for defining LVRT curve     |
| Recovery time 3  | 0...300000     | ms   | 1    | 10000   | 3rd time coordinate for defining LVRT curve     |
| Recovery time 4  | 0...300000     | ms   | 1    | 10000   | 4th time coordinate for defining LVRT curve     |
| Recovery time 5  | 0...300000     | ms   | 1    | 10000   | 5th time coordinate for defining LVRT curve     |
| Recovery time 6  | 0...300000     | ms   | 1    | 10000   | 6th time coordinate for defining LVRT curve     |
| Recovery time 7  | 0...300000     | ms   | 1    | 10000   | 7th time coordinate for defining LVRT curve     |

*Table continues on the next page*

| Parameter        | Values (Range) | Unit | Step | Default | Description                                  |
|------------------|----------------|------|------|---------|--|
| Recovery time 8  | 0...300000     | ms   | 1    | 10000   | 8th time coordinate for defining LVRT curve  |
| Recovery time 9  | 0...300000     | ms   | 1    | 10000   | 9th time coordinate for defining LVRT curve  |
| Recovery time 10 | 0...300000     | ms   | 1    | 10000   | 10th time coordinate for defining LVRT curve |

### 3.5.6.8 Monitored data

#### LVRTPTUV Monitored data

Table 490: LVRTPTUV Monitored data

| Name     | Type | Values (Range)   | Unit | Description |
|----------|------|--|------|-------------|
| LVRTPTUV | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status      |

### 3.5.6.9 Technical data

Table 491: LVRTPTUV Technical data

| Characteristic           | Value   |
|--------------------------|---|
| Operation accuracy       | Depending on the frequency of the measured voltage:<br>$f_n \pm 2 \text{ Hz}$<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times U_n$ |
| Start time <sup>69</sup> | Typically 40 ms   |
| Reset time               | Based on maximum value of <i>Recovery time</i> setting  |
| Operate time accuracy    | $\pm 1.0\%$ of the set value or $\pm 20 \text{ ms}$   |
| Suppression of harmonics | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$   |

<sup>69</sup> Tested for *Number of Start phases* = 1 out of 3, results based on statistical distribution of 1000 measurements

<sup>70</sup> Includes the delay of the signal output contact

## 3.6 Frequency protection

### 3.6.1 Frequency protection FRPFRQ

#### 3.6.1.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|----------------------|--------------------------|--------------------------|-------------------------------|
| Frequency protection | FRPFRQ                   | f>/f<,df/dt              | 81                            |

#### 3.6.1.2 Function block

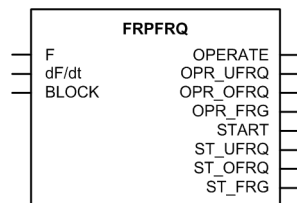


Figure 263: Function block

#### 3.6.1.3 Functionality

The frequency protection function FRPFRQ is used to protect network components against abnormal frequency conditions.

The function provides basic overfrequency, underfrequency and frequency rate-of-change protection. Additionally, it is possible to use combined criteria to achieve even more sophisticated protection schemes for the system.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

#### 3.6.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of FRPFRQ can be described using a module diagram. All the modules in the diagram are explained in the next sections.

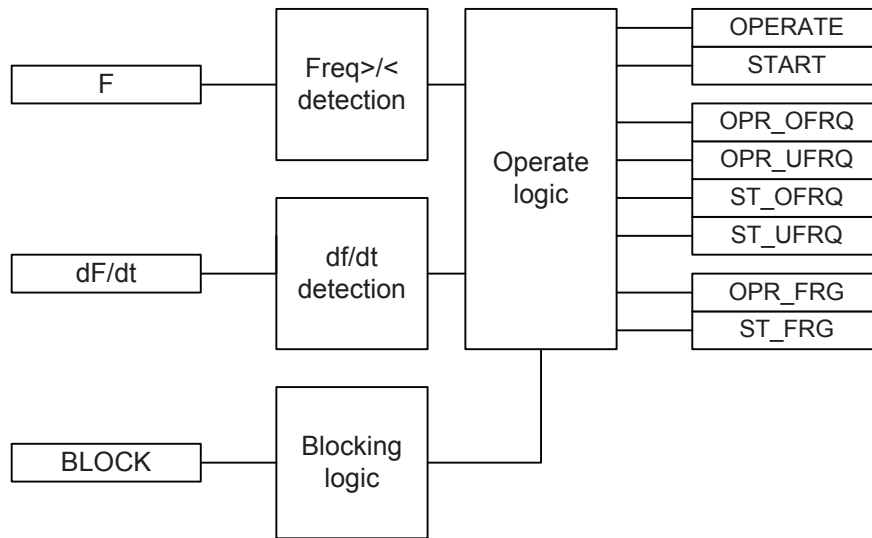


Figure 264: Functional module diagram

**Freq>/< detection**

The frequency detection module includes an overfrequency or underfrequency detection based on the *Operation mode* setting.

In the “Freq>” mode, the measured frequency is compared to the set *Start value Freq>*. If the measured value exceeds the set value of the *Start value Freq>* setting, the module reports the exceeding of the value to the operate logic module.

In the “Freq<” mode, the measured frequency is compared to the set *Start value Freq<*. If the measured value is lower than the set value of the *Start value Freq<* setting, the module reports the value to the operate logic module.

**df/dt detection**

The frequency gradient detection module includes a detection for a positive or negative rate-of-change (gradient) of frequency based on the set *Start value df/dt* value. The negative rate-of-change protection is selected when the set value is negative. The positive rate-of-change protection is selected when the set value is positive. When the frequency gradient protection is selected and the gradient exceeds the set *Start value df/dt* value, the module reports the exceeding of the value to the operate logic module.



The IED does not accept the set value "0.00" for the *Start value df/dt* setting.

**Operate logic**

This module is used for combining different protection criteria based on the frequency and the frequency gradient measurement to achieve a more sophisticated behavior of the function. The criteria are selected with the *Operation mode* setting.

Table 492: Operation modes for operation logic

| <i>Operation mode</i> | <b>Description</b>   |
|-----------------------|--|
| Freq<                 | The function operates independently as the underfrequency ("Freq<") protection function. When the measured frequency is below the set value of the <i>Start value Freq&lt;</i> setting, the module activates the START and STR_UFRQ outputs. The time characteristic is according to DT. When the operation timer has reached the value set by the <i>Operate Tm Freq</i> setting, the OPERATE and OPR_UFRQ outputs are activated. If the frequency restores before the module operates, the reset timer is activated. If the timer reaches the value set by the <i>Reset delay Tm Freq</i> setting, the operate timer resets and the START and STR_UFRQ outputs are deactivated.                          |
| Freq>                 | The function operates independently as the overfrequency ("Freq>") protection function. When the measured frequency exceeds the set value of the <i>Start value Freq&gt;</i> setting, the module activates the START and STR_OFRQ outputs. The time characteristic is according to DT. When the operation timer has reached the value set by the <i>Operate Tm Freq</i> setting, the OPERATE and OPR_OFRQ outputs are activated. If the frequency restores before the module operates, the reset timer is activated. If the timer reaches the value set by the <i>Reset delay Tm Freq</i> setting, the operate timer resets and the START and STR_OFRQ outputs are deactivated.                            |
| df/dt                 | The function operates independently as the frequency gradient ("df/dt"), rate-of-change, protection function. When the frequency gradient exceeds the set value of the <i>Start value df/dt</i> setting, the module activates the START and STR_FRG outputs. The time characteristic is according to DT. When the operation timer has reached the value set by the <i>Operate Tm df/dt</i> setting, the OPERATE and OPR_FRG outputs are activated. If the frequency gradient restores before the module operates, the reset timer is activated. If the timer reaches the value set by the <i>Reset delay Tm df/dt</i> setting, the operate timer resets and the START and STR_FRG outputs are deactivated. |
| Freq< + df/dt         | A consecutive operation is enabled between the protection methods. When the measured   |

*Table continues on the next page*

| Operation mode           | Description  |
|--------------------------|--|
|                          | <p>frequency is below the set value of the <i>Start value Freq&lt;</i> setting, the frequency gradient protection is enabled. After the frequency has dropped below the set value, the frequency gradient is compared to the set value of the <i>Start value df/dt</i> setting. When the frequency gradient exceeds the set value, the module activates the <code>START</code> and <code>STR_FRG</code> outputs. The time characteristic is according to <code>DT</code>. When the operation timer has reached the value set by the <i>Operate Tm df/dt</i> setting, the <code>OPERATE</code> and <code>OPR_FRG</code> outputs are activated. If the frequency gradient restores before the module operates, the reset timer is activated. If the timer reaches the value set by the <i>Reset delay Tm df/dt</i> setting, the operate timer resets and the <code>START</code> and <code>STR_FRG</code> outputs are deactivated. The <code>OPR_UFRQ</code> output is not active when this operation mode is used.</p>   |
| <p>Freq&gt; + df/dt</p>  | <p>A consecutive operation is enabled between the protection methods. When the measured frequency exceeds the set value of the <i>Start value Freq&gt;</i> setting, the frequency gradient protection is enabled. After the frequency exceeds the set value, the frequency gradient is compared to the set value of the <i>Start value df/dt</i> setting. When the frequency gradient exceeds the set value, the module activates the <code>START</code> and <code>STR_FRG</code> outputs. The time characteristic is according to <code>DT</code>. When the operation timer has reached the value set by the <i>Operate Tm df/dt</i> setting, the <code>OPERATE</code> and <code>OPR_FRG</code> outputs are activated. If the frequency gradient restores before the module operates, the reset timer is activated. If the timer reaches the value set by the <i>Reset delay Tm df/dt</i> setting, the operate timer resets and the <code>START</code> and <code>STR_FRG</code> outputs are deactivated. The <code>OPR_OFRQ</code> output is not active when this operation mode is used.</p> |
| <p>Freq&lt; OR df/dt</p> | <p>A parallel operation between the protection methods is enabled. The <code>START</code> output is activated when either of the measured values of the protection module exceeds its set value. Detailed information about the active module is available at the <code>STR_UFRQ</code> and <code>STR_FRG</code> outputs. The shortest operate delay time from the set <i>Operate Tm Freq</i> or <i>Operate Tm df/dt</i> is dominant regarding the</p>   |

Table continues on the next page

| <i>Operation mode</i> | <b>Description</b>   |
|-----------------------|--|
|                       | OPERATE output. The time characteristic is according to DT. The characteristic that activates the OPERATE output can be seen from the OPR_UFRQ or OPR_FRG output. If the frequency gradient restores before the module operates, the reset timer is activated. If the timer reaches the value set by the <i>Reset delay Tm df/dt</i> setting, the operate timer resets and the STR_FRG output is deactivated. If the frequency restores before the module operates, the reset timer is activated. If the timer reaches the value set by the <i>Reset delay Tm Freq</i> setting, the operate timer resets and the STR_UFRQ output is deactivated.   |
| Freq> OR df/dt        | A parallel operation between the protection methods is enabled. The START output is activated when either of the measured values of the protection module exceeds its set value. A detailed information from the active module is available at the STR_OFRQ and STR_FRG outputs. The shortest operate delay time from the set <i>Operate Tm Freq</i> or <i>Operate Tm df/dt</i> is dominant regarding the OPERATE output. The time characteristic is according to DT. The characteristic that activates the OPERATE output can be seen from the OPR_OFRQ or OPR_FRG output. If the frequency gradient restores before the module operates, the reset timer is activated. If the timer reaches the value set by the <i>Reset delay Tm df/dt</i> setting, the operate timer resets and the STR_FRG output is deactivated. If the frequency restores before the module operates, the reset timer is activated. If the timer reaches the value set by the <i>Reset delay Tm Freq</i> setting, the operate timer resets and the STR_UFRQ output is deactivated. |

The module calculates the start duration value which indicates the percentage ratio of the start situation and set operate time (DT). The start duration is available according to the selected value of the *Operation mode* setting.

**Table 493: Start duration value**

| <b>Operation mode in use</b> | <b>Available start duration value</b> |
|------------------------------|---------------------------------------|
| Freq<                        | ST_DUR_UFRQ                           |
| Freq>                        | ST_DUR_OFRQ                           |
| df/dt                        | ST_DUR_FRG                            |

The combined start duration START\_DUR indicates the maximum percentage ratio of the active protection modes. The values are available via the Monitored data view.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration > System > Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the `OPERATE` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block `OPERATE` output" mode, the function operates normally but the `OPERATE` output is not activated.

### 3.6.1.5

#### Application

The frequency protection function uses the positive phase-sequence voltage to measure the frequency reliably and accurately.

The system frequency stability is one of the main principles in the distribution and transmission network maintenance. To protect all frequency-sensitive electrical apparatus in the network, the departure from the allowed band for a safe operation should be inhibited.

The overfrequency protection is applicable in all situations where high levels of the fundamental frequency of a power system voltage must be reliably detected. The high fundamental frequency in a power system indicates an unbalance between production and consumption. In this case, the available generation is too large compared to the power demanded by the load connected to the power grid. This can occur due to a sudden loss of a significant amount of load or due to failures in the turbine governor system. If the situation continues and escalates, the power system loses its stability.

The underfrequency is applicable in all situations where a reliable detection of a low fundamental power system voltage frequency is needed. The low fundamental frequency in a power system indicates that the generated power is too low to meet the demands of the load connected to the power grid.

The underfrequency can occur as a result of the overload of generators operating in an isolated system. It can also occur as a result of a serious fault in the power system due to the deficit of generation when compared to the load. This can happen due to a fault in the grid system on the transmission lines that link two parts of the system. As a result, the system splits into two with one part having the excess load and the other part the corresponding deficit.

The frequency gradient is applicable in all the situations where the change of the fundamental power system voltage frequency should be detected reliably. The frequency gradient can be used for both increasing and decreasing the frequencies. This function provides an output signal suitable for load shedding, generator shedding, generator boosting, set point change in sub-transmission DC systems and gas turbine startup. The frequency gradient is often used in combination with a low frequency signal, especially in smaller power systems where the loss of a large generator requires quick remedial actions to secure the power system integrity. In such situations, the load shedding actions are required at a rather high frequency level. However, in combination with a large negative frequency gradient, the underfrequency protection can be used at a high setting.



### 3.6.1.6 Signals

#### FRPFRQ Input signals

Table 494: FRPFRQ Input signals

| Name  | Type    | Default | Description                                   |
|-------|---------|---------|---|
| F     | SIGNAL  | 0       | Measured frequency                            |
| dF/dt | SIGNAL  | 0       | Rate of change of frequency                   |
| BLOCK | BOOLEAN | 0=False | Block signal for activating the blocking mode |

#### FRPFRQ Output signals

Table 495: FRPFRQ Output signals

| Name     | Type    | Description                           |
|----------|---------|---------------------------------------|
| OPERATE  | BOOLEAN | Operate                               |
| OPR_OFQR | BOOLEAN | Operate signal for overfrequency      |
| OPR_UFRQ | BOOLEAN | Operate signal for underfrequency     |
| OPR_FRG  | BOOLEAN | Operate signal for frequency gradient |
| START    | BOOLEAN | Start                                 |
| ST_OFQR  | BOOLEAN | Start signal for overfrequency        |
| ST_UFRQ  | BOOLEAN | Start signal for underfrequency       |
| ST_FRG   | BOOLEAN | Start signal for frequency gradient   |

### 3.6.1.7 Settings

#### FRPFRQ Settings

Table 496: FRPFRQ Group settings (Basic)

| Parameter      | Values (Range)                | Unit | Step | Default | Description                                   |
|----------------|-------------------------------|------|------|---------|---|
| Operation mode | 1=Freq<<br>2=Freq><br>3=df/dt |      |      | 1=Freq< | Frequency protection operation mode selection |

*Table continues on the next page*

| Parameter         | Values (Range)   | Unit   | Step   | Default | Description                                     |
|-------------------|--|--------|--------|---------|---|
|                   | 4=Freq< + df/dt<br>5=Freq> + df/dt<br>6=Freq< OR df/dt<br>7=Freq> OR df/dt |        |        |         |   |
| Start value Freq> | 0.9000...1.2000  | xFn    | 0.0001 | 1.0500  | Frequency start value overfrequency             |
| Start value Freq< | 0.8000...1.1000  | xFn    | 0.0001 | 0.9500  | Frequency start value underfrequency            |
| Start value df/dt | -0.2000...0.2000   | xFn /s | 0.0025 | 0.0100  | Frequency start value rate of change            |
| Operate Tm Freq   | 80...200000  | ms     | 10     | 200     | Operate delay time for frequency                |
| Operate Tm df/dt  | 120...200000   | ms     | 10     | 400     | Operate delay time for frequency rate of change |

Table 497: FRPFRQ Non group settings (Basic)

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

Table 498: FRPFRQ Non group settings (Advanced)

| Parameter            | Values (Range) | Unit | Step | Default | Description                         |
|----------------------|----------------|------|------|---------|-------------------------------------|
| Reset delay Tm Freq  | 0...60000      | ms   | 1    | 0       | Reset delay time for frequency      |
| Reset delay Tm df/dt | 0...60000      | ms   | 1    | 0       | Reset delay time for rate of change |

### 3.6.1.8 Monitored data

#### FRPFRQ Monitored data

Table 499: FRPFRQ Monitored data

| Name         | Type    | Values (Range)   | Unit | Description    |
|--------------|---------|--|------|----------------|
| START_DUR    | FLOAT32 | 0.00...100.00  | %    | Start duration |
| ST_DUR_OFRRQ | FLOAT32 | 0.00...100.00  | %    | Start duration |
| ST_DUR_UFRQ  | FLOAT32 | 0.00...100.00  | %    | Start duration |
| ST_DUR_FRG   | FLOAT32 | 0.00...100.00  | %    | Start duration |
| FRPFRQ       | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status         |

### 3.6.1.9 Technical data

Table 500: FRPFRQ Technical data

| Characteristic        |         | Value  |
|-----------------------|---------|--|
| Operation accuracy    | $f>/f<$ | $\pm 5$ mHz  |
|                       | $df/dt$ | $\pm 50$ mHz/s (in range $ df/dt  < 5$ Hz/s)<br>$\pm 2.0\%$ of the set value (in range $5$ Hz/s $<  df/dt  < 15$ Hz/s) |
| Start time            | $f>/f<$ | $< 80$ ms  |
|                       | $df/dt$ | $< 120$ ms   |
| Reset time            |         | $< 150$ ms   |
| Operate time accuracy |         | $\pm 1.0\%$ of the set value or $\pm 30$ ms  |

### 3.6.1.10 Technical revision history

Table 501: FRPFRQ Technical revision history

| Technical revision | Change  |
|--------------------|---|
| B                  | Step value changed from 0.001 to 0.0001 for the <i>Start value Freq&gt;</i> and <i>Start value Freq&lt;</i> settings. |
| C                  | $df/dt$ setting step changed from $0.005 \times F_n /s$ to $0.0025 \times F_n /s$ .                                   |
| D                  | Internal improvement.   |

### 3.6.2 Load-shedding and restoration LSHDPFRQ

#### 3.6.2.1 Identification

| Function description          | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|-------------------------------|--------------------------|--------------------------|-------------------------------|
| Load-shedding and restoration | LSHDPFRQ                 | UFLS/R                   | 81LSH                         |

#### 3.6.2.2 Function block

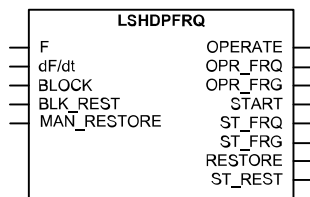


Figure 265: Function block

#### 3.6.2.3 Functionality

The load-shedding and restoration function LSHDPFRQ is capable of performing load-shedding based on underfrequency and the rate of change of the frequency. The load that is shed during the frequency disturbance can be restored once the frequency has stabilized to the normal level.

The measured system frequency is compared to the set value to detect the underfrequency condition. The measured rate of change of frequency ( $df/dt$ ) is compared to the set value to detect a high frequency reduction rate. The combination of the detected underfrequency and the high  $df/dt$  is used for the activation of the load-shedding. There is a definite time delay between the detection of the underfrequency and high  $df/dt$  and the activation of LSHDPFRQ. This time delay can be set and it is used to prevent unwanted load-shedding actions when the system frequency recovers to the normal level.



Throughout this document, “high  $df/dt$ ” is used to mean “a high rate of change of the frequency in negative direction.”

Once the frequency has stabilized, LSHDPFRQ can restore the load that is shed during the frequency disturbance. The restoration is possible manually or automatically.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

#### 3.6.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of LSHDPRQ can be described using a module diagram. All the modules are explained in the next sections.

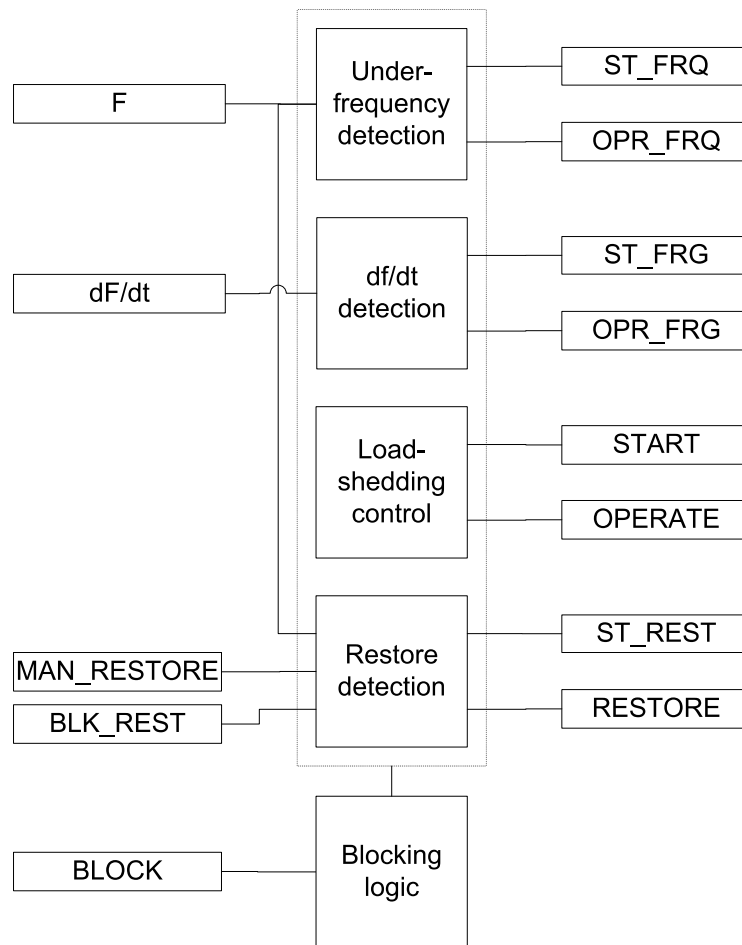


Figure 266: Functional module diagram

### Underfrequency detection

The underfrequency detection measures the input frequency calculated from the voltage signal. An underfrequency is detected when the measured frequency drops below the set value of the *Start Value Freq* setting.

The underfrequency detection module includes a timer with the definite time (DT) characteristics. Upon detection of underfrequency, operation timer activates the `ST_FRQ` output. When the underfrequency timer has reached the value set by *Operate Tm Freq*, the `OPR_FRQ` output is activated if the underfrequency condition still persists. If the frequency becomes normal before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the timer resets and the `ST_FRQ` output is deactivated.

### df/dt detection

The df/dt detection measures the input frequency calculated from the voltage signal and calculates its gradient. A high df/dt condition is detected by comparing the gradient to the *Start value df/dt* setting. The df/dt detection is activated when

the frequency gradient decreases at a faster rate than the set value of *Start value df/dt*.

The df/dt detection module includes a timer with the DT characteristics. Upon detection of df/dt, operation timer activates the `ST_FRG` output. When the timer has reached the value set by *Operate Tm df/dt*, the `OPR_FRG` output is activated if the df/dt condition still persists. If df/dt becomes normal before the module operates, the reset timer is activated. If the reset timer reaches the value of the *Reset delay time* setting, the timer resets and the `ST_FRG` output is deactivated.

#### **Load-shedding control**

The way of load-shedding, that is, whether to operate based on underfrequency or high df/dt or both, is defined with the *Load shed mode* user setting. The valid operation modes for the *Load shed mode* settings are "Freq<", "Freq< AND df/dt" and "Freq< OR df/dt".

Once the selected operation mode conditions are satisfied, the `START` and `OPERATE` output signals are activated.

When the `START` output is active, the percentage of the elapsed delay time can be monitored through `START_DUR` which is available as monitored data.

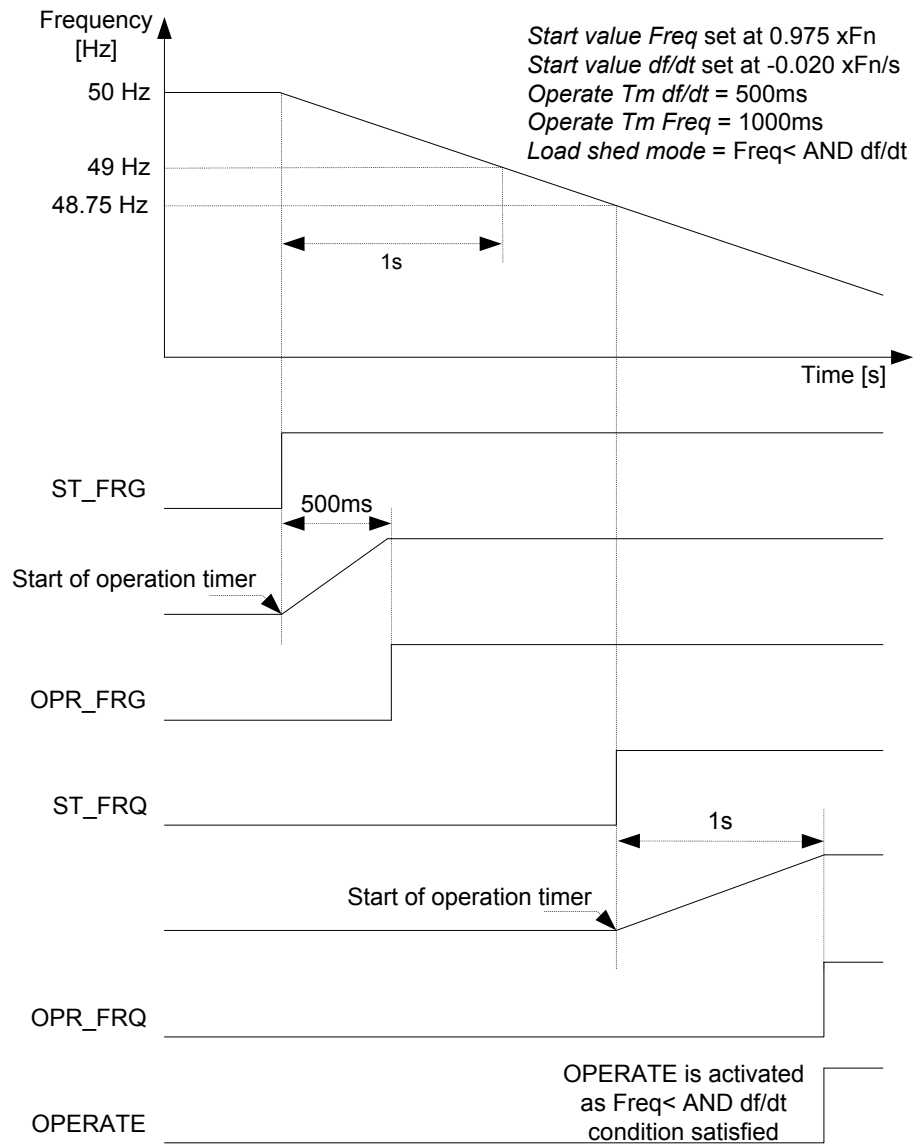


Figure 267: Load-shedding operation in the “Freq< AND df/dt>” mode when both Freq< and df/dt conditions are satisfied (Rated frequency=50 Hz)

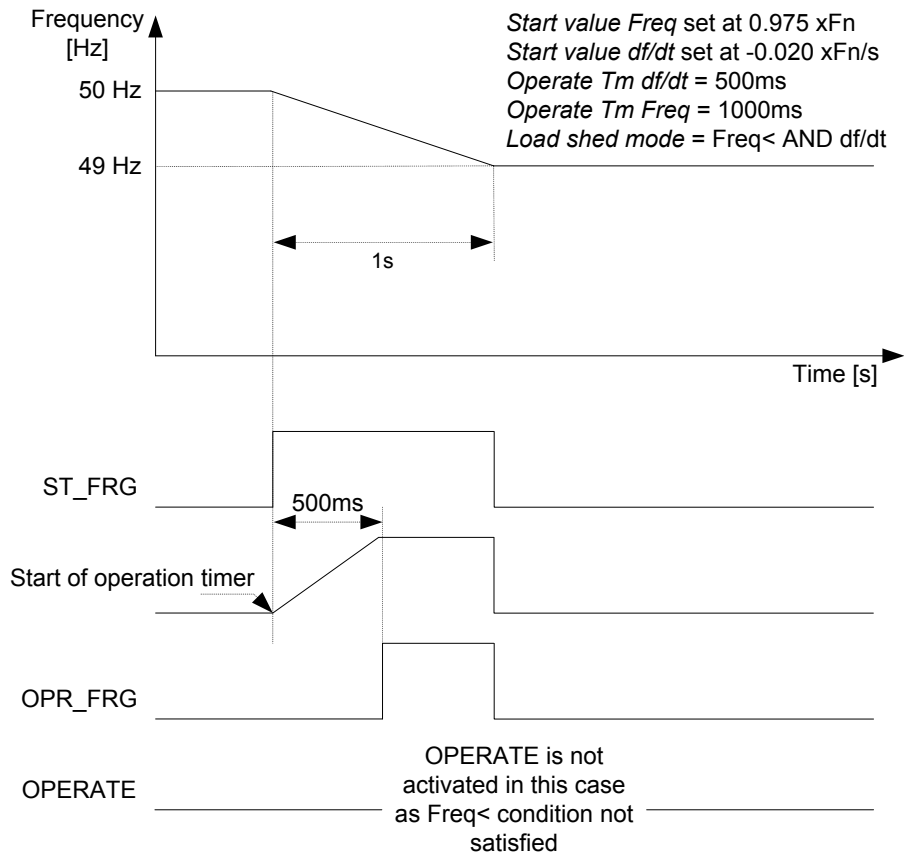


Figure 268: Load-shedding operation in the “Freq < AND df/dt >” mode when only the df/dt condition is satisfied (Rated frequency=50 Hz)

**Restore detection**

If after the activation of the OPERATE input the frequency recovers to a level above the *Restore start Va* setting, the RESTORE signal output is activated. The RESTORE output remains active for a 100 ms. The *Restore mode* setting is used to select the restoring mode to be "Disabled", "Auto" or "Manual".

| Restoring mode | Description  |
|----------------|--|
| Disabled       | Load restoration is disabled.  |
| Auto           | In the “Auto” mode, input frequency is continuously compared to the <i>Restore start Va</i> setting. The restore detection module includes a timer with the DT characteristics. Upon detection of restoring, the operation timer activates the ST_REST output. When the timer has reached the value of the <i>Restore delay time</i> setting, the RESTORE output is activated if the restoring condition still persists. If the frequency drops below the <i>Restore start Va</i> before the RESTORE output is activated, the reset timer is activated. If the reset timer |

Table continues on the next page



| Restoring mode | Description   |
|----------------|---|
|                | reaches the value of the <i>Reset delay time</i> setting, the timer resets and the ST_REST start output is deactivated.   |
| Manual         | In the "Manual" mode, a manual restoration is possible through the MAN_RESTORE input or via communication. The ST_REST output is activated if the MAN_RESTORE command is available and the frequency has exceeded the <i>Restore start Val</i> setting. The manual restoration includes a timer with the DT characteristics. When the timer has reached the set value of the <i>Restore delay time</i> setting, the RESTORE output is activated if the restoring condition still persists. If the frequency drops below the <i>Restore start Val</i> setting before the RESTORE output is activated, the reset timer is activated. If the reset timer reaches the value of the <i>Reset delay time</i> setting, the timer resets and the ST_REST start output is deactivated. |

A condition can arise where the restoring operation needs to be canceled. Activating the BLK\_REST input for the "Auto" or "Manual" modes cancels the restoring operation. In the "Manual" restoring mode, the cancellation happens even if MAN\_RESTORE is present.

Once the RESTORE output command is cancelled, the reactivation of RESTORE is possible only after the reactivation of the OPERATE output, that is, when the next load-shedding operation is detected.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration > System > Blocking mode** that selects the blocking mode. The BLOCK input can be controlled with a binary input, a horizontal communication input or an internal signal of the IED's program. The influence of the BLOCK input signal activation is preselected with the *Blocking mode* global setting.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE, OPR\_FRQ and OPR\_FRG outputs are not activated.

### 3.6.2.5

#### Application

An AC power system operates at a defined rated frequency. The nominal frequency in most systems in the world is 50 Hz or 60 Hz. The system operation is such that the operating frequency remains approximately at the nominal frequency value by a small margin. The safe margin of operation is usually less than  $\pm 0.5$  Hz. The system frequency stability is one of the main concerns in the transmission

and distribution network operation and control. To protect the frequency-sensitive electrical equipment in the network, departure from the allowed band for safe operation should be inhibited.

Any increase in the connected load requires an increase in the real power generation to maintain the system frequency. Frequency variations form whenever there are system conditions that result in an unbalance between the generation and load. The rate of change of the frequency represents the magnitude of the difference between the load and generation. A reduction in frequency and a negative rate of change of the frequency are observed when the load is greater than the generation, and an increase in the frequency along with a positive rate of change of the frequency are observed if the generation is greater than the load. The rate of change of the frequency is used for a faster decision of load-shedding. In an underfrequency situation, the load-shedding trips out the unimportant loads to stabilize the network. Thus, loads are normally prioritized so that the less important loads are shed before the important loads.

During the operation of some of the protective schemes or other system emergencies, the power system is divided into small islands. There is always a load - generation imbalance in such islands that leads to a deviation in the operating frequency from the nominal frequency. This off-nominal frequency operation is harmful to power system components like turbines and motors. Therefore, such situation must be prevented from continuing. The frequency-based load-shedding scheme should be applied to restore the operation of the system to normal frequency. This is achieved by quickly creating the load - generation balance by disconnecting the load.

As the formation of the system islands is not always predefined, several load-shedding relays are required to be deployed at various places near the load centers. A quick shedding of a large amount of load from one place can cause a significant disturbance in the system. The load-shedding scheme can be made most effective if the shedding of load feeders is distributed and discrete, that is, the loads are shed at various locations and in distinct steps until the system frequency reaches the acceptable limits.

Due to the action of load-shedding schemes, the system recovers from the disturbance and the operating frequency value recovers towards the nominal frequency. The load that was shed during the disturbance can be restored. The load-restoring operation should be done stepwise in such a way that it does not lead the system back to the emergency condition. This is done through an operator intervention or in case of remote location through an automatic load restoration function. The load restoration function also detects the system frequency and restores the load if the system frequency remains above the value of the set restoration frequency for a predefined duration.

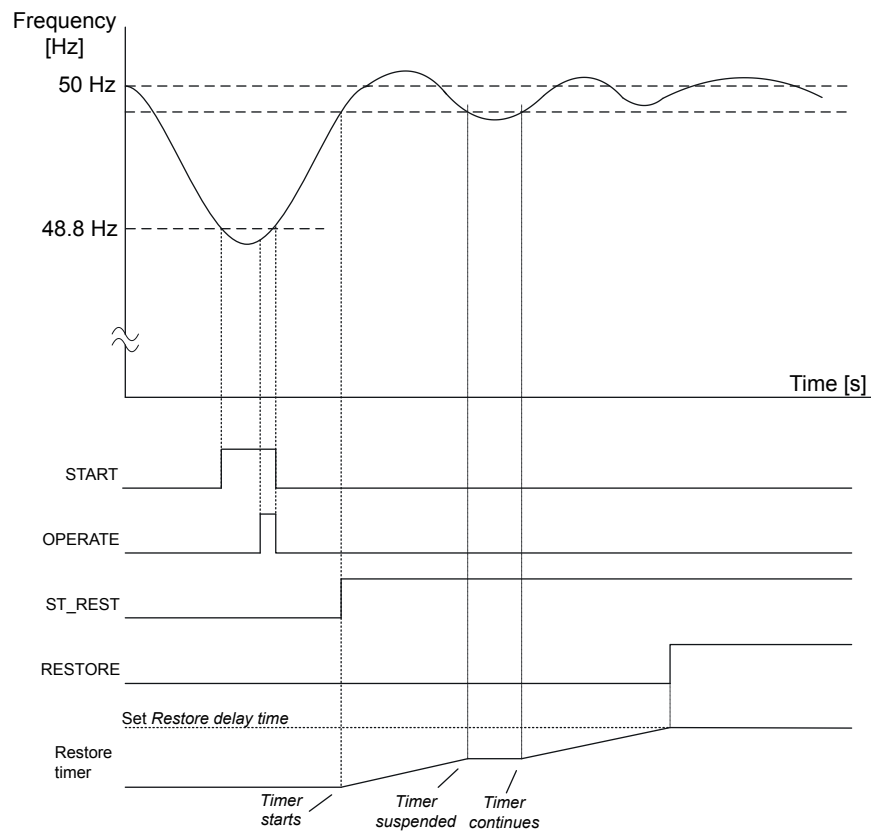


Figure 269: Operation of the load-shedding function

### Power system protection by load-shedding

The decision on the amount of load that is required to be shed is taken through the measurement of frequency and the rate of change of frequency ( $df/dt$ ). At a single location, many steps of load-shedding can be defined based on different criteria of the frequency and  $df/dt$ . Typically, the load-shedding is performed in six or four steps with each shedding increasing the portion of load from five to twenty-five percent of full load within a few seconds. After every shedding, the system frequency is read back and further shedding actions are taken only if necessary. In order to take the effect of any transient, a sufficient time delay should be set.

The value of the setting has to be well below the lowest occurring normal frequency and well above the lowest acceptable frequency of the system. The setting level, the number of steps and the distance between two steps (in time or in frequency) depend on the characteristics of the power system under consideration. The size of the largest loss of generation compared to the size of the power system is a critical parameter. In large systems, the load-shedding can be set at a high frequency level and the time delay is normally not critical. In small systems, the frequency start level has to be set at a low value and the time delay must be short.

If a moderate system operates at 50 Hz, an underfrequency should be set for different steps from 49.2 Hz to 47.5 Hz in steps of 0.3 – 0.4 Hz. The operating time for the underfrequency can be set from a few seconds to a few fractions of a second stepwise from a higher frequency value to a lower frequency value.

**Table 502: Setting for a five-step underfrequency operation**

| Load-shedding steps | Start value Freq setting    | Operate Tm Freq setting |
|---------------------|-----------------------------|-------------------------|
| 1                   | $0.984 \cdot F_n$ (49.2 Hz) | 45000 ms                |
| 2                   | $0.978 \cdot F_n$ (49.2 Hz) | 30000 ms                |
| 3                   | $0.968 \cdot F_n$ (49.2 Hz) | 15000 ms                |
| 4                   | $0.958 \cdot F_n$ (49.2 Hz) | 5000ms                  |
| 5                   | $0.950 \cdot F_n$ (49.2 Hz) | 500 ms                  |

The rate of change of frequency function is not instantaneous since the function needs time to supply a stable value. It is recommended to have a time delay long enough to take care of the signal noise.

Small industrial systems can experience the rate of change of frequency as large as 5 Hz/s due to a single event. Even large power systems can form small islands with a large imbalance between the load and generation when severe faults or combinations of faults are cleared. Up to 3 Hz/s has been experienced when a small island becomes isolated from a large system. For normal severe disturbances in large power systems, the rate of change of the frequency is much less, often just a fraction of 1.0 Hz/s.

Similarly, the setting for  $df/dt$  can be from 0.1 Hz/s to 1.2 Hz/s in steps of 0.1 Hz/s to 0.3 Hz/s for large distributed power networks, with the operating time varying from a few seconds to a few fractions of a second. Here, the operating time should be kept in minimum for the higher  $df/dt$  setting.

**Table 503: Setting for a five-step  $df/dt <$  operation**

| Load-shedding steps | Start value $df/dt$ setting        | Operate Tm $df/dt$ setting |
|---------------------|------------------------------------|----------------------------|
| 1                   | $-0.005 \cdot F_n /s$ (-0.25 Hz/s) | 8000 ms                    |
| 2                   | $-0.010 \cdot F_n /s$ (-0.25 Hz/s) | 2000 ms                    |
| 3                   | $-0.015 \cdot F_n /s$ (-0.25 Hz/s) | 1000 ms                    |
| 4                   | $-0.020 \cdot F_n /s$ (-0.25 Hz/s) | 500 ms                     |
| 5                   | $-0.025 \cdot F_n /s$ (-0.25 Hz/s) | 250 ms                     |

Once the frequency has stabilized, the shed load can be restored. The restoring operation should be done stepwise, taking care that it does not lead the system back to the emergency condition.

**Table 504: Setting for a five-step restoring operation**

| Load-shedding steps | Restoring start Val setting | Restore delay time setting |
|---------------------|-----------------------------|----------------------------|
| 1                   | $0.990 \cdot F_n$ (49.5 Hz) | 200000 ms                  |
| 2                   | $0.990 \cdot F_n$ (49.5 Hz) | 160000 ms                  |
| 3                   | $0.990 \cdot F_n$ (49.5 Hz) | 100000 ms                  |
| 4                   | $0.990 \cdot F_n$ (49.5 Hz) | 50000 ms                   |
| 5                   | $0.990 \cdot F_n$ (49.5 Hz) | 10000 ms                   |

### 3.6.2.6 Signals

#### LSHDPFRQ Input signals

Table 505: LSHDPFRQ Input signals

| Name        | Type    | Default | Description                                   |
|-------------|---------|---------|---|
| F           | SIGNAL  | 0       | Measured frequency                            |
| dF/dt       | SIGNAL  | 0       | Rate of change of frequency                   |
| BLOCK       | BOOLEAN | 0=False | Block signal for activating the blocking mode |
| BLK_REST    | BOOLEAN | 0=False | Block restore                                 |
| MAN_RESTORE | BOOLEAN | 0=False | Manual restore signal                         |

#### LSHDPFRQ Output signals

Table 506: LSHDPFRQ Output signals

| Name    | Type    | Description  |
|---------|---------|--|
| OPERATE | BOOLEAN | Operation of load shedding                           |
| OPR_FRQ | BOOLEAN | Operate signal for under frequency                   |
| OPR_FRG | BOOLEAN | Operate signal for high df/dt                        |
| START   | BOOLEAN | Start  |
| ST_FRQ  | BOOLEAN | Pick-Up signal for under frequency detection         |
| ST_FRG  | BOOLEAN | Pick-Up signal for high df/dt detection              |
| RESTORE | BOOLEAN | Restore signal for load restoring purposes           |
| ST_REST | BOOLEAN | Restore frequency attained and restore timer started |

### 3.6.2.7 Settings

#### Settings

#### LSHDPFRQ Settings

Table 507: LSHDPFRQ Group settings (Basic)

| Parameter      | Values (Range) | Unit | Step | Default | Description                |
|----------------|----------------|------|------|---------|----------------------------|
| Load shed mode | 1=Freq<        |      |      | 1=Freq< | Set the operation mode for |

*Table continues on the next page*

| Parameter          | Values (Range)                              | Unit   | Step  | Default    | Description                                       |
|--------------------|---|--------|-------|------------|---|
|                    | 6=Freq< OR<br>df/dt<br>8=Freq< AND<br>df/dt |        |       |            | load shedding function                            |
| Restore mode       | 1=Disabled<br>2=Auto<br>3=Manual            |        |       | 1=Disabled | Mode of operation of restore functionality        |
| Start value Freq   | 0.800...1.200                               | xFn    | 0.001 | 0.975      | Frequency setting/start value                     |
| Start value df/dt  | -0.200...-0.005                             | xFn /s | 0.005 | -0.010     | Setting of frequency gradient for df/dt detection |
| Operate Tm Freq    | 80...200000                                 | ms     | 10    | 200        | Time delay to operate for under frequency stage   |
| Operate Tm df/dt   | 120...200000                                | ms     | 10    | 200        | Time delay to operate for df/dt stage             |
| Restore start Val  | 0.800...1.200                               | xFn    | 0.001 | 0.998      | Restore frequency setting value                   |
| Restore delay time | 80...200000                                 | ms     | 10    | 300        | Time delay to restore                             |

Table 508: LSHDPFRQ Non group settings (Basic)

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

Table 509: LSHDPFRQ Non group settings (Advanced)

| Parameter        | Values (Range) | Unit | Step | Default | Description   |
|------------------|----------------|------|------|---------|---|
| Reset delay time | 0...60000      | ms   | 1    | 50      | Time delay after which the definite timers will reset |

### 3.6.2.8 Monitored data

#### LSHD PFRQ Monitored data

Table 510: LSHD PFRQ Monitored data

| Name      | Type    | Values (Range)   | Unit | Description    |
|-----------|---------|--|------|----------------|
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Start duration |
| LSHD PFRQ | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status         |

### 3.6.2.9 Technical data

Table 511: LSHD PFRQ Technical data

| Characteristic        |       | Value   |
|-----------------------|-------|---|
| Operation accuracy    | f<    | ±5 mHz  |
|                       | df/dt | ±100 mHz/s (in range  df/dt  < 5 Hz/s)<br>± 2.0% of the set value (in range 5 Hz/s <  df/dt  < 15 Hz/s) |
| Start time            | f<    | <80 ms  |
|                       | df/dt | <120 ms   |
| Reset time            |       | <150 ms   |
| Operate time accuracy |       | ±1.0% of the set value or ±30 ms  |

### 3.6.2.10 Technical revision history

Table 512: LSHD PFRQ Technical revision history

| Technical revision | Change                |
|--------------------|-----------------------|
| B                  | Internal improvement. |
| C                  | Internal improvement. |

## 3.7 Impedance protection

### 3.7.1 Distance protection DSTPDIS

#### 3.7.1.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|----------------------|--------------------------|--------------------------|-------------------------------|
| Distance protection  | DSTPDIS                  | Z<                       | 21P, 21N                      |

#### 3.7.1.2 Function block

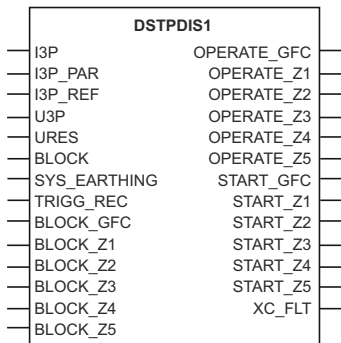


Figure 270: Function block

#### 3.7.1.3 Functionality

The distance protection function DSTPDIS provides a full-scheme distance protection function for distribution networks where three-phase tripping is allowed for all kinds of faults.

DSTPDIS has five flexible, configurable impedance zones for protection (Z1...Z5).

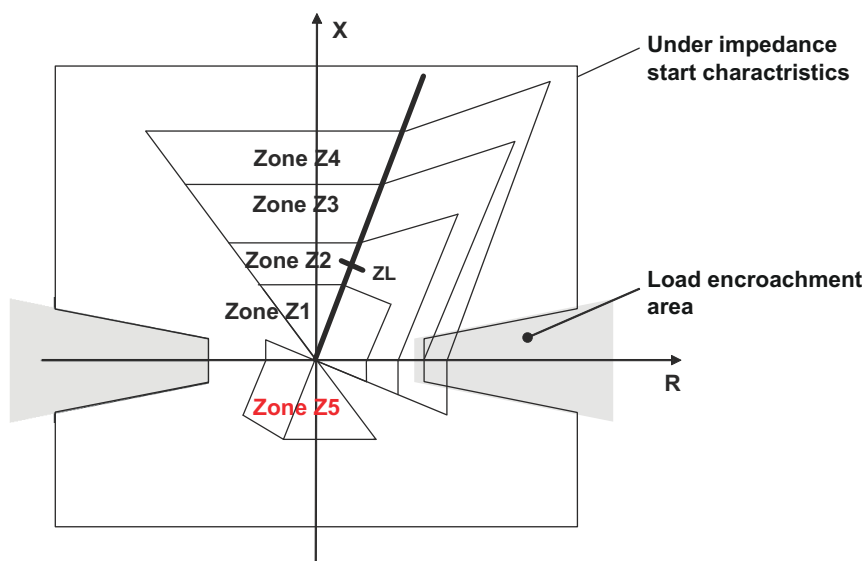


Figure 271: Zones of DSTPDIS function (example 1)



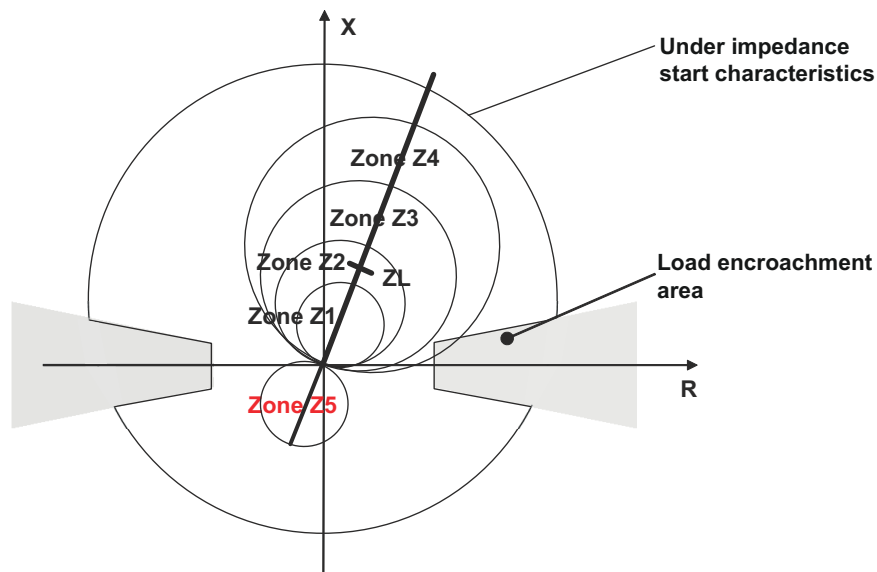


Figure 272: Zones of DSTPDIS function (example 2)

The supported zone characteristic shapes are quadrilateral, mho (circular) or bullet (quadrilateral and mho characteristics combined). Mho can be combined with directional lines to secure directionality and to enable increased fault resistance coverage with an offset mho circle.

| Imp zone shape  | Directional mode Znx |         |         |
|-----------------|----------------------|---------|---------|
|                 | Non-directional      | Forward | Reverse |
| Quadrilateral   |                      |         |         |
| Mho (circular)  |                      |         |         |
| Mho Dir line    |                      |         |         |
| Offset Dir line |                      |         |         |
| Bullet (combi)  |                      |         |         |

**Pol. = polarization method affects (mho)zone shape**

Figure 273: Possible combinations of Directional mode Znx and Zone characteristics settings. Pol. here means that the shape of the characteristic is affected by the selected polarization method of mho circle (Pol quantity zone = "Cross pol", "Pos. seq. volt.", "Self pol")

The directional lines are polarized with the set polarizing quantity of all impedance measuring elements. In addition, the memory voltage that is based on positive sequence voltage substitute for the measured voltage with any impedance measurement element polarization if the corresponding voltage drops too low.

DSTPDIS has separate and independent measurement elements for each fault loop in the distance protection zone. In addition to the full scheme design, the separate measuring elements are used for general fault detection and faulted phase selection.

DSTPDIS supports both fault detection dependent control of zone timers and zonededicated phasewise timer control for maximum application flexibility.

The impedance measurement is always done the same way regardless of the zone shape. The operation is based on the impedance mapping approach where the fault loop impedance is first calculated and then compared to the zone boundaries. If impedance is recognized within the operation zone, the corresponding operate output is activated after the operate time has elapsed.

The impedance measurement is based on full-cycle DFT filtered current and voltage phasors.

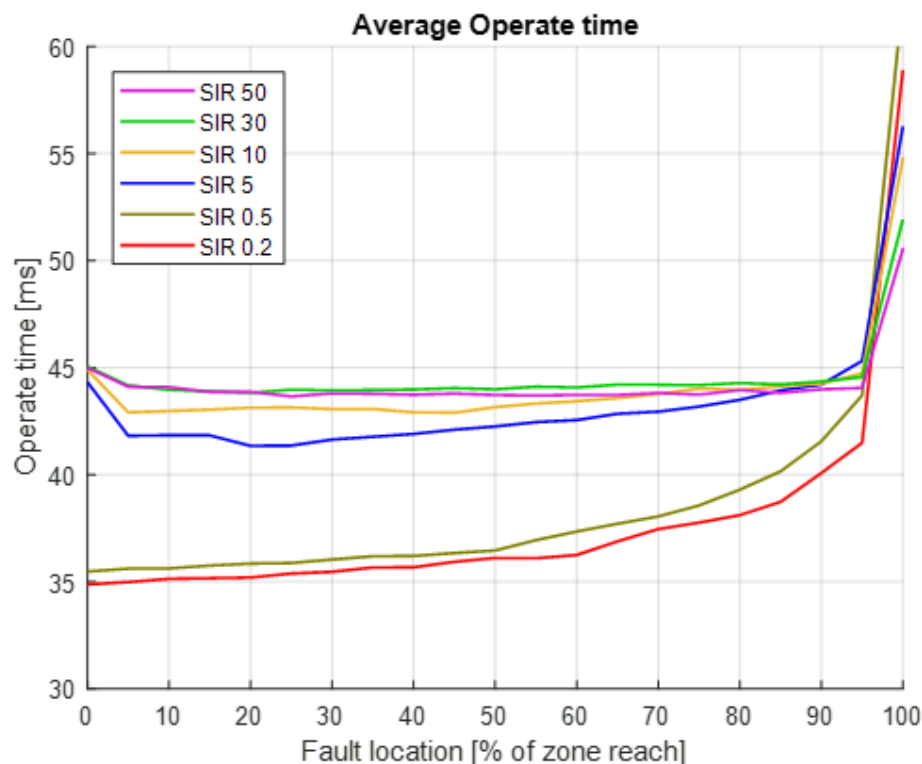


Figure 274: Average operate time of DSTPDIS according to IEC 60255-121 network models Short line and Long line (50 Hz)

SIR curves are plotted from the data which includes variation of fault location (0... 100% of zone reach, 5% step), fault type (LN, LL, LLN, LLL) and fault inception angle (0, 30, 60, 90 degrees). Each combination has been repeated ten times giving the total number of 26880 shots. The operate times include the delay of relay output contacts. The SIR curves presented in Figure 241 were obtained using the static power outputs (SPOs) and with *Zone timer mode* = "common".

### 3.7.1.4 Analog channel configuration

DSTPDIS has five analog group inputs which must be properly configured.

**Table 513: Analog inputs**

| Input   | Description  |
|---------|--|
| I3P     | Three-phase currents   |
| I3P_PAR | Three-phase currents Utilized when <i>Par line Comp zone x</i> is set to True  |
| I3P_REF | Three-phase currents Utilized when <i>EF detection Mod GFC</i> is set to "Io AND IoRef"  |
| U3P     | Three-phase voltages   |
| URES    | Residual voltage (measured) Utilized when <i>EF detection Mod GFC</i> is set to "Io OR Uo" or "Io AND Uo". Utilized also if only main voltages are available but <i>Phase voltage Meas</i> is set to "Accurate". |

There are a few special conditions which must be noted with the configuration.

**Table 514: Special conditions**

| Condition                          | Description  |
|------------------------------------|--|
| U3P connected to real measurements | The function can work with any two phase voltage channels connected but it is recommended to connect all three voltage channels. |

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

### 3.7.1.5

#### Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The function consists of sub-functions which are described in the next sections.

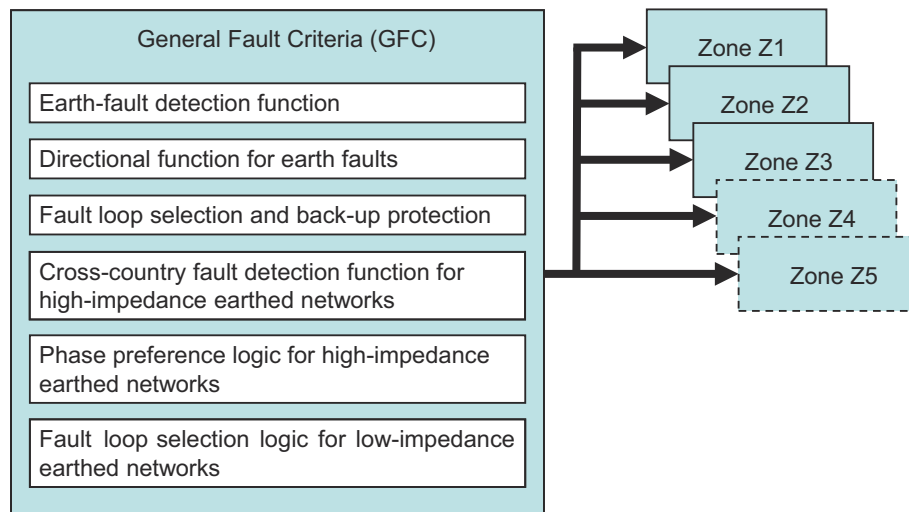


Figure 275: Main functionality of DSTPDIS

All outputs and the operation of all sub-functions can be blocked with the `BLOCK` binary input signal. In addition, it resets the timers.

### Blocking

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration > System > Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the `OPERATE_Z1...5` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the `OPERATE_Z1...5` output is not activated.

In addition, the function has zone-specific blocking signals `BLOCK_Z1...5`. The signal resets zone timers disabling the corresponding start and operate output activation.

`BLOCK_GFC` deactivates `START_GFC` and `OPERATE_GFC`. It also resets GFC operate time (set by *Operate delay GFC*). Blocking does not prevent GFC operation.

### Earth-fault detection function

The recognition of an earth fault is an important part in identifying the correct fault type. This information is used in faulted loop (phase) selection to release the correct impedance-measuring elements. The earth-fault recognition is always required to release the phase-to-earth impedance-measuring elements.

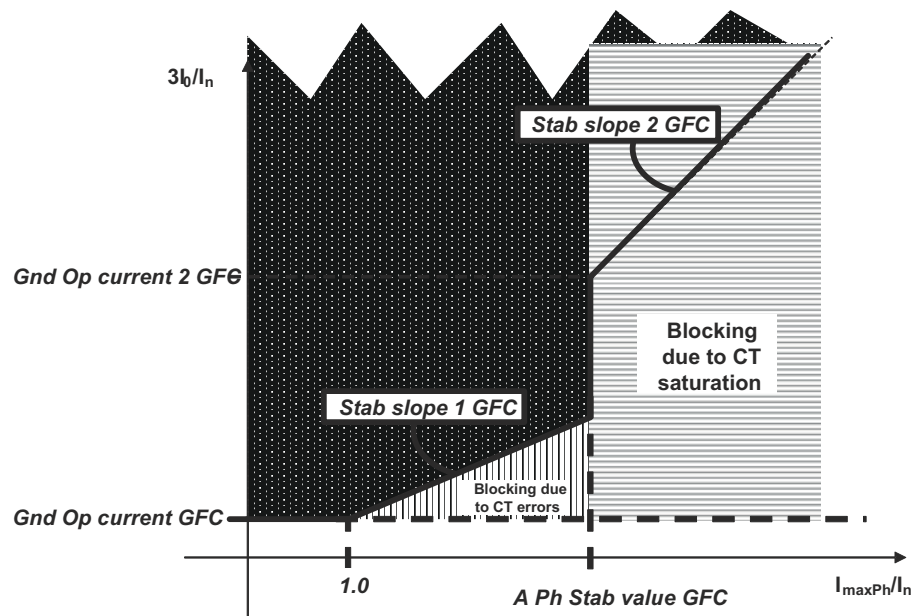
The earth-fault detection is indicated with the `EARTH_FLT` monitored data. The earth-fault detection criterion can be defined with the *EF detection Mod GFC* setting. The fundamental criterion is based on the residual current. The residual voltage and reference neutral current, measured from the transformer neutral point, can be used for the earth-fault detection criteria.

**Table 515: Selection of earth-fault detection criteria**

| Setting              | Enumerator name   |
|----------------------|---|
| EF detection Mod GFC | <ul style="list-style-type: none"> <li>• Io</li> <li>• Io OR Uo</li> <li>• Io AND Uo</li> <li>• Io AND IoRef</li> </ul> |

If the residual current  $I_0$  is derived from the phase currents either by the summation connection of CTs, that is, the Holmgreen connection, or by internally summing the phase currents, there is a risk of a false earth-fault detection due to apparent residual current from the current transformer errors. This risk can be eliminated using a stabilized residual current measurement. The stabilization is enabled by setting the *EF Cur stabilization* setting to "True". The stabilization increases the residual current *Gnd Op current GFC* threshold setting when the maximum phase current exceeds the nominal current. The increase is defined with the *Stab slope 1 GFC* setting. The apparent residual current may exist during short circuits and in inrush current situations if the CTs saturate partially. The earth-fault detection function takes the CT saturation into account with additional stabilization settings *Gnd Op current 2 GFC*, *A Ph Stab value GFC* and *Stab slope 2 GFC*.

Setting *EF Cur stabilization* to "False" disables the stabilization of the residual current measurement and should be used only when the residual current is measured with a cable current transformer. The residual current threshold setting for earth-fault detection is *Gnd Op current GFC*. If the residual current is measured from a transformer neutral point, *Gnd Op A Ref GFC* is used. This is valid when the setting *EF detection Mod GFC* is "Io AND IoRef".



*Figure 276: Stabilized residual current measurement for earth-fault detection*

The residual voltage can also be used as a complementary criterion for earth-fault detection. This is valid when the setting *EF detection Mod GFC* is "Io OR Uo" or *EF detection Mod GFC* is "Io AND Uo". The threshold setting for the residual voltage is *Gnd Str voltage GFC*.

### Directional function for earth faults

In low-impedance earthed networks, when the *System grounding GFC* setting is set to "Low impedance", the earth-fault detection function can be optionally supervised by a directional function which can be enabled with the *Dir mode EF GFC* setting. If *Dir mode EF GFC* is set to "Forward" or "Reverse", the earth-fault direction is also detected. The calculated direction for the earth fault is indicated in the DIR\_E\_FLT monitored data ("unknown", "forward", "backward" (reverse), "both"). Direction criteria do not directly affect earth-fault detection, but the earth-fault direction information is used for zone starting, when only those directional zones that are set to the indicated earth-fault direction can be started.

The operation characteristic of the directional function is defined by three settings: *Chr angle GFC*, *Min phase angle GFC* and *Max phase angle GFC*.

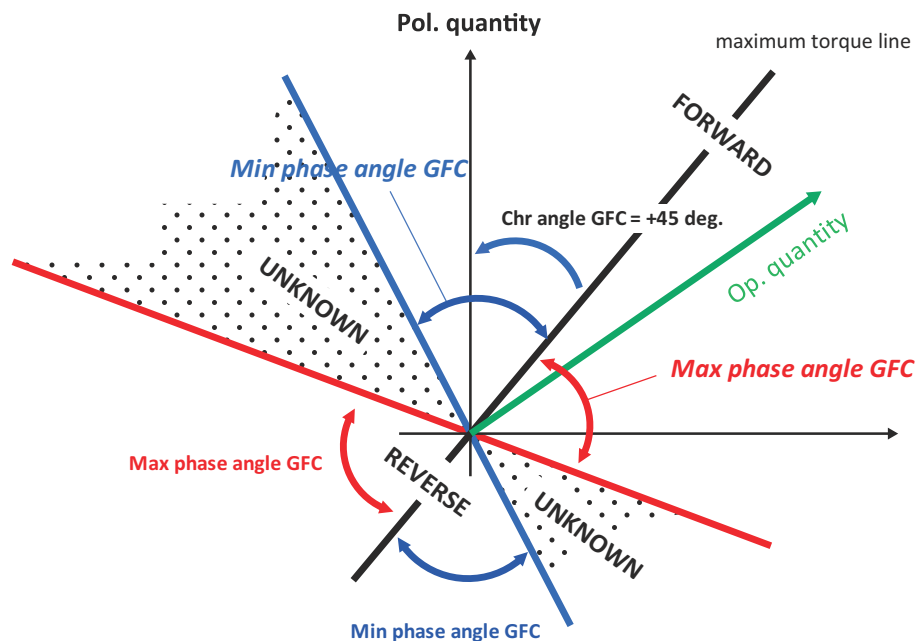


Figure 277: Characteristic of the directional function for earth faults

The *Chr angle GFC* setting, also known as relay characteristic angle or basic angle, is used to turn the directional characteristic. It has a positive value when the operating quantity lags the polarizing quantity and a negative value when the operating quantity leads the polarizing quantity. For low-impedance earthed networks, *Chr angle GFC* equals the angle of the fault loop impedance and is typically positive.

The *Min phase angle GFC* and *Max phase angle GFC* settings define the width of the operating sector. These settings are mirror-symmetric to the origin for reverse (backward).

The directional function for earth faults must operate at fault current values below the magnitude of the load currents. The use of sequence quantities is preferred for polarizing quantity as phase quantities are affected by the load currents. Four possibilities are available and defined by the *Pol quantity GFC* setting.

**Table 516: Polarizing quantities for optional directional function for earth faults in low-impedance earthed networks**

| Pol quantity GFC | Polarizing quantity  | Operating quantity | Description                            |
|------------------|----------------------|--------------------|--|
| Zero seq. volt.  | $-U_0$               | $I_0$              | Zero-sequence voltage polarization     |
| Neg. seq. volt.  | $-U_2$               | $I_2$              | Negative-sequence voltage polarization |
| Zero seq. cur.   | $I_{0ref}$           | $I_0$              | Zero-sequence current polarization     |
| Zro vol. OR cur. | $-U_0$ OR $I_{0ref}$ | $I_0$              | Dual polarization                      |



The polarizing quantity is  $-U_0$  and the operating quantity is  $I_0$  in case of zero-sequence voltage polarization.

The polarizing quantity is  $-U_2$  and the operating quantity is  $I_2$  in case of negative-sequence polarization.

In case of zero-sequence current polarization "Zero seq. cur.", the zero-sequence current  $I_0$  of the protected line is the operating quantity while another reference zero-sequence current  $I_{0ref}$  is the polarizing quantity.  $I_{0ref}$ , for example, could be the current from the neutral of a power transformer. In case of zero-sequence current polarization, the relay characteristic angle *Chr angle GFC* is internally fixed and is equal to zero degrees. The zero-sequence current direction must remain unchanged during all network configurations and faults. Therefore, all transformer configurations or constructions are not suitable for polarization.

In case of dual polarization "Zro vol. OR cur.", the zero-sequence voltage polarization and zero-sequence current polarization elements are logically OR:ed. Typically, when  $I_0$  is high,  $U_0$  is low, and when  $I_0$  is low,  $U_0$  is high. Hence the protection can benefit from both elements as the two polarization methods complement each other. If the zero-sequence current polarization source is switched off for service, the flexibility is increased as the zero-sequence voltage polarization can be used.

### Faulted loop phase selection

A reliable identification of a fault and faulted phases is needed to guarantee a selective operation of the distance protection. This information is used to release correct measuring elements of the protection zones.

In DSTPDIS, the faulted phase selection can be done in various ways and defined with the *Phase Sel mode GFC* setting.

**Table 517: Supported methods for phase selection**

| Setting            | Enumerator value  |
|--------------------|---|
| Phase Sel mode GFC | <ul style="list-style-type: none"> <li>• Overcurrent</li> <li>• Vol Dep Overcur</li> <li>• Under impedance</li> <li>• OC AND Und impedance</li> </ul> |

- The "Overcurrent" method is the basic method for identifying the faulted phases. It can be used in applications where the fault current magnitude exceeds the load current despite the changes in the network configuration and fault type.

- The “Vol Dep Overcur” method combines overcurrent and undervoltage conditions. An undervoltage condition allows lower current threshold settings and increases the sensitivity of the fault detection.
- The “Under impedance” method uses fault loop impedance for identifying the faulted phases. The underimpedance characteristic can be either quadrilateral or circular in shape. The sensitivity of the fault detection is defined by an independent setting in resistive and reactive reaches. The underimpedance method is supervised by a load encroachment logic which ensures that the load impedance does not interfere with the faulted phase selection.

The “OC AND Und impedance” method combines “Overcurrent” and “Under impedance” methods so that both criteria have to be fulfilled.

All phase selection methods require that all three phase currents are measured and all three phase-to-earth voltages are available. If only phase-to-phase voltages are available (*Phase voltage Meas* = “Ph-to-ph without Uo”), only phase-to-phase measuring loops can be released for measurement. The release of phase-to-earth fault measuring elements is then blocked, *RELEASE\_PE* = “No fault”.

The operation of the faulted phase selection function is highly dependent on the earth-fault detection function. The phase preference or faulted loop selection logic can be set to filter the faulted phases to be released for measurement in the protection zones.

The general indication of a fault is given in the binary output *START\_GFC*. The faulted phase information can be found from the integer monitored data signal *STARTS\_GFC*.

**Table 518: Enumeration values for integer monitored data signal *STARTS\_GFC***

| Enumeration name | Value |
|------------------|-------|
| No fault         | -5    |
| AG Fault         | 1     |
| BG Fault         | 2     |
| CG Fault         | 3     |
| AB Fault         | 4     |
| BC Fault         | 5     |
| CA Fault         | 6     |
| ABC Fault        | 7     |

The fault loops released for measurement are indicated with the integer monitored data signals *RELEASE\_PE* and *RELEASE\_PP*. These signals may be filtered by the phase preference of the faulted loop selection logic.

**Table 519: Enumeration values for integer monitored data signal *RELEASE\_PE***

| Enumeration name | Value |
|------------------|-------|
| No fault         | -5    |
| AG Fault         | 1     |
| BG Fault         | 2     |
| CG Fault         | 3     |
| AB Fault         | 4     |

*Table continues on the next page*



| Enumeration name | Value |
|------------------|-------|
| BC Fault         | 5     |
| CA Fault         | 6     |
| ABC Fault        | 7     |

**Table 520: Enumeration values for integer monitored data signal RELEASE\_PP**

| Enumeration name | Value |
|------------------|-------|
| No fault         | -5    |
| AB Fault         | 4     |
| BC Fault         | 5     |
| CA Fault         | 6     |
| ABC Fault        | 7     |

The phase selection function can be set to issue an operate signal as the faulted phase selection uses independent measuring elements from the distance protection zones. This can be applied as a back-up protection for the measurement zones. The time delay of the operate signals is defined with the *Operate delay GFC* setting. The operate signal is the binary output OPERATE\_GFC.

*Faulted loop phase selection by the overcurrent method*

The "Overcurrent" method is the basic method used for identifying the faulted phases. It can be used in applications where the fault current magnitude exceeds the load current despite the possible changes in the network configuration and fault type.

In the overcurrent-based faulted phase selection method, the amplitude of each phase current is compared to the *Str A Ph Sel GFC* threshold setting. If the phase current magnitude exceeds the value of *Str A Ph Sel GFC*, that particular phase is faulty.



Earth-fault recognition is always required to release a phase-to-earth impedance-measuring element.

**Table 521: Conversion from element start to monitored data signals**

| Start of element       | START_GFC | STARTS_GFC | RELEASE_P E | RELEASE_P P |
|------------------------|-----------|------------|-------------|-------------|
| $I_A >$ &<br>EARTH_FLT | TRUE      | AG Fault   | AG Fault    | No fault    |
| $I_B >$ &<br>EARTH_FLT | TRUE      | BG Fault   | BG Fault    | No fault    |
| $I_C >$ &<br>EARTH_FLT | TRUE      | CG Fault   | CG Fault    | No fault    |
| $I_A >$ & $I_B >$      | TRUE      | AB Fault   | No fault    | AB Fault    |

*Table continues on the next page*

| Start of element  | START_GFC | STARTS_GFC | RELEASE_PE | RELEASE_PP |
|---|-----------|------------|------------|------------|
| $I_B > \& I_C >$  | TRUE      | BC Fault   | No fault   | BC Fault   |
| $I_C > \& I_A >$  | TRUE      | CA Fault   | No fault   | CA Fault   |
| $I_A > \& I_B > \&$<br>EARTH_FLT                        | TRUE      | AB Fault   | AB Fault   | AB Fault   |
| $I_B > \& I_C > \&$<br>EARTH_FLT                        | TRUE      | BC Fault   | BC Fault   | BC Fault   |
| $I_C > \& I_A > \&$<br>EARTH_FLT                        | TRUE      | CA Fault   | CA Fault   | CA Fault   |
| $I_A > \& I_B > \& I_C >$ <sup>71</sup>                 | TRUE      | ABC Fault  | No fault   | ABC Fault  |
| $I_A > \& I_B > \& I_C > \&$<br>EARTH_FLT <sup>72</sup> | TRUE      | ABC Fault  | ABC Fault  | ABC Fault  |

In case of a high-impedance earthed network, a phase preference logic can be added to complement the phase selection in case of a cross-country fault. This can affect the `RELEASE_PE` signals.

In case of a low-impedance earthed network, a faulted loop selection logic can be added to complement the phase selection in case of a two-phase-to-earth fault. This can affect the `RELEASE_PE` and `RELEASE_PP` signals.

#### *Faulted phase selection, the voltage-dependent overcurrent method*

The "Voltdep overcur" method combines the overcurrent and undervoltage conditions. The phase current amplitude is compared to the *Str A Ph Sel GFC* threshold setting but a lower current *Lo A Ph Sel GFC* threshold is valid during an undervoltage condition. This increases the sensitivity of the fault detection. The amplitude of phase-to-earth and phase-to-phase voltages is compared to the *Ph V Ph Sel GFC* and *PP V Ph Sel GFC* settings. In case of a three-phase fault, the phase-to-phase voltages are monitored and compared to the *PP V Ph Sel GFC* setting.



Earth-fault recognition is always required to release a phase-to-earth impedance-measuring element.

<sup>71</sup> This applies to near three-phase faults. If voltages are still relatively high, all PP releases are given.

<sup>72</sup> This applies to near three-phase faults with EF indication. If voltages are still relatively high, all PE and PP releases (except ABC Fault) are given.

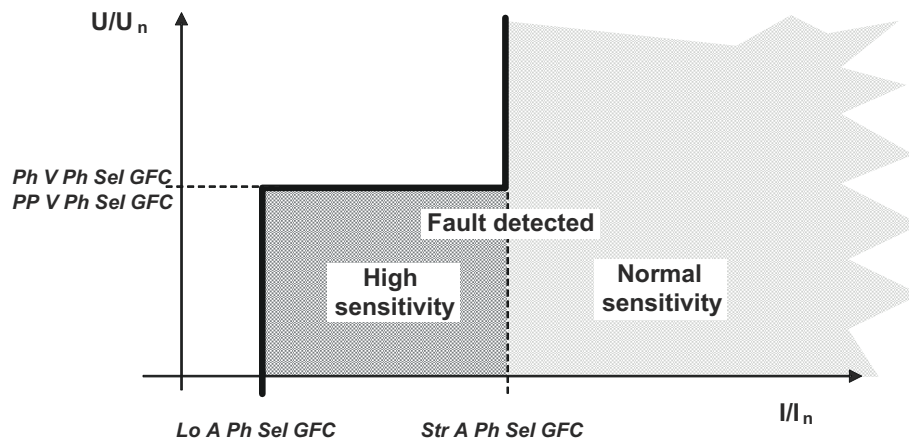


Figure 278: Overcurrent/undervoltage characteristics

Table 522: Conversion from element start to monitored data signals

| Start of element  | START_GFC | STARTS_GFC | RELEASE_P E | RELEASE_P P |
|---|-----------|------------|-------------|-------------|
| $I_A > \& U_A < \& EARTH\_FLT   I_A >> \& EARTH\_FLT$                       | TRUE      | AG Fault   | AG Fault    | No fault    |
| $I_B > \& U_B < \& EARTH\_FLT   I_B >> \& EARTH\_FLT$                       | TRUE      | BG Fault   | BG Fault    | No fault    |
| $I_C > \& U_C < \& EARTH\_FLT   I_C >> \& EARTH\_FLT$                       | TRUE      | CG Fault   | CG Fault    | No fault    |
| $I_A > \& I_B > \& U_{AB} <   I_A >> \& I_B >>$                             | TRUE      | AB Fault   | No fault    | AB Fault    |
| $I_B > \& I_C > \& U_{BC} <   I_B >> \& I_C >>$                             | TRUE      | BC Fault   | No fault    | BC Fault    |
| $I_C > \& I_A > \& U_{CA} <   I_C >> \& I_A >>$                             | TRUE      | CA Fault   | No fault    | CA Fault    |
| $I_A > \& I_B > \& U_{AB} < \& EARTH\_FLT   I_A >> \& I_B >> \& EARTH\_FLT$ | TRUE      | AB Fault   | AB Fault    | AB Fault    |
| $I_B > \& I_C > \& U_{BC} < \& EARTH\_FLT  $                                | TRUE      | BC Fault   | BC Fault    | BC Fault    |

Table continues on the next page

| Start of element  | START_GFC | STARTS_GFC | RELEASE_P E | RELEASE_P P |
|---|-----------|------------|-------------|-------------|
| $I_B >> \& I_C >> \&$<br>EARTH_FLT  |           |            |             |             |
| $I_C > \& I_A > \& U_{CA} < \&$<br>EARTH_FLT  <br>$I_C >> \& I_A >> \&$<br>EARTH_FLT  | TRUE      | CA Fault   | CA Fault    | CA Fault    |
| $I_A > \& I_B > \& I_C \&$<br>$U_{AB} < \& U_{BC} < U_{CA} <  $<br>$I_A >> , I_B >> \& I_C >> $ <sup>73</sup>                               | TRUE      | ABC Fault  | No fault    | ABC Fault   |
| $I_A > \& I_B > \& I_C \&$<br>$U_{AB} < \& U_{BC} < U_{CA}$<br>< & EARTH_FLT  <br>$I_A >> , I_B >> \& I_C >> \&$<br>EARTH_FLT <sup>74</sup> | TRUE      | ABC Fault  | No fault    | ABC Fault   |

- $I_x >$  Phase current exceeds the *Lo A Ph Sel GFC* setting
- $I_x >>$  Phase current exceeds the *Str A Ph Sel GFC* setting
- $U_x <$  Phase voltage undershoots the *Ph V Ph Sel GFC* setting
- $U_{xy} <$  Phase-to-phase voltage undershoots the *PP V Ph Sel GFC* setting

*Faulted phase selection, the underimpedance method*

The "Under impedance" and "OC AND Und impedance" methods use fault loop impedance for identifying the faulted phases. The advantage of the underimpedance criterion is that the sensitivity of the fault detection is independent of the source impedance. The underimpedance function has six impedance measuring elements. The phase-to-earth measuring elements are calculated:

$$\underline{Z}_A = \frac{U_A}{I_A}$$

(Equation 22)

<sup>73</sup> This applies to near three-phase faults. If voltages are still relatively high, all PP releases are given.

<sup>74</sup> This applies to near three-phase faults with EF indication. If voltages are still relatively high, all PE and PP releases (except ABC Fault) are given.

$$\underline{Z}_B = \frac{U_B}{I_B}$$

(Equation 23)

$$\underline{Z}_C = \frac{U_C}{I_C}$$

(Equation 24)

The phase-to-phase measuring elements are based on the formula:

$$\underline{Z}_{AB} = \frac{U_{AB}}{I_{AB}}$$

(Equation 25)

$$\underline{Z}_{BC} = \frac{U_{BC}}{I_{BC}}$$

(Equation 26)

$$\underline{Z}_{CA} = \frac{U_{CA}}{I_{CA}}$$

(Equation 27)

The faulted phase identification is done by comparing the measured impedance to the operating characteristics in the impedance domain. If a measured fault loop impedance is inside the characteristics, the corresponding phases are identified as faulty.

The shape of the characteristic is selected with the *Z Chr Mod Ph Sel GFC* setting. Two shapes are available.

- "Mho (circular)", Non-directional mho
- "Quadrilateral", Non-directional quadrilateral

The two shapes can be flexibly configured. It is possible to set the reactive reaches independently in forward and in reverse direction and for phase-to-earth (Gnd) and phase-to-phase (PP) measurement elements, for example, the *X Gnd Fwd reach GFC*, *X Gnd Rv reach GFC*, *X PP Fwd reach GFC* and *X PP Rv reach GFC* settings. Also, the resistive reach in case of quadrilateral characteristic can be set both forward and reverse independently of reactive reaches, for example, the *Ris Gnd Fwd Rch GFC*, *Ris Gnd Rv Rch GFC*, *Ris PP Fwd Rch GFC* and *Ris PP Rv Rch GFC* settings. The characteristic is always mirror-symmetric around the reactance axis.



The impedance settings are in primary ohms.

In case of heavy loaded feeders, the optional load encroachment logic can be enabled with the *Load Dsr mode GFC* setting. The logic reserves an area for load

impedance defined by the *Ris Fwd Rch Lod GFC*, *Ris Rv Rch Lod GFC* and *Angle load area GFC* settings.

The underimpedance characteristics in case of phase-to-earth measuring elements are illustrated in *Figure 279* and *Figure 280*. Similar characteristics apply also to phase-to-phase measuring elements with independent settings.

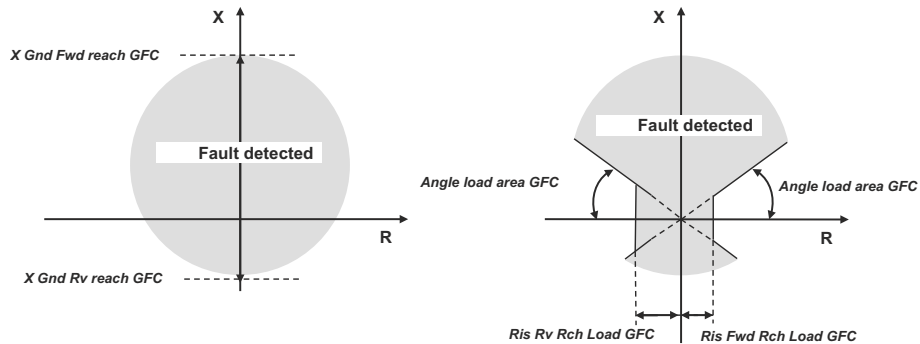


Figure 279: Circular mho underimpedance characteristics

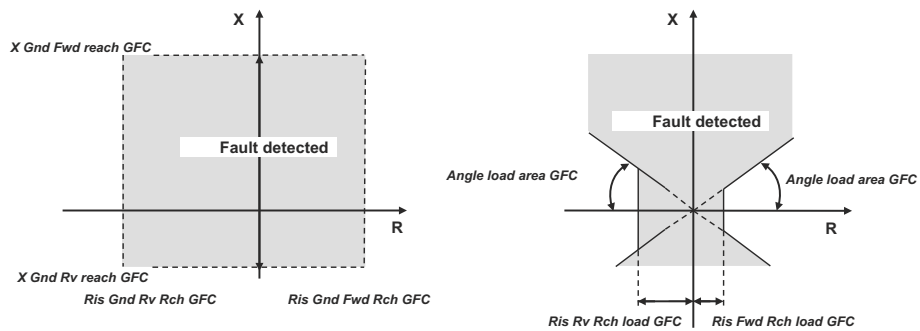


Figure 280: Quadrilateral underimpedance characteristics

Table 523: Conversion from element start to monitored data signals

| Start of element      | START_GFC | STARTS_GFC | RELEASE_P E | RELEASE_P P |
|-----------------------|-----------|------------|-------------|-------------|
| $Z_A < \& EARTH\_FLT$ | TRUE      | AG Fault   | AG Fault    | No fault    |
| $Z_B < \& EARTH\_FLT$ | TRUE      | BG Fault   | BG Fault    | No fault    |
| $Z_C < \& EARTH\_FLT$ | TRUE      | CG Fault   | CG Fault    | No fault    |
| $Z_{AB} <$            | TRUE      | AB Fault   | No fault    | AB Fault    |
| $Z_{BC} <$            | TRUE      | BC Fault   | No fault    | BC Fault    |
| $Z_{CA} <$            | TRUE      | CA Fault   | No fault    | CA Fault    |

Table continues on the next page

| Start of element  | START_GFC | STARTS_GFC | RELEASE_PE | RELEASE_PP |
|---|-----------|------------|------------|------------|
| Z <sub>AB</sub> < & EARTH_FLT   | TRUE      | AB Fault   | AB Fault   | AB Fault   |
| Z <sub>BC</sub> < & EARTH_FLT   | TRUE      | BC Fault   | BC Fault   | BC Fault   |
| Z <sub>CA</sub> < & EARTH_FLT   | TRUE      | CA Fault   | CA Fault   | CA Fault   |
| Z <sub>AB</sub> < & Z <sub>BC</sub> < & Z <sub>CA</sub> < <sup>75</sup>             | TRUE      | ABC Fault  | No fault   | ABC Fault  |
| Z <sub>AB</sub> < & Z <sub>BC</sub> < & Z <sub>CA</sub> < & EARTH_FLT <sup>76</sup> | TRUE      | ABC Fault  | No fault   | ABC Fault  |

In case of a high-impedance earthed network, a phase preference logic can be added to complement the phase selection in case of a cross-country fault. This can affect the RELEASE\_PE signals.

In case of a low-impedance earthed network, a faulted loop selection logic can be added to complement the phase selection in case of a two-phase-to-earth fault. This can affect the RELEASE\_PE and RELEASE\_PP monitored data signals.

#### Cross-country fault detection function for high-impedance earthed networks

In isolated and high-impedance earthed networks, the overvoltages produced by a single-phase earth fault may lead to a cross-country fault, where two simultaneous single-phase earth faults are present in the system but in different locations and phases. The cross-country fault is hazardous because the magnitude of the fault current through earth can be as high as in the case of a two-phase short circuit fault. The protection must therefore remove the cross-country fault quickly without sacrificing the selectivity. This can be done with a phase preference logic which is activated by the cross-country fault detection function. The phase preference logic transforms the fault into an ordinary single-phase earth fault by selectively tripping one of the faulted feeders.

The cross-country detecting function can become active only if the network is either isolated or high-impedance earthed (*System grounding GFC* = "High impedance" or selection "From input" and binary input SYS\_EARTHING is active).

The fault detection is based on monitoring two quantities.

- Residual current
- Phase-to-phase voltages

A cross-country fault is detected if:

- An earth fault is detected, EARTH\_FLT = TRUE.

AND

<sup>75</sup> This applies to near three-phase faults. If voltages are still relatively high, all PP releases are given, depending on the impedances seen inside the GFC zone.

<sup>76</sup> This applies to near three-phase faults with EF indication. If voltages are still relatively high, all or some PE and PP releases (except ABC Fault) are given, depending on the impedances seen inside the GFC zone.

- The calculated residual current exceeds the value of *Gnd Op A XC GFC* setting. This setting value should exceed the highest expected single-phase earth-fault current (calculated from phase currents). The condition is needed because the cable current transformer saturates easily due to the high fault current.

## AND

- The residual overcurrent condition must be valid at least for the duration defined by the *Cross-country DI GFC* setting. This shows that the detection is not misled by the high-magnitude initial transients of a single-phase earth fault.

## OR

- Any phase-to-phase voltage drops below the value of the *PP voltage XC GFC* setting. The undervoltage condition is based on the fact that during a single-phase earth fault, the phase-to-phase voltages are unaffected in isolated and highimpedance earthed networks. The fulfilment of this criterion in combination with the residual overcurrent condition avoids the need for any delays.

The detection of a cross-country fault is indicated by the `XC_FLT` output signal.

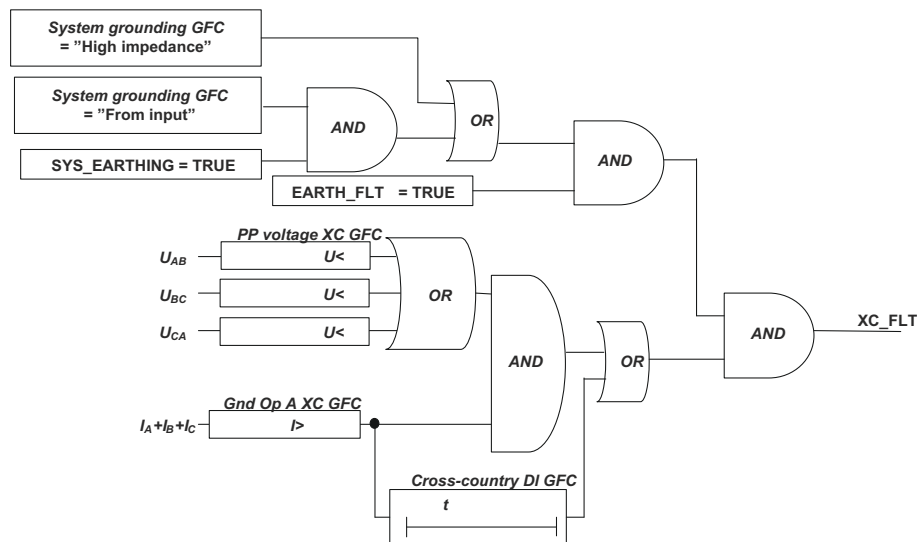


Figure 281: Cross-country fault detection logic for high-impedance earthed networks

### Phase preference logic for high-impedance earthed networks

The phase preference logic is applicable only in isolated and high-impedance earthed networks. The phase preference logic for high-impedance earthed networks is a supplement to the faulted phase identification function. It provides selective filtering of phase-to-earth measurement elements in case of a cross-country fault or double earth-fault in isolated and high-impedance earthed networks.

The logic releases the preferred phase-to-earth loop for measurement when a crosscountry fault with two faulted phase-to-earth loops is detected. If only one faulted phase-to-earth loop is detected by phase selection logic (GFC), the other faulted phase-to-earth loop is determined by analysing voltages. The phase preference scheme must be set in the same way for the entire system so that all distance relays measure the same preferred phase-to-earth loop. As a result, the cross-country fault is changed into an ordinary single-phase earth-fault by selectively tripping one of the faulted feeders.



The phase preference logic influences only the selection of the phase-earth loops and has no effect on the selection of the phase-to-phase loops. The influence is seen in the `RELEASE_PE` monitored data. The logic does not affect the `RELEASE_PP` monitored data or `START_GFC/STARTS_GFC` outputs.

All schemes, except "No filter", require a cross-country fault detection `XC_FLT = TRUE`; otherwise all the phase-to-earth measuring elements are blocked resulting in `RELEASE_PE` value "No fault". This guarantees that tripping at a single-phase earth fault in the high-impedance earthed network is blocked.

If a cross-country fault is detected, `XC_FLT = TRUE` and only a single fault loop can be identified as faulty by the faulted phase selection function, then that loop is directly selected for measurement. In such a case, simultaneous tripping of both faulted feeders during a cross-country fault is expected.

Example: Consider a cross-country fault where phases A and B become faulted simultaneously. All relays, R1, R2, R3 and R4, are equipped with an "Acyc C-A-B" phase preference scheme.

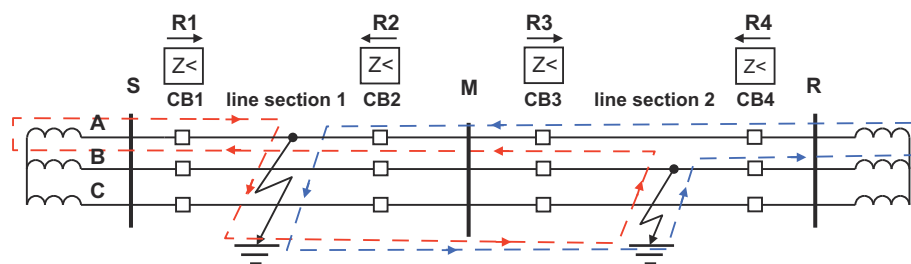


Figure 282: Cross-country fault (or double earth fault) in a high-impedance earthed system

The expected operations of the relays are:

- R1: The cross-country fault cannot be detected as the residual current does not flow through relay R1. The phase-to-phase loop AB is measured in the forward direction but the estimated impedance represents an average impedance between two fault locations and therefore is not seen in zone Z1.
- R2: The cross-country fault is detected as a large residual current flows through relay R2. Phase A earth fault is seen in forward direction and phase B earth fault in reverse direction. Based on "Acyc C-A-B" phase preference scheme, phase A is selected for measurement. Relay R2 operates without delay and opens the CB2 circuit breaker.
- R3: The cross-country fault is detected when a large residual current flows through relay R3. The phase A earth fault is seen in reverse direction and phase B earth fault in forward direction. Based on the "Acyc C-A-B" phase preference scheme, phase A is selected for measurement. As the fault direction does not coincide with the zone direction, relay R3 does not operate.
- R4: Same as relay R1

As a result of the circuit breaker CB2 operation, the cross-country fault is transformed into an ordinary single-phase earth fault.

Table 493, Table 494 and Table 495 summarize the available phase preference logic schemes and their operation in different fault scenarios. The logic is selected with the *Ph Prf mode Hi Z GFC* setting. In case the logic is not required, then the "No filter" option should be selected.



“No filter” option does not block the single-phase earth-faults, therefore this option should be used with caution.

**Table 524: Supported phase preference logic schemes for high-impedance earthed networks and their operation in case of single phase start with and without cross-country fault detection**

| Ph Prf mode Hi Z GFC |               | Faulted loops  |                |                |            |            |            |
|----------------------|---------------|----------------|----------------|----------------|------------|------------|------------|
|                      |               | A & EARTH_FL T | B & EARTH_FL T | C & EARTH_FL T | A & XC_FLT | B & XC_FLT | C & XC_FLT |
|                      |               | RELEASE_PE     |                |                | RELEASE_PP |            |            |
| 1                    | No filter     | AG Fault       | BG Fault       | CG Fault       | AG Fault   | BG Fault   | CG Fault   |
| 2                    | No preference | No fault       | No fault       | No fault       | AG Fault   | BG Fault   | CG Fault   |
| 3                    | Cyc A-B-C-A   | No fault       | No fault       | No fault       | AG Fault   | BG Fault   | CG Fault   |
| 4                    | Cyc A-C-B-A   | No fault       | No fault       | No fault       | AG Fault   | BG Fault   | CG Fault   |
| 5                    | Acyc A-B-C    | No fault       | No fault       | No fault       | AG Fault   | BG Fault   | CG Fault   |
| 6                    | Acyc A-C-B    | No fault       | No fault       | No fault       | AG Fault   | BG Fault   | CG Fault   |
| 7                    | Acyc B-A-C    | No fault       | No fault       | No fault       | AG Fault   | BG Fault   | CG Fault   |
| 8                    | Acyc B-C-A    | No fault       | No fault       | No fault       | AG Fault   | BG Fault   | CG Fault   |
| 9                    | Acyc C-A-B    | No fault       | No fault       | No fault       | AG Fault   | BG Fault   | CG Fault   |
| 10                   | Acyc C-B-A    | No fault       | No fault       | No fault       | AG Fault   | BG Fault   | CG Fault   |

**Table 525: Supported phase preference logic schemes for high-impedance earthed networks and their operation in case of two phase starts without cross-country fault detection**

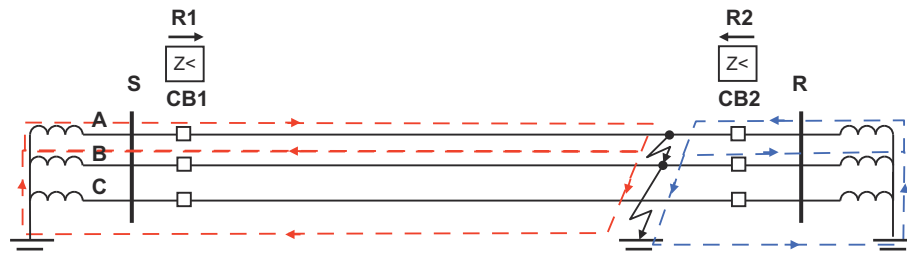
| Ph Prf mode Hi Z GFC |               | Faulted loops    |                  |                  |                  |                  |                  |
|----------------------|---------------|------------------|------------------|------------------|------------------|------------------|------------------|
|                      |               | A & B EARTH_FL T | B & C EARTH_FL T | C & A EARTH_FL T | A & B EARTH_FL T | B & C EARTH_FL T | C & A EARTH_FL T |
|                      |               | RELEASE_PE       |                  |                  | RELEASE_PP       |                  |                  |
| 1                    | No filter     | AB Fault         | BC Fault         | CA Fault         | AB Fault         | BC Fault         | CA Fault         |
| 2                    | No preference | No fault         | No fault         | No fault         | AB Fault         | BC Fault         | CA Fault         |
| 3                    | Cyc A-B-C-A   | No fault         | No fault         | No fault         | AB Fault         | BC Fault         | CA Fault         |
| 4                    | Cyc A-C-B-A   | No fault         | No fault         | No fault         | AB Fault         | BC Fault         | CA Fault         |
| 5                    | Acyc A-B-C    | No fault         | No fault         | No fault         | AB Fault         | BC Fault         | CA Fault         |
| 6                    | Acyc A-C-B    | No fault         | No fault         | No fault         | AB Fault         | BC Fault         | CA Fault         |
| 7                    | Acyc B-A-C    | No fault         | No fault         | No fault         | AB Fault         | BC Fault         | CA Fault         |
| 8                    | Acyc B-C-A    | No fault         | No fault         | No fault         | AB Fault         | BC Fault         | CA Fault         |
| 9                    | Acyc C-A-B    | No fault         | No fault         | No fault         | AB Fault         | BC Fault         | CA Fault         |
| 10                   | Acyc C-B-A    | No fault         | No fault         | No fault         | AB Fault         | BC Fault         | CA Fault         |

**Table 526: Supported phase preference logic schemes for high-impedance earthed networks and their operation in case of two phase starts with cross-country fault detection**

| Ph Pref logic Hi Imp |               | Faulted loops |              |              |              |              |              |
|----------------------|---------------|---------------|--------------|--------------|--------------|--------------|--------------|
|                      |               | A & B XC_FLT  | B & C XC_FLT | C & A XC_FLT | A & B XC_FLT | B & C XC_FLT | C & A XC_FLT |
|                      |               | RELEASE_PE    |              |              | RELEASE_PP   |              |              |
| 1                    | No filter     | AB Fault      | BC Fault     | CA Fault     | AB Fault     | BC Fault     | CA Fault     |
| 2                    | No preference | AB Fault      | BC Fault     | CA Fault     | AB Fault     | BC Fault     | CA Fault     |
| 3                    | Cyc A-B-C-A   | AB Fault      | BC Fault     | CA Fault     | AB Fault     | BC Fault     | CA Fault     |
| 4                    | Cyc A-C-B-A   | AB Fault      | BC Fault     | CA Fault     | AB Fault     | BC Fault     | CA Fault     |
| 5                    | Acyc A-B-C    | AB Fault      | BC Fault     | CA Fault     | AB Fault     | BC Fault     | CA Fault     |
| 6                    | Acyc A-C-B    | AB Fault      | BC Fault     | CA Fault     | AB Fault     | BC Fault     | CA Fault     |
| 7                    | Acyc B-A-C    | AB Fault      | BC Fault     | CA Fault     | AB Fault     | BC Fault     | CA Fault     |
| 8                    | Acyc B-C-A    | AB Fault      | BC Fault     | CA Fault     | AB Fault     | BC Fault     | CA Fault     |
| 9                    | Acyc C-A-B    | AB Fault      | BC Fault     | CA Fault     | AB Fault     | BC Fault     | CA Fault     |
| 10                   | Acyc C-B-A    | AB Fault      | BC Fault     | CA Fault     | AB Fault     | BC Fault     | CA Fault     |

**Faulted loop phase selection for low-impedance earthed networks**

The faulted loop selection logic for low-impedance earthed networks serves as a supplement to the faulted phase identification function and it provides a selective filtering of measurement elements in case of a two-phase-to-earth fault in low-impedance earthed networks. The earth faults can be located close to each other.



*Figure 283: Two-phase-to-earth fault in low-impedance earthed system*

Impedance can be measured during a two-phase-to-earth fault when the earth faults are located in the same direction and they are in close proximity to each other. Generally, too large an impedance is measured for the lagging phase-to-earth loop, for example phase B in an AB-E fault. Similarly, low impedance is measured for the leading phase-to-earth loop, for example phase A in an AB-E fault. The corresponding phase-to-phase loop is measured correctly, for example phase-to-phase loop AB in an AB-E fault.

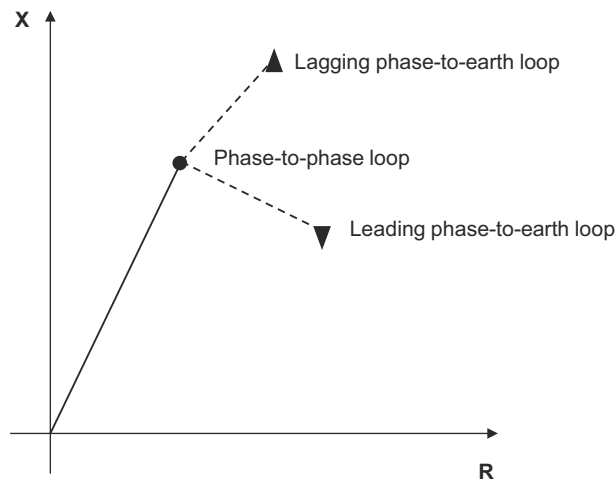


Figure 284: Impedance measured during a two-phase-to-earth fault

The available faulted loop selection logic schemes allow blocking the phase-earth loop of the leading phase to prevent overreaching *Ph Prf mode Lo Z GFC* = "BLK leading PE".

It is also possible to block the lagging phase-earth loop, *Ph Prf mode Lo Z GFC* = "BLK lagging PE". If only the phase-to-phase loop or phase-to-earth loops must be measured, settings *Ph Prf mode Lo Z GFC* = "PP only" or *Ph Prf mode Lo Z GFC* = "PE only" should be used, and if the logic is not required, "All loops" option should be selected.

The tables summarize the available faulted loop selection logic schemes and their operations. The logic is selected with the *Ph Prf mode Lo Z GFC* setting.

**Table 527: Supported faulted loop phase selection schemes for low-impedance earthed networks and their influence on the RELEASE\_PE monitored data**

| Element start     | Ph Prf mode Lo Z GFC |          |          |                |                |
|-------------------|----------------------|----------|----------|----------------|----------------|
|                   | All loops            | PE only  | PP only  | BLK leading PE | BLK lagging PE |
| <b>RELEASE_PE</b> |                      |          |          |                |                |
| A & B & EARTH_FLT | AB Fault             | AB Fault | No fault | BG Fault       | AG Fault       |
| B & C & EARTH_FLT | BC Fault             | BC Fault | No fault | CG Fault       | BG Fault       |
| C & A & EARTH_FLT | CA Fault             | CA Fault | No fault | AG Fault       | CG Fault       |

**Table 528: Supported faulted loop phase selection schemes for low-impedance earthed networks and their influence on the RELEASE\_PP monitored data**

| Element start     | Ph Prf mode Lo Z GFC |          |          |                |                |
|-------------------|----------------------|----------|----------|----------------|----------------|
|                   | All loops            | PE only  | PP only  | BLK leading PE | BLK lagging PE |
| RELEASE_PP        |                      |          |          |                |                |
| A & B & EARTH_FLT | AB Fault             | No fault | AB Fault | AB Fault       | AB Fault       |
| B & C & EARTH_FLT | BC Fault             | No fault | BC Fault | BC Fault       | BC Fault       |
| C & A & EARTH_FLT | CA Fault             | No fault | CA Fault | CA Fault       | CA Fault       |

**Impedance protection zones**

DSTPDIS has five flexible and configurable impedance zones Z1..Z5. The number of active zones has to be selected by setting *Select active zones*. For example, all five zones can be set active by selection "All 5 zones" and only zone 1 is activated by "Zone 1". The purpose of this setting is effectively dimming non-active zone settings in PCM600 or the protection relay's HMI.

Example: If only zones 1 and 3 should be activated, "Zones 1-3" should be selected and then zone 2 timers can be disabled or BLOCK\_Z2 can be activated to hide zone 2 operations.

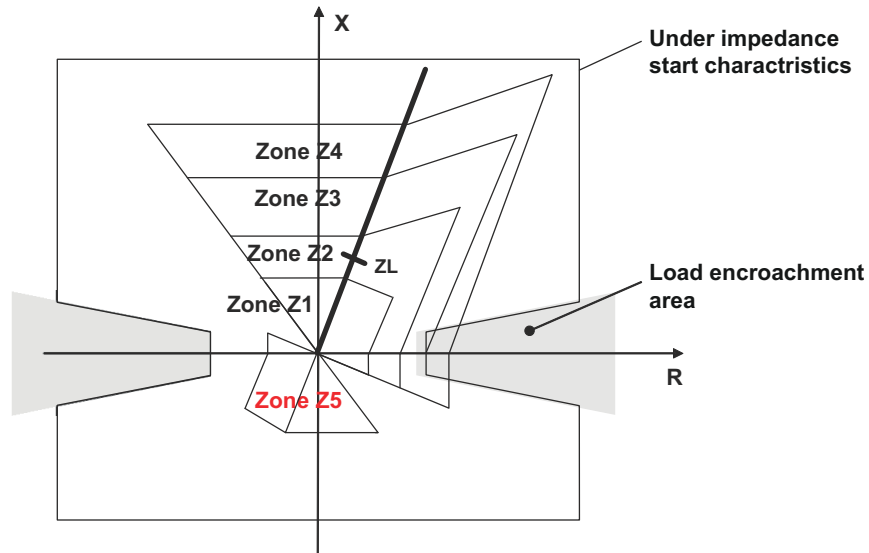


Figure 285: Zones of DSTPDIS function (example 1)

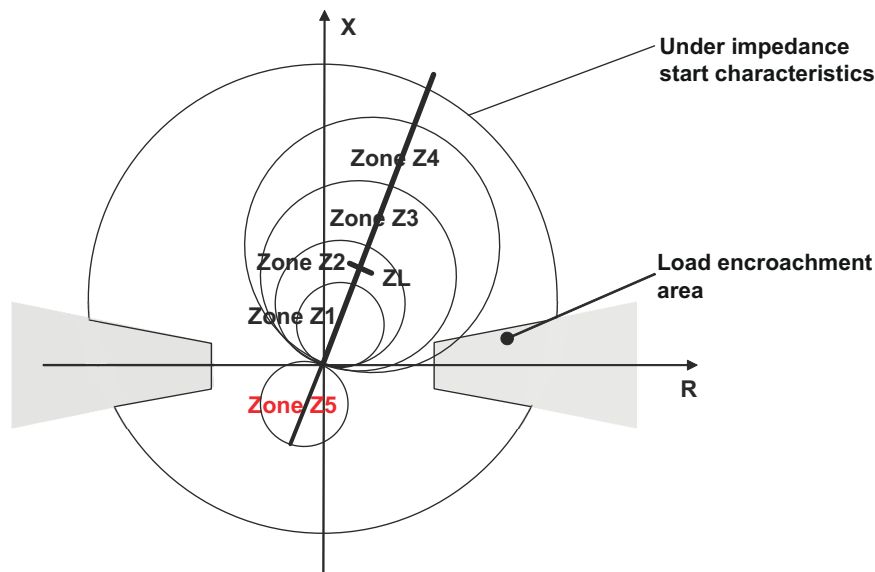


Figure 286: Zones of DSTPDIS function (example 2)

Each zone in DSTPDIS provides three independent phase-to-earth and three phase-to-phase measuring elements. A three-phase fault is measured with a dedicated measuring element. Each measuring element is controlled by the faulted loop phase selection function. Based on the recognized fault type, the release signals are given for the corresponding measuring elements.

DSTPDIS supports both fault detection dependent control of zone timers and zonededicated timer control for maximum application flexibility. Zone-dedicated timer control is enabled when configuration parameter *Zone timer mode* is set to "Independent" (change requires relay reboot). In this case, operate delay timers of protection zones are independent of each other and start when a fault is seen in their protection zone. Fault detection dependent control of zone timers is enabled when *Zone timer mode* is set to "Common". In this case, operate delay timers of all protection zones start simultaneously as soon as the fault is seen by the GFC. The operation of a particular zone is given after the set *Operate delay GFC* (considering the fault type) is detected. The actual operate time is the value calculated from the initial fault detection and it is not affected, for example, in case the fault moves between zones.

The general indication of fault for each zone is given in the *START\_Zx* ( $x = 1...5$ ) binary output. The faulted phase information can be found from the *STARTS\_Zx* ( $x = 1... 5$ ) integer type output signal. This signal indicates (bitwise) the started measuring elements for the corresponding phase. Value 0 does not exist but due to the IEC 61850 standard requirement, it is shown by value "-5" as "No fault". Value range is thus -5, 1..63. The three-phase fault is here indicated by "AB Fault, BC Fault, CA Fault". However, three-phase fault indication for GFC depends also on the additional condition for voltage (see Table 491).

Table 529: STARTS\_Zx information

| Value | Value information |
|-------|-------------------|
| -5    | No zone starts    |
| 1     | AG Fault          |
| 2     | BG Fault          |

Table continues on the next page

| Value | Value information                                |
|-------|--|
| 3     | AG Fault, BG Fault                               |
| 4     | CG Fault   |
| 5     | AG Fault, CG Fault                               |
| 6     | BG Fault, CG Fault                               |
| 7     | AG Fault, BG Fault, CG Fault                     |
| 8     | AB Fault   |
| 9     | AG Fault, AB Fault                               |
| 10    | BG Fault, AB Fault                               |
| 11    | AG Fault, BG Fault, AB Fault                     |
| 12    | CG Fault, AB Fault                               |
| 13    | AG Fault, CG Fault, AB Fault                     |
| 14    | BG Fault, CG Fault, AB Fault                     |
| 15    | AG Fault, BG Fault, CG Fault, AB Fault           |
| 16    | BC Fault   |
| 17    | AG Fault, BC Fault                               |
| 18    | BG Fault, BC Fault                               |
| 19    | AG Fault, BG Fault, BC Fault                     |
| 20    | CG Fault, BC Fault                               |
| 21    | AG Fault, CG Fault, BC Fault                     |
| 22    | BG Fault, CG Fault, BC Fault                     |
| 23    | AG Fault, BG Fault, CG Fault, BC Fault           |
| 24    | AB Fault, BC Fault                               |
| 25    | AG Fault, AB Fault, BC Fault                     |
| 26    | BG Fault, AB Fault, BC Fault                     |
| 27    | AG Fault, BG Fault, AB Fault, BC Fault           |
| 28    | CG Fault, AB Fault, BC Fault                     |
| 29    | AG Fault, CG Fault, AB Fault, BC Fault           |
| 30    | BG Fault, CG Fault, AB Fault, BC Fault           |
| 31    | AG Fault, BG Fault, CG Fault, AB Fault, BC Fault |
| 32    | CA Fault   |
| 33    | AG Fault, CA Fault                               |
| 34    | BG Fault, CA Fault                               |
| 35    | AG Fault, BG Fault, CA Fault                     |
| 36    | CG Fault, CA Fault                               |
| 37    | AG Fault, CG Fault, CA Fault                     |
| 38    | BG Fault, CG Fault, CA Fault                     |
| 39    | AG Fault, BG Fault, CG Fault, CA Fault           |
| 40    | AB Fault, CA Fault                               |
| 41    | AG Fault, AB Fault, CA Fault                     |
| 42    | BG Fault, AB Fault, CA Fault                     |
| 43    | AG Fault, BG Fault, AB Fault, CA Fault           |

*Table continues on the next page*

| Value | Value information  |
|-------|--|
| 44    | CG Fault, AB Fault, CA Fault                               |
| 45    | AG Fault, CG Fault, AB Fault, CA Fault                     |
| 46    | BG Fault, CG Fault, AB Fault, CA Fault                     |
| 47    | AG Fault, BG Fault, CG Fault, AB Fault, CA Fault           |
| 48    | BC Fault, CA Fault   |
| 49    | AG Fault, BC Fault, CA Fault                               |
| 50    | BG Fault, BC Fault, CA Fault                               |
| 51    | AG Fault, BG Fault, BC Fault, CA Fault                     |
| 52    | CG Fault, BC Fault, CA Fault                               |
| 53    | AG Fault, CG Fault, BC Fault, CA Fault                     |
| 54    | BG Fault, CG Fault, BC Fault, CA Fault                     |
| 55    | AG Fault, BG Fault, CG Fault, BC Fault, CA Fault           |
| 56    | AB Fault, BC Fault, CA Fault                               |
| 57    | AG Fault, AB Fault, BC Fault, CA Fault                     |
| 58    | BG Fault, AB Fault, BC Fault, CA Fault                     |
| 59    | AG Fault, BG Fault, AB Fault, BC Fault, CA Fault           |
| 60    | CG Fault, AB Fault, BC Fault, CA Fault                     |
| 61    | AG Fault, CG Fault, AB Fault, BC Fault, CA Fault           |
| 62    | BG Fault, CG Fault, AB Fault, BC Fault, CA Fault           |
| 63    | AG Fault, BG Fault, CG Fault, AB Fault, BC Fault, CA Fault |



The operate signal from each zone is the `OPERATE_Zx` ( $x = 1...5$ ) binary output signal.

The output from each zone can be blocked and the timers are also reset with the `BLOCK_Zx` ( $x = 1...5$ ) binary input signal.

The `TLT_ANG_CONFLICT` monitored data is an assisting integer output which supervises the validity of a tilt angle of quadrilateral characteristics so that the characteristics always produce a closed boundary.

#### *Impedance measurement*

DSTPDIS provides three independent phase-to-earth and phase-to-phase measuring elements per zone. The three-phase fault is measured with a dedicated measurement element.

The impedance measurement is done similarly regardless of the zone shape. The operation is based on impedance mapping where the fault loop impedance is first calculated and then compared with the zone boundaries. If impedance is recognized inside the operation zone, the corresponding operate output is activated after the operate time has elapsed.



### Phase-to-earth impedance measuring elements

The phase-to-earth impedance measuring elements provide the basic earth-fault protection in direct or low-impedance earthed networks. The earth-fault protection is enabled with the setting *Op Mod Gnd loops Znx* ( $x = 1...5$ ) = "True". The enabling requires that all three phase-to-earth voltages are measured. Otherwise, the release of the earth-fault measuring elements is automatically blocked.

The reach of phase-to-earth measuring elements is based on loop impedance

$$\underline{Z}_1 + \underline{Z}_N + R_F = (R_1 + (R_0 - R_1)/3) + j \cdot (X_1 + (X_0 - X_1)/3) + R_F$$

(Equation 28)



The earth return path impedance is included in the calculated fault loop impedance of the phase-to-earth measuring element.

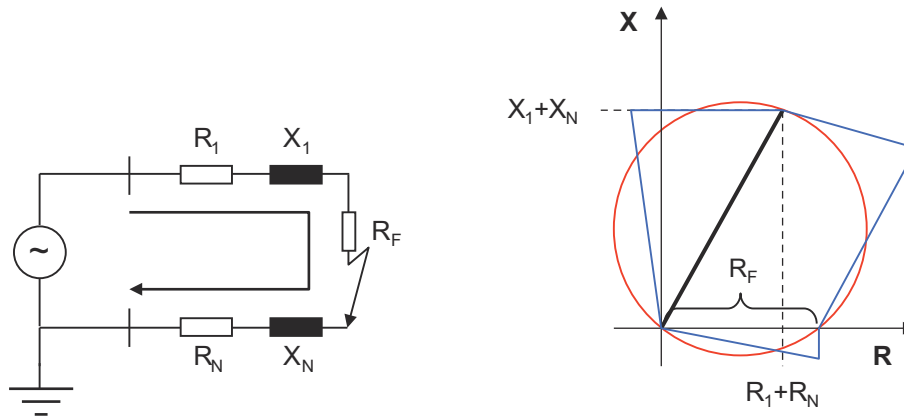


Figure 287: The fault loop impedance model for phase-to-earth impedance measuring elements

- $R_1$  Positive-sequence resistance from measuring point to fault location
- $X_1$  Positive-sequence reactance from measuring point to fault location
- $R_N$  Earth return path resistance =  $(R_0 - R_1)/3$  from measuring point to fault location
- $X_N$  Earth return path reactance =  $(X_0 - X_1)/3$  from measuring point to fault location
- $R_0$  Zero-sequence resistance from measuring point to fault location
- $X_0$  Zero-sequence reactance from measuring point to fault location
- $R_F$  Physical fault resistance between phase and earth (includes arc and earthing resistances)

Considering the load in case of a single line-to-earth fault, conventional distance protection might overreach at the exporting end and underreach at the importing end. DSTPDIS has a load compensation functionality which increases the security in such applications. Load compensation is enabled with the setting *Load Comp zone x* ( $x = 1...5$ ) = "True".



Load compensation is used only with single phase-to-earth faults. Load compensation is not used if multiple phases are included in the fault (more than one single earth fault release).

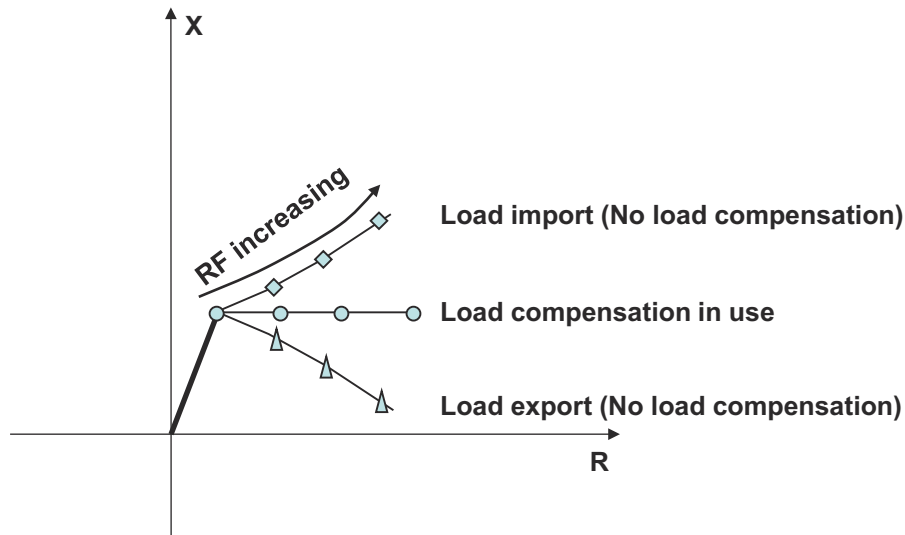


Figure 288: Operation principle of load compensation functionality

When three-phase feeders are placed close to each other, a mutual inductive zero-sequence coupling of the current path exists. This has an impact during earth faults. If no measures are taken, this leads to errors in the impedance calculation. The residual current of the parallel line induces a voltage in the protection line and changes the measured voltage at the relay location. The influence depends on the system configuration, that is, the magnitude and polarity of the residual current in a parallel line.

The phase-to-earth impedance measuring elements in DSTPDIS take the zero-sequence mutual coupling into account in impedance calculation. The compensation is enabled and set with settings *Par line Comp zone x* (= "True"), *Mutual RO zone x* and *Mutual XO zone x* ( $x = 1...5$ ). The residual current of the parallel line must be available and connected to the  $I_{3P\_PAR}$  input. The earth-current balance logic is implemented to prevent malfunctioning of the protection relay on the healthy parallel line. This means that the parallel compensation functionality is internally blocked when the ratio between residual current of the parallel line and protected lines exceeds the *Fact EF current Bal* configuration setting.



The parallel line compensation functionality is only used with single phase-to-earth faults. Parallel line compensation is not used if multiple phases are included into fault (more than one single earth fault releases).

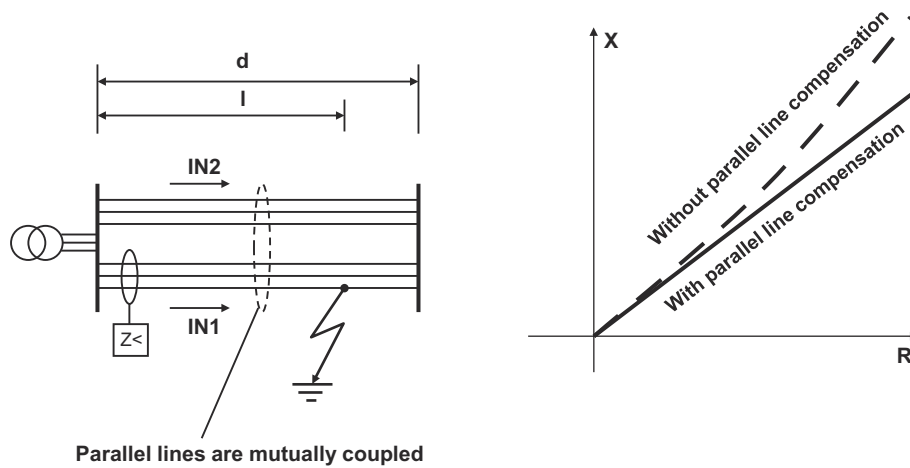


Figure 289: Operation principle of parallel line compensation functionality

The operation time delay is defined with the *Gnd operate DI Znx* (x = 1...5) setting. The timer can be disabled with the *Gnd Op DI mode Znx* = "False" setting. This blocks the OPERATE\_Zx (x = 1...5) output of the phase-to-earth measuring elements.

*Phase-to-phase impedance measuring elements*

The phase-to-phase distance protection is suitable as a basic protection function against two-phase short circuit faults in various networks, regardless of the treatment of the neutral point. The short circuit fault protection is enabled with the *Op Mod PP loops Znx* (x = 1...5) = "True" setting.

The reach of the phase-to-phase measuring elements is based on the loop impedance

$$\underline{Z}_{-1} + \frac{R_F}{2} = R_1 + j \cdot X_1 + \frac{R_F}{2}$$

(Equation 29)

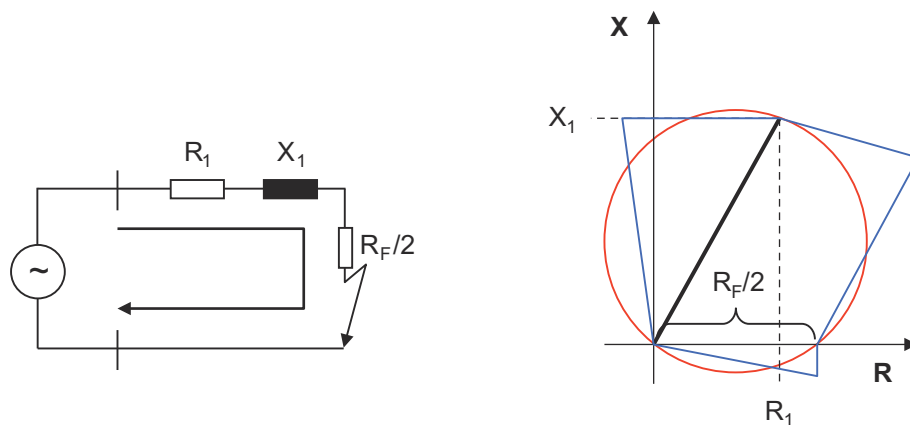


Figure 290: The fault loop impedance model for phase-to-phase impedance measuring elements

- $R_1$  Positive-sequence resistance from measuring point to fault location.
- $X_1$  Positive-sequence reactance from measuring point to fault location.
- $R_F$  Physical fault resistance between phases, for example, arc resistance.



The phase-to-phase impedance measuring elements measure only half of the physical fault resistance between phases. This must be taken into account when the resistive reach of the phase-to-phase elements is set (that is, setting the value of 5 Ω corresponds 5+5=10 Ω of physical arc resistance between phases).

The resistive reach setting is common for phase-to-phase and three-phase impedance measuring elements.

The operation time delay is defined with the setting *PP operate delay Znx* ( $x = 1... 5$ ). The timer can be disabled with the setting *PP Op delay Mod Znx* = "False". This blocks the *OPERATE\_Zx* ( $x = 1... 5$ ) output of the phase-to-phase measuring elements.

*Three-phase impedance measuring element*

DSTPDIS has a dedicated measuring element for a three-phase short circuit fault for each zone. The three-phase measuring element uses the positive-sequence quantities for a fault loop impedance estimation which increases the accuracy by reducing the influence of line parameter asymmetry. This is advantageous especially in case of non-transposed, asymmetrical lines. The three-phase impedance measuring element is enabled together with the phase-to-phase impedance elements by the setting *Op Mod PP loops Znx* ( $x = 1... 5$ ) = "True".

The reach of the three-phase measuring element is based on the loop impedance:

Three-phase measuring element reach

$$Z_1 + R_F = R_1 + j X_1 + R_F$$

(Equation 30)

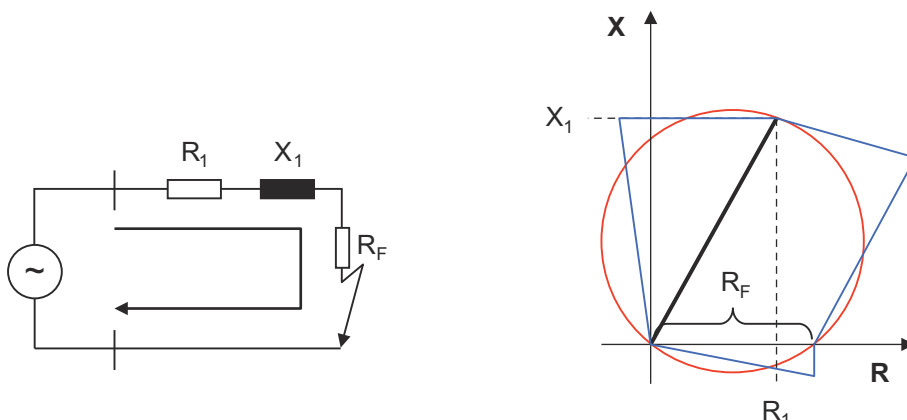


Figure 291: The fault loop impedance model for three-phase impedance measuring element

- $R_1$  Positive-sequence resistance from measuring point to fault location
- $X_1$  Positive-sequence reactance from measuring point to fault location.
- $R_F$  Physical fault resistance per phase, for example, arc resistance.



The three-phase impedance measuring element measures the physical fault resistance per phase. The resistive reach setting is common for three-phase and phase-to-phase impedance measuring elements.

The time delay of operation is defined with the *PP operate delay Znx* ( $x = 1...5$ ) setting. The timer can be disabled with the setting *PP Op delay Mod Znx* = "False". This blocks the *OPERATE\_Zx* ( $x = 1...5$ ) output of the three-phase measuring elements.

#### Entering the line reach

The line reach is entered in primary ohms. The impedance format is selected with *Impedance mode Zn* = "Rectangular" for the vectors R, X and "Polar" for the magnitude and angle.

#### Impedance mode Zn = Rectangular

In case of phase-to-phase or three-phase impedance measuring elements, the line reach is defined with:

- Resistive reach: *R1 zone x* ( $x = 1...5$ )
- Reactive reach: *X1 zone x* ( $x = 1...5$ )

In case of non-directional characteristics, the reactive reach in reverse direction is defined with the *X1 reverse zone x* ( $x = 1...5$ ) setting. The characteristic line angle, denoted as  $\alpha$ , is the same for both forward and reverse direction.

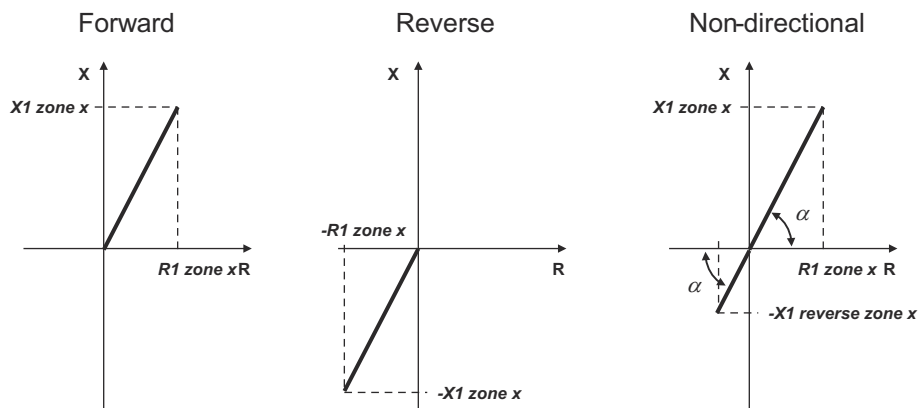


Figure 292: Settings which define the line reach for phase-to-phase or three-phase impedance measuring elements if *Impedance mode Zn* = "Rectangular"

In case of phase-to-earth impedance measuring elements, the line reach is defined with:

- Resistive reach :  $(2 \cdot R1 \text{ zone } x + R0 \text{ zone } x) / 3$ , ( $x = 1...5$ )
- Reactive reach :  $(2 \cdot X1 \text{ zone } x + X0 \text{ zone } x) / 3$ , ( $x = 1...5$ )

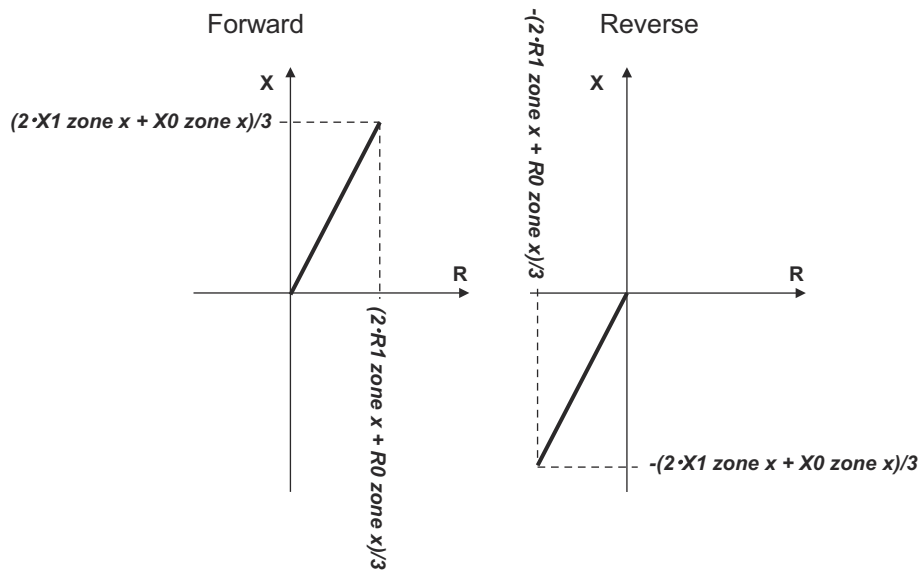


Figure 293: Settings which define the line reach for phase-to-earth impedance measuring elements if Impedance mode Zn = "Rectangular", forward or reverse directionality

In case of non-directional characteristics, the reactive reach in reverse direction is defined with the X1 reverse zone x (x = 1...5) setting. The total reactive reach in reverse direction includes a part which is common to both forward and reverse direction. This part is automatically calculated based on the values of the settings R1 zone x, R0 zone 0, X1 zone x and X0 zone x. The characteristic line angle, denoted as α, is the same for forward and reverse direction.

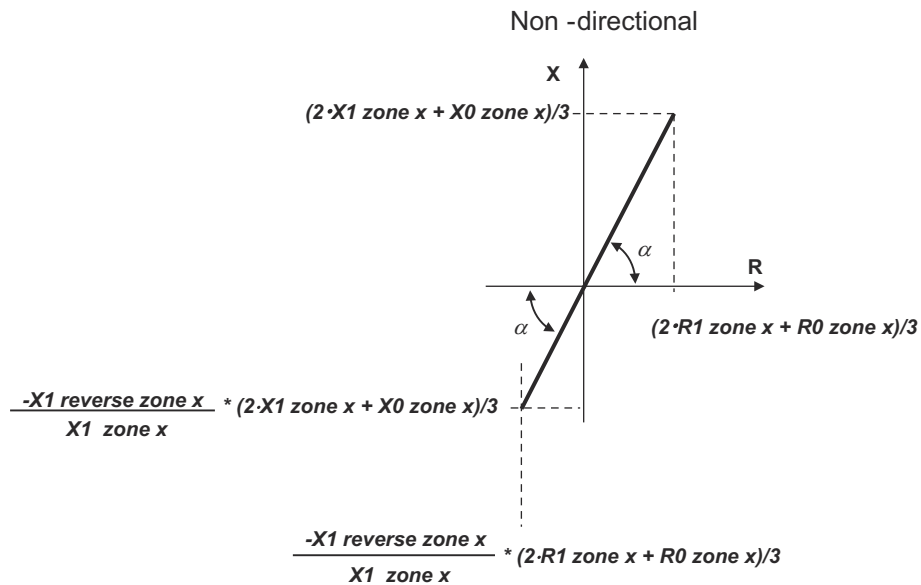


Figure 294: Settings which define the line reach for phase-to-earth impedance measuring elements if Impedance mode Zn = "Rectangular", non-directional directionality

### Impedance mode $Z_n = \text{Polar}$

In case of phase-to-phase or three-phase impedance measuring elements, the line reach is defined with:

- $Z1 \text{ zone } x$  ( $x = 1...5$ )
- $Z1 \text{ angle zone } x$  ( $x = 1...5$ )

In case of non-directional characteristics, the reactive reach magnitude in reverse direction is defined with the  $Z1 \text{ reverse zone } x$  ( $x = 1...5$ ) setting. The characteristic line angle,  $Z1 \text{ angle zone } x$ , is the same for forward and reverse direction.

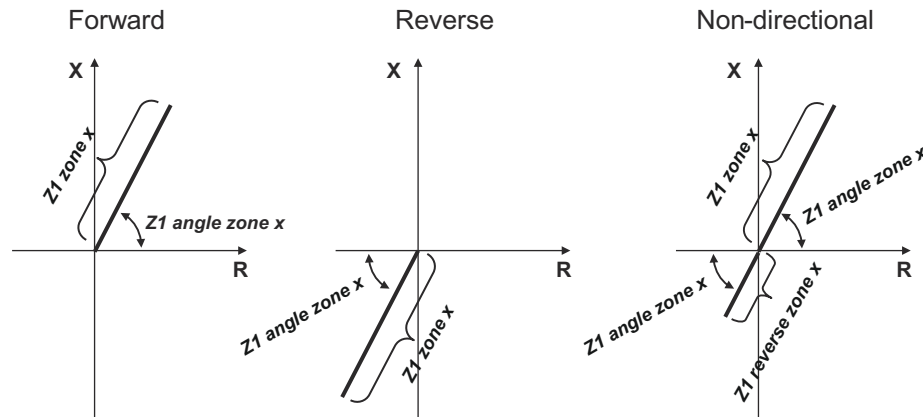


Figure 295: Settings which define the line reach for phase-to-phase or three-phase impedance measuring elements if Impedance mode  $Z_n = \text{"Polar"}$

In case of phase-to-earth impedance measuring elements, the line reach is defined with:

- $Z1 \text{ zone } x$  ( $x = 1...5$ )
- $Z1 \text{ angle zone } x$  ( $x = 1...5$ )
- $\text{Factor } K0 \text{ zone } x$  ( $x = 1...5$ )
- $\text{Factor } K0 \text{ angle } Z_n x$  ( $x = 1...5$ )

The reach magnitude and angle are:

$$\text{Magnitude} = \text{abs}(\underline{Z1} + \underline{Z1} \times \underline{K_N})$$

(Equation 31)

$$\text{Angle} = \text{angle}(\underline{Z1} + \underline{Z1} \underline{K_N})$$

$$\underline{Z1} = Z1 \text{ zone } x (\cos(Z1 \text{ angle zone } x) + j \sin(Z1 \text{ angle zone } x))$$

$$\underline{K_N} = \text{Factor } K0 \text{ zone } x (\cos(\text{Factor } K0 \text{ angle } z_n x) + j \sin(\text{Factor } K0 \text{ angle } z_n x))$$

(Equation 32)

In case of non-directional characteristics, the reactive reach in reverse direction is defined with the  $Z1 \text{ reverse zone } x$  ( $x = 1...5$ ) setting.

$$\underline{Z}_{1R} = Z_{1\text{reverse zone}} x (\cos(Z_{1\text{angle zone}}) + j \sin(Z_{1\text{angle zone}}))$$

(Equation 33)

The total reactive reach in reverse direction includes a part which is defined by the residual compensation factor  $K_N$ . The characteristic line angle, denoted as  $\alpha$ , is the same for forward and reverse direction.

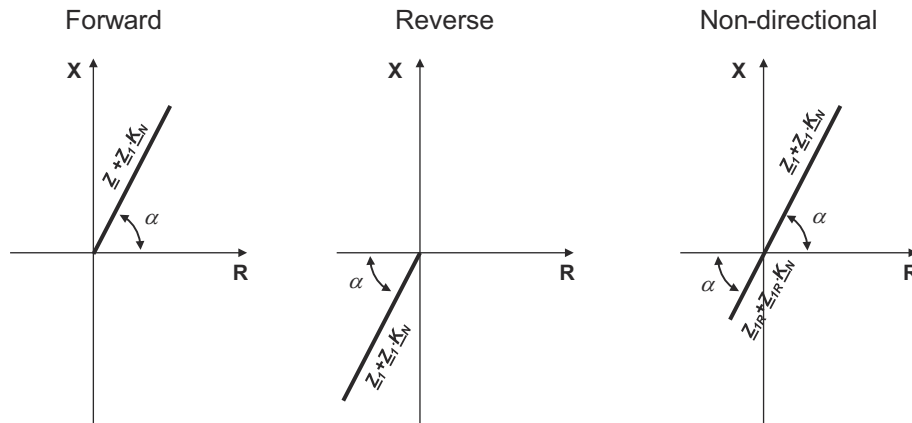


Figure 296: Settings which define the line reach for phase-to-earth impedance measuring elements if Impedance mode  $Z_n = \text{"Polar"}$

*Protection zone characteristics*

DSTPDIS has both “Quadrilateral” and “Mho (circular)” characteristics available for the protection zones and they can be combined also with the bullet characteristic. The shape of a tripping characteristic can be set independently for phase-to-earth, phase-to-phase or three-phase impedance elements. The zone shape is defined with the *Impedance Chr Gnd Zn* setting for phase-to-earth impedance elements, and with the *Impedance Chr PP Zn* setting for phase-to-phase or three-phase impedance elements. The alternatives are "Quadrilateral", "Mho (circular)", "Mho Dir line", "Offset Dir line" and "Bullet (combi)".

All impedance values defining the zone shape are entered in primary ohms. Angles are given in degrees.

*Quadrilateral characteristic*

If the zone has the "Quadrilateral" shape, DSTPDIS has a polygonal tripping characteristic.



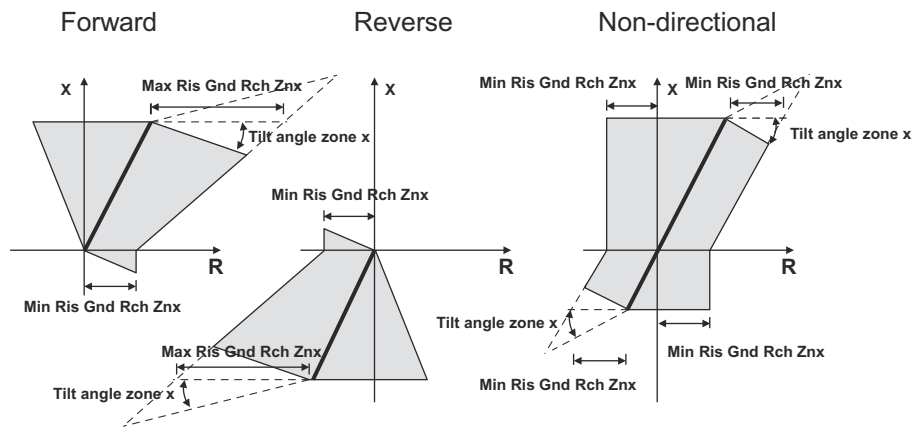


Figure 297: Tripping characteristic for phase-to-earth impedance elements if the zone shape is quadrilateral. The tilt angle is set to compensate for possible under- or overreaching.

The reach in the reactive direction is defined by the line reach independently for phase-to-earth and for phase-to-phase/three-phase elements. The resistive reach is defined at the minimum and maximum resistive reach with settings *Min Ris Gnd Rch Znx*, *Max Ris Gnd Rch Znx*, *Min Ris PP Rch Znx*, *Max Ris PP Rch Znx* ( $x = 1...5$ ). In case of a non-directional zone, only settings *Min Ris Gnd Rch Znx* and *Min Ris PP Rch Znx* ( $x = 1...5$ ) are valid. The resistive reach can be set independently for phase-to-earth and for phase-to-phase or three-phase elements.

In case of phase-to-earth impedance elements, the resistive reach value corresponds to the physical fault resistance between phase and earth including arc and earthing resistance.

The reactive reach can be adjusted by tilting the top reactance boundary line by an angle defined with *Tilt angle zone x* ( $x = 1...5$ ). The negative value decreases the tripping zone area while the positive value increases the tripping area. The negative value is used in case of underreaching zones to compensate a possible overreaching. The positive value is used in case of overreaching zones to compensate a possible underreaching.

Compensation of over-reaching with under-reaching zone  
*Tilt angle zone x < 0 deg.*

Compensation of under-reaching with over-reaching zone  
*Tilt angle zone x > 0 deg.*

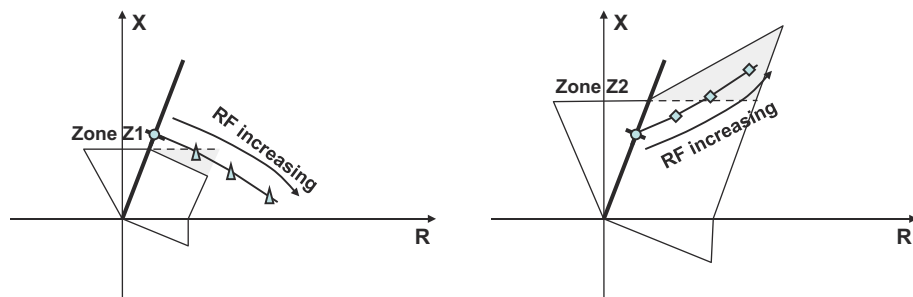


Figure 298: Operation principle of top reactance line tilting

The tilt angle must be carefully set. If the tilt angle has been set to a value where polygon boundaries do not form a close loop for an element, an internal mechanism modifies the tilt angle for that element so that the polygon boundary is always closed. If the set tilt angle is suitable for another element, the tilt angle

of that element is not internally modified. Tilt angle conflicts are monitored by TLT\_ANG\_CONFLICT value. This integer value is a ten-bit value indicating tilt angle modifications per zone and fault type.

**Table 530: TLT\_ANG\_CONFLICT description**

| TLT_ANG_CONFLICT bit field | Description  |
|----------------------------|--|
| (MSB) xx xx xx xx YZ (LSB) | Y active = Zone 1 earth-fault impedance element tilt angle modified<br>Z active = Zone 1 short circuit impedance element tilt angle modified |
| (MSB) xx xx xx YZ zz (LSB) | Y active = Zone 2 earth-fault impedance element tilt angle modified<br>Z active = Zone 2 short circuit impedance element tilt angle modified |
| (MSB) xx xx YZ xx xx (LSB) | Y active = Zone 3 earth-fault impedance element tilt angle modified<br>Z active = Zone 3 short circuit impedance element tilt angle modified |
| (MSB) xx YZ xx xx xx (LSB) | Y active = Zone 4 earth-fault impedance element tilt angle modified<br>Z active = Zone 4 short circuit impedance element tilt angle modified |
| (MSB) YZ xx xx xx xx (LSB) | Y active = Zone 5 earth-fault impedance element tilt angle modified<br>Z active = Zone 5 short circuit impedance element tilt angle modified |

For example, TLT\_ANG\_CONFLICT value "36" = "00 00 10 01 00" indicates that the tilt angles of the zone 2 earth-fault impedance element and zone 3 short circuit or three-phase impedance element have been modified. These zone settings should be checked to see whether a non-zero TLT\_ANG\_CONFLICT value has been found although, internally, the polygon boundary has been closed for existing settings.

#### *Directional lines*

The direction of a zone is defined with setting *Directional mode Znx* = "Nondirectional", "Forward" or "Reverse". The directionality of each zone can be set independently of other zones. For example, zones Z1 and Z2 can be set in the "Forward" direction and Z3 in the "Reverse" direction. Furthermore, the optionally supervised earth-fault directional criteria (in low-impedance earthed networks) given for GFC are checked here together with zone direction criteria fulfilment.

The directionality of a quadrilateral zone is defined with two independent directional lines. The directional lines can be included into the mho characteristics to secure the directionality or to transform the non-directional mho characteristic into a directional one.

The directional lines are adjusted with the *Min phase angle zone* and *Max phase angle zone* settings, which are common for all the zones. The angles are given in

degrees. The directional lines are polarized with the *Pol quantity zone* method. By default, the polarization method is positive-sequence voltage ("Pos. seq. volt.").

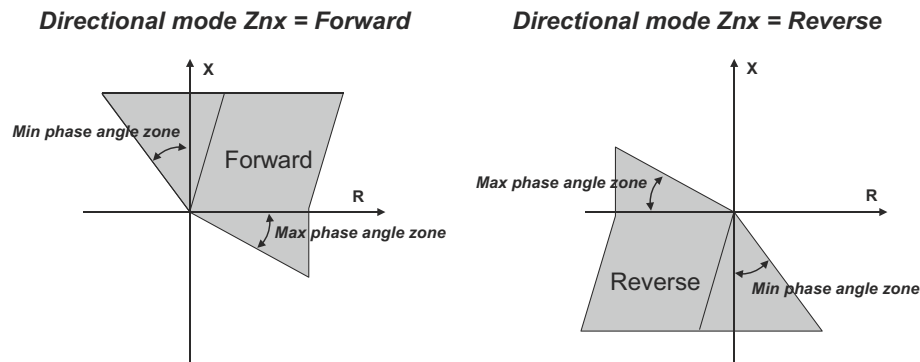


Figure 299: Settings that adjust directional lines in case of quadrilateral characteristics

The calculated direction of the fault or load (if there is no fault present) current is indicated in the monitored data DIRECTION = "unknown", "forward", "backward" or "both". It is important to check setting *X1 reverse zone x* (or *Z1 reverse zone x* reactance part) for quadrilateral directional characteristics (see [Figure 291](#) and the corresponding phase-to-earth impedance given in [Figure 293](#)) so that it does not restrict the negative-reactance reach defined by settings *Min Ris Gnd/PP Rch Znx* and *Max phase angle zone*.

#### Memory voltage

The memory voltage is based on the healthy positive-sequence voltage stored during the network healthy state. This fictive voltage is substituted for the measured voltage with any impedance measurement element polarization if the corresponding voltage drops too low (limit is 5%  $U_n$ ). Fictive voltage use is indicated by the active monitored data output VMEM\_USED. The polarized impedance direction for a corresponding impedance element is frozen after a fixed 100 ms of fictive voltage use, but the memory function enables impedance polarization to operate up to a maximum of 300 s. This time can be set with the *Voltage Mem time* setting. After set *Voltage Mem time* elapses, fictive voltage (and frozen impedance direction) can no more be used without memory refreshment by a healthy positive-sequence voltage and also the frozen impedance direction is reset.



Switch onto fault function (CVPSOF) should be used together with distance protection. CVPSOF accelerates and secures the operation of the protection if a close-in three-phase fault is detected immediately after circuit breaker closing.

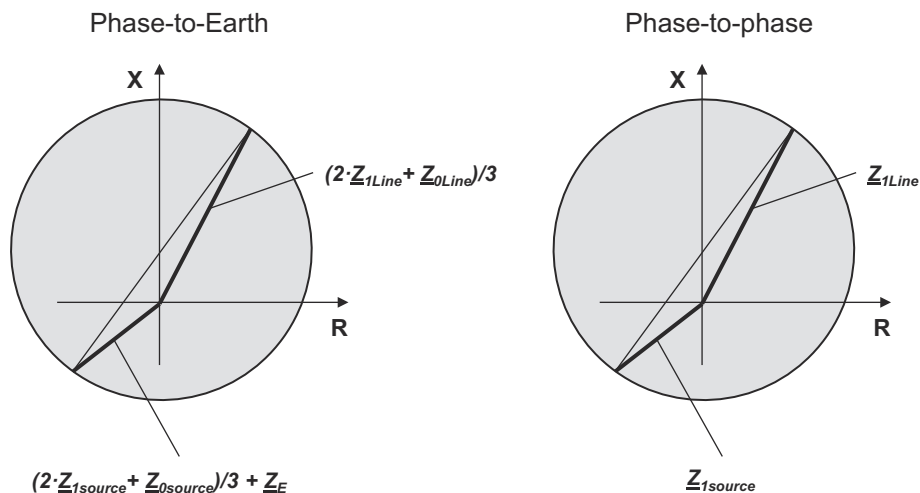
#### Mho circular characteristic

When the zone characteristic is "Mho (circular)", the distance protection has a circular tripping characteristic. The zone reach is defined independently by the line reach for phase-to-earth and phase-to-phase or three-phase elements. The resistive reach of the tripping characteristic depends on the selected polarization method defined with setting *Pol quantity zone* = "Cross pol", "Pos. seq. volt." or "Self pol". The non-directional mho characteristic is an exception as it is independent of the selected polarization method. It is always explicitly defined by the reach settings and thus fixed in the impedance plane.

**Table 531: Polarization methods and corresponding polarization voltages**

| Fault loop       | Self pol         | Cross pol                                | Pos. seq. volt.              |
|------------------|------------------|--|------------------------------|
| Z <sub>A</sub>   | U <sub>L1</sub>  | $j \cdot U_{L23} / \sqrt{3}$             | U <sub>1</sub>               |
| Z <sub>B</sub>   | U <sub>L2</sub>  | $j \cdot U_{L31} / \sqrt{3}$             | U <sub>1</sub> · 1∠-120°     |
| Z <sub>C</sub>   | U <sub>L3</sub>  | $j \cdot U_{L23} / \sqrt{3}$             | U <sub>1</sub> · 1∠120°      |
| Z <sub>AB</sub>  | U <sub>L12</sub> | $j \cdot (U_{L23} - U_{L31}) / \sqrt{3}$ | U <sub>1</sub> · √3 · 1∠30°  |
| Z <sub>BC</sub>  | U <sub>L23</sub> | $j \cdot (U_{L31} - U_{L12}) / \sqrt{3}$ | U <sub>1</sub> · √3 · 1∠-90° |
| Z <sub>CA</sub>  | U <sub>L31</sub> | $j \cdot (U_{L12} - U_{L23}) / \sqrt{3}$ | U <sub>1</sub> · √3 · 1∠150° |
| Z <sub>ABC</sub> | U <sub>1</sub>   |  |                              |

In case of cross-polarization "Cross pol", the polarization voltages are theoretically quadrature to the fault loop voltage. The phase angle of the polarization voltage is rotated 90° to match the original fault loop voltage. The cross-polarization expands the tripping characteristic according to the prevailing system conditions. In case of short circuit faults, the circle expands as a function of the source impedance magnitude Z<sub>1source</sub>. In case of an earth fault, the circle expands as a function of the source impedance Z<sub>1source</sub>, Z<sub>0source</sub> and earthing impedance magnitudes Z<sub>E</sub> as  $(2 \cdot Z_{1source} + Z_{0source}) / 3 + Z_E$ .



*Figure 300: Tripping characteristic in case the zone characteristic is "Mho (circular)" and Pol quantity zone is "Cross pol"*

In case of positive-sequence polarization "Pos. seq. volt.", the polarization voltage is the positive-sequence voltage. The voltage phase angle is rotated to match the original fault loop voltage. The positive-sequence polarization expands the tripping characteristic according to the prevailing system conditions. In case of short circuit faults, the circle expands as a function of the source impedance magnitude Z<sub>1source</sub>/2. In case of an earth fault, the circle expands as a function of source impedance and earthing impedance magnitudes:  $(Z_{1source} + Z_{0source}) / 3 + Z_E$ .

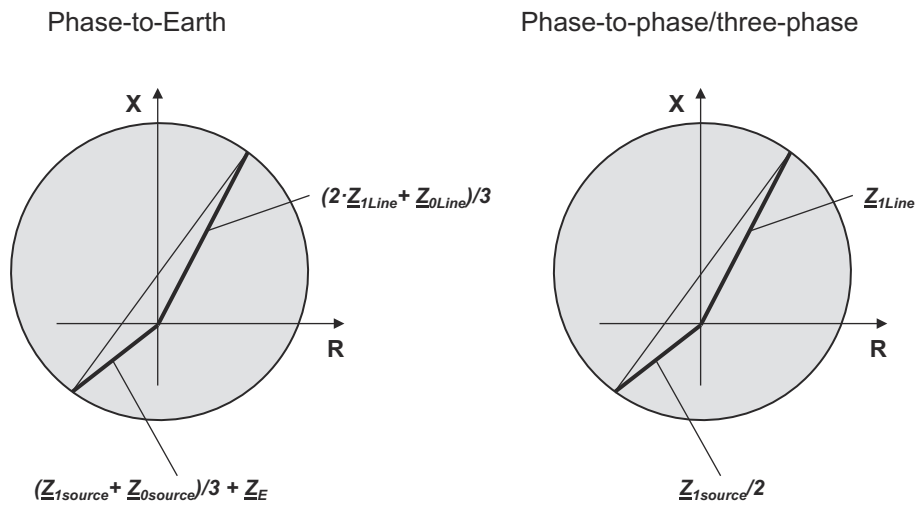


Figure 301: Tripping characteristic in case the zone characteristic is "Mho (circular)" and Pol quantity zone is "Pos. seq. volt."

One alternative for polarization is also "Self pol" despite the drawbacks when using it as a polarization method. The mho circle does not expand when using this polarization method.

In case of cross and positive-sequence polarization, the expansion of the mho circle is a positive feature as the fault resistance coverage is increased. The reach of the zone is not affected by the expansion. The greatest expansion is obtained with cross-polarization.

The directional offset mho is explicitly defined by the reach settings and is thus fixed in the impedance plane. The polarization method does not expand this circle even for directional mode. However, directional lines criteria are defined using polarized signals.

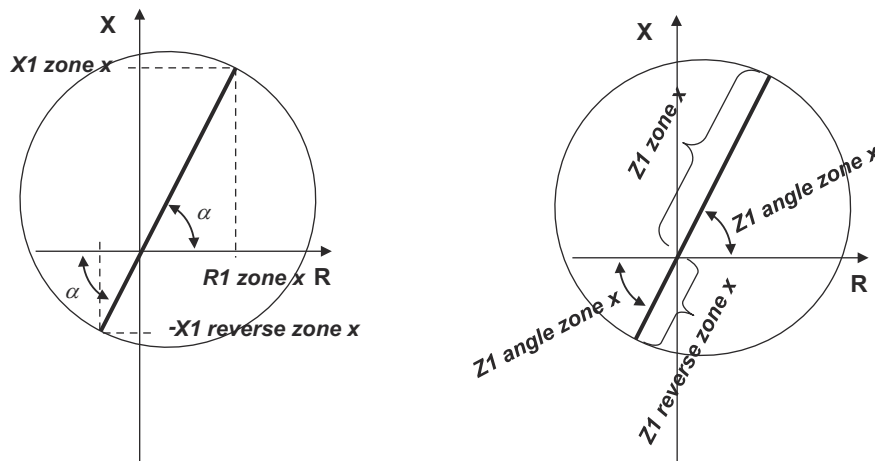


Figure 302: Tripping characteristic for phase-to-phase or three-phase impedance measuring elements if Impedance Chr PP Zn is "Mho (circular)" and Directional mode Znx is "Non-directional". On the left, Impedance mode Zn is "Rectangular". On the right, Impedance mode Zn is "Polar".

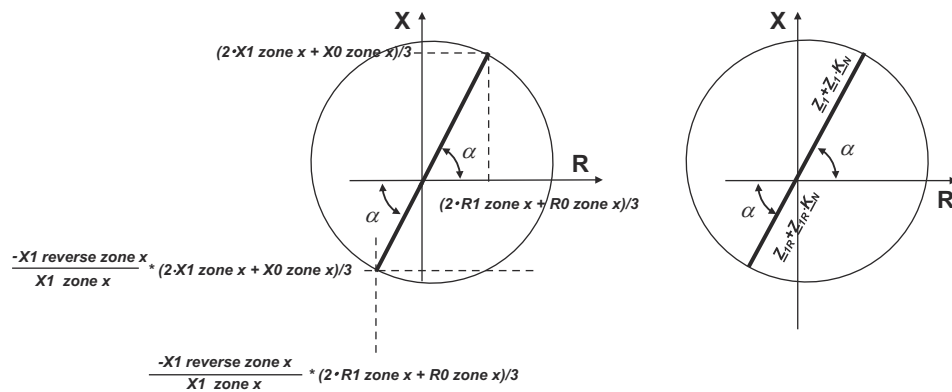


Figure 303: Tripping characteristic for phase-to-earth impedance measuring elements if Impedance Chr GND Zn is "Mho (circular)" and Directional mode Znx is "Non-directional". On the left, Impedance mode Zn is "Rectangular". On the right, Impedance mode Zn is "Polar".

*Adding of directional lines into circular mho characteristic*

Directional lines which are always included in the directional quadrilateral characteristic can also be included in the mho characteristics to secure the directionality or to transform the non-directional mho characteristics into a directional one.

Directional lines with mho are available only when the zone is set to directional, that is, *Directional mode Znx* is "Forward" or "Reverse".

The directionality of the directional mho characteristic is secured with directional lines by setting *Impedance Chr Gnd Zn* and *Impedance Chr PP Zn* to "Mho Dir line". The directional mho characteristic can also be created by adding directional lines in the offset mho characteristic. This is done by selecting *Impedance Chr Gnd Zn* and *Impedance Chr PP Zn* as "Offset Dir line".

| Imp zone shape  | Directional mode Znx |         |         |
|-----------------|----------------------|---------|---------|
|                 | Non-directional      | Forward | Reverse |
| Quadrilateral   |                      |         |         |
| Mho (circular)  |                      |         |         |
| Mho Dir line    |                      |         |         |
| Offset Dir line |                      |         |         |
| Bullet (combi)  |                      |         |         |

Pol. = polarization method affects (mho)zone shape

Figure 304: Possible combinations of Directional mode Znx and zone characteristics settings. Pol. in the figure means that the shape of the characteristic is affected by the selected polarization method of the mho circle, Pol quantity zone = "Cross pol", "Pos. seq. volt.", "Self pol").

*Bullet combi characteristic*

If the impedance zone shape equals "Bullet (combi)", the distance protection has a tripping characteristic which is a combination of the quadrilateral and mho. All settings relevant to the quadrilateral and mho are applicable. The shape of the "Bullet (combi)" characteristic is affected by the selected polarization method of the mho circle (*Pol quantity zone* = "Cross pol", "Pos. seq. volt.", "Self pol").

The directionality of the "Bullet (combi)" characteristic is defined by the directional lines when *Directional mode Znx* is "Forward" or "Reverse". For directional "Bullet (combi)" characteristic, the quadrilateral resistance does not reach negative (positive) values for "Forward" ("Reverse") direction (see [Figure 305](#)).

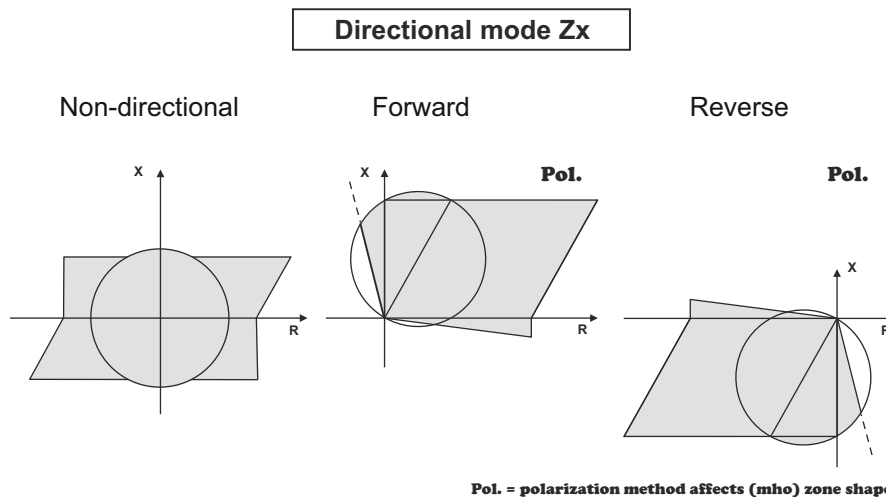


Figure 305: Bullet combi tripping characteristic. Pol. in the figure means the shape of the characteristic is affected by the selected polarization method, Pol quantity zone = "Cross pol", "Pos. seq. volt.", "Self pol"

### 3.7.1.6 Recorded data

The required information for later fault analysis is recorded when the recording function of DSTPDIS is triggered by activating TRIGG\_REC input or writing to the corresponding DO "LD0.GFCPDIS1.RcdTrg.stVal". During external triggering (input signal TRIGG\_REC), the recorded data of all zones and the phase selection function are recorded.

A total of three sets of recorded data are saved in data banks Fault 1, 2 and 3. Data bank Fault 1 holds the most recent recorded data and the older data is moved into the following banks (1->2 and 2->3) when triggering occurs. When all three banks have data and a new triggering occurs, the latest data is placed into bank 1 and the data in bank 3 is overwritten by the data from bank 2.

**Table 532: Recorded data for the phase selection function**

| Parameter name        | Description  |
|-----------------------|--|
| Time                  | Recorded data time stamp   |
| Release PE-loop       | Release signals for PE loops, GFC  |
| Release PP-loop       | Release signals for PP/3P loops, GFC   |
| Earth fault detected  | Indication of a single-phase earth fault, GFC  |
| Cross country fault   | Indication of a cross-country fault (high imp. earthed), GFC   |
| Earth fault direction | Earth-fault direction (low imp. earthed), GFC  |
| Operate of all zones  | Operate signals of all zones (this is zone information but it is taken here because it represents all zone information combined) |



The values of parameter Operate of all zones indicate by a number (0...31) which zones have been operated.

**Table 533: Enumerator values for parameter Operate of all zones**

| Enumerator value | Description       |
|------------------|-------------------|
| 0                | No zone operates  |
| 1                | Zone 1            |
| 2                | Zone 2            |
| 3                | Zones 1 and 2     |
| 4                | Zone 3            |
| 5                | Zones 1 and 3     |
| 6                | Zones 2 and 3     |
| 7                | Zones 1,2 and 3   |
| 8                | Zone 4            |
| 9                | Zones 1 and 4     |
| 10               | Zones 2 and 4     |
| 11               | Zones 1,2 and 4   |
| 12               | Zones 3 and 4     |
| 13               | Zones 1,3 and 4   |
| 14               | Zones 2,3 and 4   |
| 15               | Zones 1,2,3 and 4 |
| 16               | Zone 5            |
| 17               | Zones 1 and 5     |
| 18               | Zones 2 and 5     |
| 19               | Zones 1,2 and 5   |
| 20               | Zones 3 and 5     |
| 21               | Zones 1,3 and 5   |
| 22               | Zones 2,3 and 5   |
| 23               | Zones 1,2,3 and 5 |
| 24               | Zones 4 and 5     |
| 25               | Zones 1,4 and 5   |

*Table continues on the next page*

| Enumerator value | Description         |
|------------------|---------------------|
| 26               | Zones 2,4 and 5     |
| 27               | Zones 1,2,4 and 5   |
| 28               | Zones 3,4 and 5     |
| 29               | Zones 1,3,4 and 5   |
| 30               | Zones 2,3,4 and 5   |
| 31               | Zones 1,2,3,4 and 5 |

**Table 534: Recorded data parameters regarding specific zones**

| Parameter            | Description                        |
|----------------------|------------------------------------|
| Fault/load Dir Znx   | Direction of fault or load zone Zx |
| Dir resistance Znx   | Direction resistance, zone Zx      |
| Dir reactance Znx    | Direction reactance, zone Zx       |
| Flt loop 1st Ris Znx | First PE-Loop resistance, zone Zx  |
| Flt loop 1st Rea Znx | First PE-Loop reactance, zone Zx   |
| Flt loop 2nd Ris Znx | Second PE-Loop resistance, zone Zx |
| Flt loop 2nd Rea Znx | Second PE-Loop reactance, zone Zx  |
| Flt PP-loop Ris Znx  | PP-Loop resistance, zone Zx        |
| Flt PP-loop Rea Znx  | PP-Loop reactance, zone Zx         |
| Phase reactance Znx  | Phase reactance Znx                |

Besides the already mentioned recorded data, the monitored data zone outputs give information regarding zone 1 particularly. The direction of the fault is indicated with the monitored data DIRECTION ("unknown", "forward", "backward" or "both"). In case of a no-fault condition, the direction of the load current seen by a three-phase fault measuring element (based on positive-sequence signal data) is indicated. DIR\_LOOP\_R and DIR\_LOOP\_X are the loop resistance and reactance from the impedance calculation used in directional discrimination for zone 1. Depending on the released fault loops, the calculated fault loop impedance can be read from the parameters FLTLOOP\_RFST, FLTLOOP\_XFST, FLTLOOP\_RPP and FLTLOOP\_XPP. If two phase-to-earth loops are released simultaneously for measurement, the second phase-to-earth impedance can be found from the parameters FLTLOOP\_RSND and FLTLOOP\_XSND. The corresponding positive-sequence phase-to-earth fault reactance can be found from parameter FLTPH\_X.



The impedances are shown in primary ohms.

### 3.7.1.7 Application

DSTPDIS provides a fast and reliable protection for overhead lines and power cables. The function is applied in distribution and sub-transmission networks where three-phase tripping is allowed for all kinds of faults.

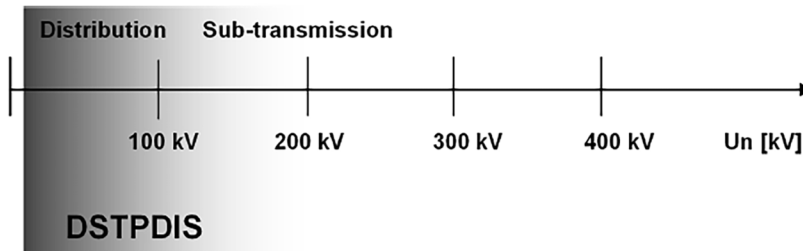


Figure 306: Application scope of DSTPDIS

Typically these networks are operated in ring or meshed type configurations. The switching state of these networks is changed frequently due to daily operation and load flow considerations. The networks also include varying capacities of distributed generation which makes it impossible to apply simple overcurrent-based schemes. In these networks, DSTPDIS is used to provide a fast and selective protection for overhead lines and power cables. It can also be applied for radial feeders to increase the sensitivity of the protection, especially if the short circuit power of the source is low or it changes due to network operation.

From the selectivity point of view, it is advantageous that in the protection chain all functions in different positions operate according to the same measuring principle. Therefore, DSTPDIS can also be applied for the backup protection of main transformers and buses. This way, selectivity in the distance protection of the outgoing lines is easier to achieve.

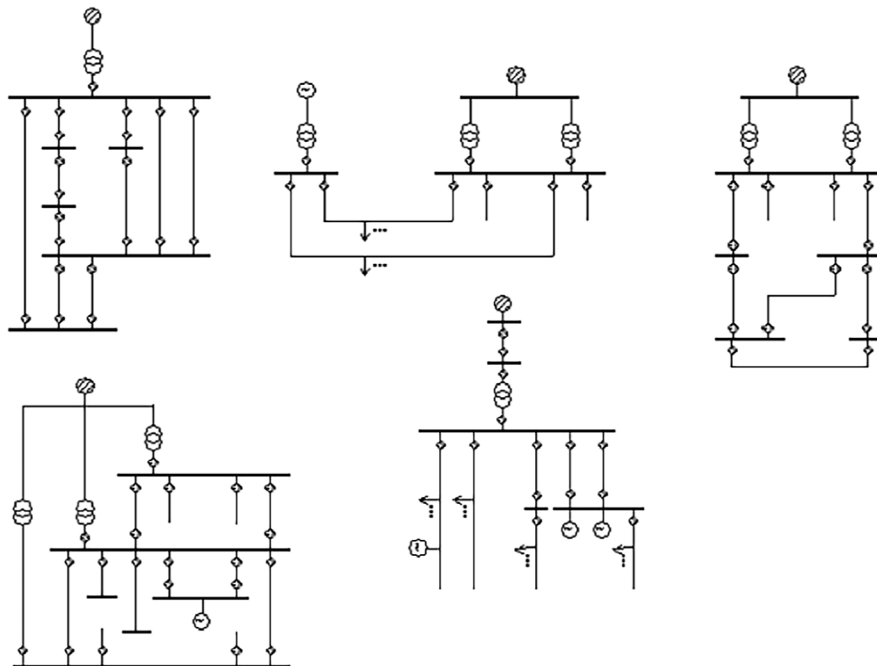


Figure 307: Typical network configurations for DSTPDIS application

DSTPDIS has five flexible configurable impedance zones for protection (Z1...Z5).

Phase-to-earth distance protection is a basic earth-fault protection in solidly or low-impedance earthed networks. Together with the phase preference logic, it also serves as a selective protection function at cross-country faults in isolated or Petersen coil compensated networks. In certain applications, system earthing is changed during operation from high-impedance to low-impedance earthed system due to fault location procedures. DSTPDIS can be used in such applications by setting System grounding GFC to "From input" and by providing information about the type of earthing through binary input `SYS_EARTHING`. Low (inactive) `SYS_EARTHING` input indicates low-impedance earthing system.

DSTPDIS is suitable as a basic protection function against two- and three-phase faults in various networks, regardless of the treatment of the neutral point. The independent setting of the reach in the reactive and the resistive directions makes it possible to create a fast and selective short circuit protection in many applications.

### 3.7.1.8

## Signals

### DSTPDIS Signals

**Table 535: DSTPDIS Input signals**

| Name         | Type    | Default | Description                                   |
|--------------|---------|---------|---|
| I3P          | SIGNAL  | -       | Three-phase currents                          |
| I3P_PAR      | SIGNAL  | -       | Three-phase currents                          |
| I3P_REF      | SIGNAL  | -       | Three-phase currents                          |
| U3P          | SIGNAL  | -       | Three-phase voltages                          |
| URES         | SIGNAL  | -       | Residual voltage                              |
| BLOCK        | BOOLEAN | 0=False | Block signal for activating the blocking mode |
| SYS_EARTHING | BOOLEAN | 0=False | Network earthing method                       |
| TRIGG_REC    | BOOLEAN | 0=False | External triggering for all recorded data     |
| BLOCK_GFC    | BOOLEAN | 0=False | Block GFC operate                             |
| BLOCK_Z1     | BOOLEAN | 0=False | Block zone 1                                  |
| BLOCK_Z2     | BOOLEAN | 0=False | Block zone 2                                  |
| BLOCK_Z3     | BOOLEAN | 0=False | Block zone 3                                  |
| BLOCK_Z4     | BOOLEAN | 0=False | Block zone 4                                  |
| BLOCK_Z5     | BOOLEAN | 0=False | Block zone 5                                  |

**Table 536: DSTPDIS Output signals**

| Name        | Type    | Description  |
|-------------|---------|--|
| OPERATE_GFC | BOOLEAN | Time delayed operate signal, GFC                             |
| OPERATE_Z1  | BOOLEAN | Time delayed operate signal, zone 1                          |
| OPERATE_Z2  | BOOLEAN | Time delayed operate signal, zone 2                          |
| OPERATE_Z3  | BOOLEAN | Time delayed operate signal, zone 3                          |
| OPERATE_Z4  | BOOLEAN | Time delayed operate signal, zone 4                          |
| OPERATE_Z5  | BOOLEAN | Time delayed operate signal, zone 5                          |
| START_GFC   | BOOLEAN | Start, GFC   |
| START_Z1    | BOOLEAN | General start signal, zone 1                                 |
| START_Z2    | BOOLEAN | General start signal, zone 2                                 |
| START_Z3    | BOOLEAN | General start signal, zone 3                                 |
| START_Z4    | BOOLEAN | General start signal, zone 4                                 |
| START_Z5    | BOOLEAN | General start signal, zone 5                                 |
| XC_FLT      | BOOLEAN | Indication of a cross-country-fault (high imp. earthed), GFC |

### 3.7.1.9

## Settings

### DSTPDIS Group settings (Basic)

**Table 537: DSTPDIS Group settings (Basic)**

| Parameter          | Values (Range)  | Unit | Step | Default       | Description            |
|--------------------|---|------|------|---------------|------------------------|
| Phase Sel mode GFC | 1=Overcurrent<br>2=Vol Dep Overcur<br>3=Under impedance |      |      | 1=Overcurrent | Phase selection method |

*Table continues on the next page*

| Parameter            | Values (Range)                                       | Unit | Step | Default         | Description   |
|----------------------|--|------|------|-----------------|---|
|                      | 4=OC AND Und impedance                               |      |      |                 |   |
| EF detection Mod GFC | 1=Io<br>2=Io OR Uo<br>3=Io AND Uo<br>4=Io AND IoR-ef |      |      | 1=Io            | Earth-fault (EF) detection method                         |
| Operate delay GFC    | 100...60000  | ms   | 10   | 3000            | Time delay to operate, GFC                                |
| Str A Ph Sel GFC     | 0.10...10.00   | xIn  | 0.01 | 2.00            | Phase current start value, PSL                            |
| Lo A Ph Sel GFC      | 0.10...10.00   | xIn  | 0.01 | 0.80            | Phase current start value, voltage dep. over current, PSL |
| Ph V Ph Sel GFC      | 0.05...1.00  | xUn  | 0.01 | 0.46            | PE-voltage start value, voltage dep. over current, PSL    |
| PP V Ph Sel GFC      | 0.10...1.00  | xUn  | 0.01 | 0.80            | PP-voltage start value, voltage dep. over current, PSL    |
| Z Chr Mod Ph Sel GFC | 1=Quadrilateral<br>2=Mho (circular)                  |      |      | 1=Quadrilateral | Impedance characteristic, underimpedance, PSL             |
| Load Dsr mode GFC    | 0=False<br>1=True                                    |      |      | 0=False         | Enable load discrimination, underimpedance, PSL           |
| X Gnd Fwd reach GFC  | 0.00...3000.00                                       | ohm  | 0.01 | 40.00           | Reactive forward reach for PE-loops, underimpedance, PSL  |
| X Gnd Rv reach GFC   | 0.00...3000.00                                       | ohm  | 0.01 | 40.00           | Reactive reverse reach for PE-loops,                      |

*Table continues on the next page*

| Parameter           | Values (Range) | Unit | Step | Default | Description  |
|---------------------|----------------|------|------|---------|--|
|                     |                |      |      |         | underimpedance, PSL  |
| Ris Gnd Fwd Rch GFC | 0.00...500.00  | ohm  | 0.01 | 100.00  | Resistive forward reach for PE-loops, underimpedance, PSL            |
| Ris Gnd Rv Rch GFC  | 0.00...500.00  | ohm  | 0.01 | 100.00  | Resistive reverse reach for PE-loops, underimpedance, PSL            |
| X PP Fwd reach GFC  | 0.00...3000.00 | ohm  | 0.01 | 40.00   | Reactive forward reach for PP-loops, underimpedance, PSL             |
| X PP Rv reach GFC   | 0.00...3000.00 | ohm  | 0.01 | 40.00   | Reactive reverse reach for PP-loops, underimpedance, PSL             |
| Ris PP Fwd Rch GFC  | 0.00...100.00  | ohm  | 0.01 | 30.00   | Resistive forward reach for PP-loops, underimpedance, PSL            |
| Ris PP Rv Rch GFC   | 0.00...100.00  | ohm  | 0.01 | 30.00   | Resistive reverse reach for PP-loops, underimpedance, PSL            |
| Ris Fwd Rch Lod GFC | 0.00...3000.00 | ohm  | 0.01 | 80.00   | Resistive forward reach for load discrimination, underimpedance, PSL |
| Ris Rv Rch Lod GFC  | 0.00...3000.00 | ohm  | 0.01 | 80.00   | Resistive reverse reach for load discrimination, underimpedance, PSL |
| Angle load area GFC | 5.0...45.0     | deg  | 0.1  | 25.0    | Load discrimination angle, PSL                                       |

*Table continues on the next page*

| Parameter            | Values (Range)                              | Unit | Step | Default   | Description  |
|----------------------|---|------|------|-----------|--|
| Gnd Op current GFC   | 0.00...10.00                                | xIn  | 0.01 | 0.10      | Basic start value for residual curr., EF- detection function |
| Gnd Op A Ref GFC     | 0.01...10.00                                | xIn  | 0.01 | 0.10      | Transformer neutral curr. start val., EF- detection function |
| Gnd Str voltage GFC  | 0.02...1.00                                 | xUn  | 0.01 | 0.15      | Residual voltage start value, EF-detection function          |
| Gnd Op A XC GFC      | 0.10...10.00                                | xIn  | 0.01 | 0.20      | Residual current start value, XC-fault detection function    |
| PP voltage XC GFC    | 0.10...1.00                                 | xUn  | 0.01 | 0.80      | PP-voltage start value, XC-fault detection function          |
| Directional mode Zn1 | 2=Forward<br>3=Reverse<br>1=Non-directional |      |      | 2=Forward | Directional mode, zone 1                                     |
| Op Mod PP loops Zn1  | 0=False<br>1=True                           |      |      | 0=False   | Enable PP/3P-loop measurement, zone 1                        |
| PP Op delay Mod Zn1  | 0=False<br>1=True                           |      |      | 1=True    | Enable operate timer for PP/3P-loops, zone 1                 |
| R1 zone 1            | 0.00...3000.00                              | ohm  | 0.01 | 40.00     | Positive sequence resistive reach, zone 1                    |
| X1 zone 1            | 0.00...3000.00                              | ohm  | 0.01 | 40.00     | Positive sequence reactive reach, zone 1                     |
| X1 reverse zone 1    | 0.00...3000.00                              | ohm  | 0.01 | 40.00     | Pos. seq. reactive reach in rev. dir.,                       |

*Table continues on the next page*



| Parameter            | Values (Range)    | Unit | Step | Default | Description   |
|----------------------|-------------------|------|------|---------|---|
|                      |                   |      |      |         | non-dir. zone 1                                       |
| Z1 zone 1            | 0.01...3000.00    | ohm  | 0.01 | 56.57   | Positive sequence reach, zone 1                       |
| Z1 angle zone 1      | 15.0...90.0       | deg  | 0.1  | 45.0    | Positive sequence line angle, zone 1                  |
| Z1 reverse zone 1    | 0.00...3000.00    | ohm  | 0.01 | 56.57   | Positive sequence reach in rev. dir., non-dir. zone 1 |
| Min Ris PP Rch Zn1   | 0.00...100.00     | ohm  | 0.01 | 30.00   | Minimum resistive reach of PP/3P-loops, zone 1        |
| Max Ris PP Rch Zn1   | 0.00...100.00     | ohm  | 0.01 | 30.00   | Maximum resistive reach of PP/3P-loops, zone 1        |
| PP operate delay Zn1 | 40...60000        | ms   | 1    | 40      | Time delay to operate of PP/3P-loops, zone 1          |
| Op Mod Gnd loops Zn1 | 0=False<br>1=True |      |      | 0=False | Enable PE-loop measurement, zone 1                    |
| Gnd Op DI mode Zn1   | 0=False<br>1=True |      |      | 1=True  | Enable operate timer for PE-loops, zone 1             |
| Load Comp zone 1     | 0=False<br>1=True |      |      | 1=True  | Enable load compensation for PE-loops, zone 1         |
| R0 zone 1            | 0.00...3000.00    | ohm  | 0.01 | 160.00  | Zero sequence resistive reach, zone 1                 |
| X0 zone 1            | 0.00...3000.00    | ohm  | 0.01 | 160.00  | Zero sequence reactive reach, zone 1                  |
| Factor K0 zone 1     | 0.0...4.0         |      | 0.1  | 1.0     | Residual compensation                                 |

*Table continues on the next page*

| Parameter            | Values (Range)                              | Unit | Step | Default   | Description  |
|----------------------|---|------|------|-----------|--|
|                      |   |      |      |           | factor magnitude, zone 1                               |
| Factor K0 angle Zn1  | -135...135                                  | deg  | 1    | 0         | Residual compensation factor angle, zone 1             |
| Min Ris Gnd Rch Zn1  | 0.00...500.00                               | ohm  | 0.01 | 100.00    | Minimum resistive reach of PE-loops, zone 1            |
| Max Ris Gnd Rch Zn1  | 0.00...500.00                               | ohm  | 0.01 | 100.00    | Maximum resistive reach of PE-loops, zone 1            |
| Gnd operate DI Zn1   | 40...60000                                  | ms   | 1    | 40        | Time delay to operate of PE-loops, zone 1              |
| Directional mode Zn2 | 1=Non-directional<br>2=Forward<br>3=Reverse |      |      | 2=Forward | Directional mode, zone 2                               |
| Op Mod PP loops Zn2  | 0=False<br>1=True                           |      |      | 0=False   | Enable PP/3P-loop measurement, zone 2                  |
| PP Op delay Mod Zn2  | 0=False<br>1=True                           |      |      | 1=True    | Enable operate timer for PP/3P-loops, zone 2           |
| R1 zone 2            | 0.00...3000.00                              | ohm  | 0.01 | 40.00     | Positive sequence resistive reach, zone 2              |
| X1 zone 2            | 0.00...3000.00                              | ohm  | 0.01 | 40.00     | Positive sequence reactive reach, zone 2               |
| X1 reverse zone 2    | 0.00...3000.00                              | ohm  | 0.01 | 40.00     | Pos. seq. reactive reach in rev. dir., non-dir. zone 2 |
| Z1 zone 2            | 0.01...3000.00                              | ohm  | 0.01 | 56.57     | Positive sequence reach, zone 2                        |

*Table continues on the next page*

| Parameter            | Values (Range)    | Unit | Step | Default | Description   |
|----------------------|-------------------|------|------|---------|---|
| Z1 angle zone 2      | 15.0...90.0       | deg  | 0.1  | 45.0    | Positive sequence line angle, zone 2                  |
| Z1 reverse zone 2    | 0.00...3000.00    | ohm  | 0.01 | 56.57   | Positive sequence reach in rev. dir., non-dir. zone 2 |
| Min Ris PP Rch Zn2   | 0.00...100.00     | ohm  | 0.01 | 30.00   | Minimum resistive reach of PP/3P-loops, zone 2        |
| Max Ris PP Rch Zn2   | 0.00...100.00     | ohm  | 0.01 | 30.00   | Maximum resistive reach of PP/3P-loops, zone 2        |
| PP Op delay Mod Zn2  | 40...60000        | ms   | 1    | 40      | Enable operate timer for PP/3P-loops, zone 2          |
| Op Mod Gnd loops Zn2 | 0=False<br>1=True |      |      | 0=False | Enable PE-loop measurement, zone 2                    |
| Gnd Op DI mode Zn2   | 0=False<br>1=True |      |      | 1=True  | Enable operate timer for PE-loops, zone 2             |
| Load Comp zone 2     | 0=False<br>1=True |      |      | 1=True  | Enable load compensation for PE-loops, zone 2         |
| R0 zone 2            | 0.00...3000.00    | ohm  | 0.01 | 160.00  | Zero sequence resistive reach, zone 2                 |
| X0 zone 2            | 0.00...3000.00    | ohm  | 0.01 | 160.00  | Zero sequence reactive reach, zone 2                  |
| Factor K0 zone 2     | 0.0...4.0         |      | 0.1  | 1.0     | Residual compensation factor magnitude, zone 2        |
| Factor K0 angle Zn2  | -135...135        | deg  | 1    | 0       | Residual compensation                                 |

*Table continues on the next page*

| Parameter            | Values (Range)                              | Unit | Step | Default   | Description  |
|----------------------|---|------|------|-----------|--|
|                      |   |      |      |           | factor angle, zone 2                                   |
| Min Ris Gnd Rch Zn2  | 0.00...500.00                               | ohm  | 0.01 | 100.00    | Minimum resistive reach of PE-loops, zone 2            |
| Max Ris Gnd Rch Zn2  | 0.00...500.00                               | ohm  | 0.01 | 100.00    | Maximum resistive reach of PE-loops, zone 2            |
| Gnd operate DI Zn2   | 40...60000                                  | ms   | 1    | 40        | Time delay to operate of PE-loops, zone 2              |
| Directional mode Zn3 | 1=Non-directional<br>2=Forward<br>3=Reverse |      |      | 2=Forward | Directional mode, zone 3                               |
| Op Mod PP loops Zn3  | 0=False<br>1=True                           |      |      | 0=False   | Enable PP/3P-loop measurement, zone 3                  |
| PP Op delay Mod Zn3  | 0=False<br>1=True                           |      |      | 1=True    | Enable operate timer for PP/3P-loops, zone 3           |
| R1 zone 3            | 0.00...3000.00                              | ohm  | 0.01 | 40.00     | Positive sequence resistive reach, zone 3              |
| X1 zone 3            | 0.00...3000.00                              | ohm  | 0.01 | 40.00     | Positive sequence reactive reach, zone 3               |
| X1 reverse zone 3    | 0.00...3000.00                              | ohm  | 0.01 | 40.00     | Pos. seq. reactive reach in rev. dir., non-dir. zone 3 |
| Z1 zone 3            | 0.01...3000.00                              | ohm  | 0.01 | 56.57     | Positive sequence reach, zone 3                        |
| Z1 angle zone 3      | 15.0...90.0                                 | deg  | 0.1  | 45.0      | Positive sequence line angle, zone 3                   |

Table continues on the next page

| Parameter            | Values (Range)    | Unit | Step | Default | Description   |
|----------------------|-------------------|------|------|---------|---|
| Z1 reverse zone 3    | 0.00...3000.00    | ohm  | 0.01 | 56.57   | Positive sequence reach in rev. dir., non-dir. zone 3 |
| Min Ris PP Rch Zn3   | 0.00...100.00     | ohm  | 0.01 | 30.00   | Minimum resistive reach of PP/3P-loops, zone 3        |
| Max Ris PP Rch Zn3   | 0.00...100.00     | ohm  | 0.01 | 30.00   | Maximum resistive reach of PP/3P-loops, zone 3        |
| PP operate delay Zn3 | 40...60000        | ms   | 1    | 40      | Time delay to operate of PP/3P-loops, zone 3          |
| Op Mod Gnd loops Zn3 | 0=False<br>1=True |      |      | 0=False | Enable PE-loop measurement, zone 3                    |
| Gnd Op DI mode Zn3   | 0=False<br>1=True |      |      | 1=True  | Enable operate timer for PE-loops, zone 3             |
| Load Comp zone 3     | 0=False<br>1=True |      |      | 1=True  | Enable load compensation for PE-loops, zone 3         |
| R0 zone 3            | 0.00...3000.00    | ohm  | 0.01 | 160.00  | Zero sequence resistive reach, zone 3                 |
| X0 zone 3            | 0.00...3000.00    | ohm  | 0.01 | 160.00  | Zero sequence reactive reach, zone 3                  |
| Factor K0 zone 3     | 0.0...4.0         |      | 0.1  | 1.0     | Residual compensation factor magnitude, zone 3        |
| Factor K0 angle Zn3  | -135...135        | deg  | 1    | 0       | Residual compensation factor angle, zone 3            |
| Min Ris Gnd Rch Zn3  | 0.00...500.00     | ohm  | 0.01 | 100.00  | Minimum resistive reach                               |

*Table continues on the next page*

| Parameter            | Values (Range)                              | Unit | Step | Default   | Description  |
|----------------------|---|------|------|-----------|--|
|                      |   |      |      |           | of PE-loops, zone 3                                    |
| Max Ris Gnd Rch Zn3  | 0.00...500.00                               | ohm  | 0.01 | 100.00    | Maximum resistive reach of PE-loops, zone 3            |
| Gnd operate DI Zn3   | 40...60000                                  | ms   | 1    | 40        | Time delay to operate of PE-loops, zone 3              |
| Directional mode Zn4 | 1=Non-directional<br>2=Forward<br>3=Reverse |      |      | 2=Forward | Directional mode, zone 4                               |
| Op Mod PP loops Zn4  | 0=False<br>1=True                           |      |      | 0=False   | Enable PP/3P-loop measurement, zone 4                  |
| PP Op delay Mod Zn4  | 0=False<br>1=True                           |      |      | 1=True    | Enable operate timer for PP/3P-loops, zone 4           |
| R1 zone 4            | 0.00...3000.00                              | ohm  | 0.01 | 40.00     | Positive sequence resistive reach, zone 4              |
| X1 zone 4            | 0.00...3000.00                              | ohm  | 0.01 | 40.00     | Positive sequence reactive reach, zone 4               |
| X1 reverse zone 4    | 0.00...3000.00                              | ohm  | 0.01 | 40.00     | Pos. seq. reactive reach in rev. dir., non-dir. zone 4 |
| Z1 zone 4            | 0.01...3000.00                              | ohm  | 0.01 | 56.57     | Positive sequence reach, zone 4                        |
| Z1 angle zone 4      | 15.0...90.0                                 | deg  | 0.1  | 45.0      | Positive sequence line angle, zone 4                   |
| Z1 reverse zone 4    | 0.00...3000.00                              | ohm  | 0.01 | 56.57     | Positive sequence reach in rev. dir., non-dir. zone 4  |

*Table continues on the next page*

| Parameter            | Values (Range)    | Unit | Step | Default | Description                                    |
|----------------------|-------------------|------|------|---------|--|
| Min Ris PP Rch Zn4   | 0.00...100.00     | ohm  | 0.01 | 30.00   | Minimum resistive reach of PP/3P-loops, zone 4 |
| Max Ris PP Rch Zn4   | 0.00...100.00     | ohm  | 0.01 | 30.00   | Maximum resistive reach of PP/3P-loops, zone 4 |
| PP operate delay Zn4 | 40...60000        | ms   | 1    | 40      | Time delay to operate of PP/3P-loops, zone 4   |
| Op Mod Gnd loops Zn4 | 0=False<br>1=True |      |      | 0=False | Enable PE-loop measurement, zone 4             |
| Gnd Op DI mode Zn4   | 0=False<br>1=True |      |      | 1=True  | Enable operate timer for PE-loops, zone 4      |
| Load Comp zone 4     | 0=False<br>1=True |      |      | 1=True  | Enable load compensation for PE-loops, zone 4  |
| R0 zone 4            | 0.00...3000.00    | ohm  | 0.01 | 160.00  | Zero sequence resistive reach, zone 4          |
| X0 zone 4            | 0.00...3000.00    | ohm  | 0.01 | 160.00  | Zero sequence reactive reach, zone 4           |
| Factor K0 zone 4     | 0.0...4.0         |      | 0.1  | 1.0     | Residual compensation factor magnitude, zone 4 |
| Factor K0 angle Zn4  | -135...135        | deg  | 1    | 0       | Residual compensation factor angle, zone 4     |
| Min Ris Gnd Rch Zn4  | 0.00...500.00     | ohm  | 0.01 | 100.00  | Minimum resistive reach of PE-loops, zone 4    |
| Max Ris Gnd Rch Zn4  | 0.00...500.00     | ohm  | 0.01 | 100.00  | Maximum resistive reach                        |

*Table continues on the next page*

| Parameter            | Values (Range)                              | Unit | Step | Default   | Description  |
|----------------------|---|------|------|-----------|--|
|                      |   |      |      |           | of PE-loops, zone 4                                    |
| Gnd operate DI Zn4   | 40...60000                                  | ms   | 1    | 40        | Time delay to operate of PE-loops, zone 4              |
| Directional mode Zn5 | 1=Non-directional<br>2=Forward<br>3=Reverse |      |      | 2=Forward | Directional mode, zone 5                               |
| Op Mod PP loops Zn5  | 0=False<br>1=True                           |      |      | 0=False   | Enable PP/3P-loop measurement, zone 5                  |
| PP Op delay Mod Zn5  | 0=False<br>1=True                           |      |      | 1=True    | Enable operate timer for PP/3P-loops, zone 5           |
| R1 zone 5            | 0.00...3000.00                              | ohm  | 0.01 | 40.00     | Positive sequence resistive reach, zone 5              |
| X1 zone 5            | 0.00...3000.00                              | ohm  | 0.01 | 40.00     | Positive sequence reactive reach, zone 5               |
| X1 reverse zone 5    | 0.00...3000.00                              | ohm  | 0.01 | 40.00     | Pos. seq. reactive reach in rev. dir., non-dir. zone 5 |
| Z1 zone 5            | 0.01...3000.00                              | ohm  | 0.01 | 56.57     | Positive sequence reach, zone 5                        |
| Z1 angle zone 5      | 15.0...90.0                                 | deg  | 0.1  | 45.0      | Positive sequence line angle, zone 5                   |
| Z1 reverse zone 5    | 0.00...3000.00                              | ohm  | 0.01 | 56.57     | Positive sequence reach in rev. dir., non-dir. zone 5  |
| Min Ris PP Rch Zn5   | 0.00...100.00                               | ohm  | 0.01 | 30.00     | Minimum resistive reach of PP/3P-loops, zone 5         |

Table continues on the next page



| Parameter            | Values (Range)    | Unit | Step | Default | Description                                    |
|----------------------|-------------------|------|------|---------|--|
| Max Ris PP Rch Zn5   | 0.00...100.00     | ohm  | 0.01 | 30.00   | Maximum resistive reach of PP/3P-loops, zone 5 |
| PP operate delay Zn5 | 40...60000        | ms   | 1    | 40      | Time delay to operate of PP/3P-loops, zone 5   |
| Op Mod Gnd loops Zn5 | 0=False<br>1=True |      |      | 0=False | Enable PE-loop measurement, zone 5             |
| Gnd Op DI mode Zn5   | 0=False<br>1=True |      |      | 1=True  | Enable operate timer for PE-loops, zone 5      |
| Load Comp zone 5     | 0=False<br>1=True |      |      | 1=True  | Enable load compensation for PE-loops, zone 5  |
| R0 zone 5            | 0.00...3000.00    | ohm  | 0.01 | 160.00  | Zero sequence resistive reach, zone 5          |
| X0 zone 5            | 0.00...3000.00    | ohm  | 0.01 | 160.00  | Zero sequence reactive reach, zone 5           |
| Factor K0 zone 5     | 0.0...4.0         |      | 0.1  | 1.0     | Residual compensation factor magnitude, zone 5 |
| Factor K0 angle Zn5  | -135...135        | deg  | 1    | 0       | Residual compensation factor angle, zone 5     |
| Min Ris Gnd Rch Zn5  | 0.00...500.00     | ohm  | 0.01 | 100.00  | Minimum resistive reach of PE-loops, zone 5    |
| Max Ris Gnd Rch Zn5  | 0.00...500.00     | ohm  | 0.01 | 100.00  | Maximum resistive reach of PE-loops, zone 5    |
| Gnd operate DI Zn5   | 40...60000        | ms   | 1    | 40      | Time delay to operate of PE-loops, zone 5      |

**DSTPDIS Group settings (Advanced)****Table 538: DSTPDIS Group settings (Advanced)**

| Parameter            | Values (Range)   | Unit | Step | Default           | Description   |
|----------------------|--|------|------|-------------------|---|
| Gnd Op current 2 GFC | 0.10...10.00   | xIn  | 0.01 | 1.00              | Res. curr. start value for slope 2, EF-detection function     |
| Stab slope 1 GFC     | 0.00...0.30  |      | 0.01 | 0.10              | Slope 1 for res. curr. stabilization, EF-detection function   |
| Stab slope 2 GFC     | 0.00...1.00  |      | 0.01 | 1.00              | Slope 2 for res. current stabilization, EF-detection function |
| A Ph Stab value GFC  | 1.00...10.00   | xIn  | 0.01 | 2.00              | Phase current start value for slope 2, EF-detection function  |
| Dir mode EF GFC      | 1=Non-directional<br>2=Forward<br>3=Reverse                                      |      |      | 1=Non-directional | Directional mode, earth-fault directional function            |
| Pol quantity GFC     | -1=Zro vol.OR cur.<br>2=Zero seq. cur.<br>3=Zero seq. volt.<br>4=Neg. seq. volt. |      |      | 3=Zero seq. volt. | Polarization method, earth-fault directional function         |
| Chr angle GFC        | -179...180   | deg  | 1    | 75                | Characteristic angle, earth-fault directional function        |
| Max phase angle GFC  | 0...90   | deg  | 1    | 80                | Right hand side angle, earth-fault di-                        |

*Table continues on the next page*

| Parameter            | Values (Range)    | Unit | Step | Default | Description  |
|----------------------|-------------------|------|------|---------|--|
|                      |                   |      |      |         | rectional function   |
| Min phase angle GFC  | 0...90            | deg  | 1    | 80      | Left hand side angle, earth-fault directional function       |
| Cross-country DI GFC | 0...10000         | ms   | 10   | 100     | Time delay for residual current, XC-fault detection function |
| Tilt angle zone 1    | -45...45          | deg  | 1    | 0       | Tilt angle (positive value increases zone area), zone 1      |
| Par line Comp zone 1 | 0=False<br>1=True |      |      | 0=False | Enable parallel line compensation for PE- loops, zone 1      |
| Mutual R0 zone 1     | 0.00...3000.00    | ohm  | 0.01 | 40.00   | Parallel line zero sequence mutual resistance, zone 1        |
| Mutual X0 zone 1     | 0.00...3000.00    | ohm  | 0.01 | 40.00   | Parallel line zero sequence mutual reactance, zone 1         |
| Tilt angle zone 2    | -45...45          | deg  | 1    | 0       | Tilt angle (positive value increases zone area), zone 2      |
| Par line Comp zone 2 | 0=False<br>1=True |      |      | 0=False | Enable parallel line compensation for PE- loops, zone 2      |
| Mutual R0 zone 2     | 0.00...3000.00    | ohm  | 0.01 | 40.00   | Parallel line zero sequence mutual resistance, zone 2        |

*Table continues on the next page*

| Parameter            | Values (Range)    | Unit | Step | Default | Description   |
|----------------------|-------------------|------|------|---------|---|
| Mutual X0 zone 2     | 0.00...3000.00    | ohm  | 0.01 | 40.00   | Parallel line zero sequence mutual reactance, zone 2    |
| Tilt angle zone 3    | -45...45          | deg  | 1    | 0       | Tilt angle (positive value increases zone area), zone 3 |
| Par line Comp zone 3 | 0=False<br>1=True |      |      | 0=False | Enable parallel line compensation for PE- loops, zone 3 |
| Mutual R0 zone 3     | 0.00...3000.00    | ohm  | 0.01 | 40.00   | Parallel line zero sequence mutual resistance, zone 3   |
| Mutual X0 zone 3     | 0.00...3000.00    | ohm  | 0.01 | 40.00   | Parallel line zero sequence mutual reactance, zone 3    |
| Tilt angle zone 4    | -45...45          | deg  | 1    | 0       | Tilt angle (positive value increases zone area), zone 4 |
| Par line Comp zone 4 | 0=False<br>1=True |      |      | 0=False | Enable parallel line compensation for PE- loops, zone 4 |
| Mutual R0 zone 4     | 0.00...3000.00    | ohm  | 0.01 | 40.00   | Parallel line zero sequence mutual resistance, zone 4   |
| Mutual X0 zone 4     | 0.00...3000.00    | ohm  | 0.01 | 40.00   | Parallel line zero sequence mutual reactance, zone 4    |
| Tilt angle zone 5    | -45...45          | deg  | 1    | 0       | Tilt angle (positive value increases                    |

*Table continues on the next page*

| Parameter            | Values (Range)    | Unit | Step | Default | Description   |
|----------------------|-------------------|------|------|---------|---|
|                      |                   |      |      |         | zone area), zone 5                                      |
| Par line Comp zone 5 | 0=False<br>1=True |      |      | 0=False | Enable parallel line compensation for PE- loops, zone 5 |
| Mutual R0 zone 5     | 0.00...3000.00    | ohm  | 0.01 | 40.00   | Parallel line zero sequence mutual resistance, zone 5   |
| Mutual X0 zone 5     | 0.00...3000.00    | ohm  | 0.01 | 40.00   | Parallel line zero sequence mutual reactance, zone 5    |

#### DSTPDIS Non group settings (Basic)

Table 539: DSTPDIS Non group settings (Basic)

| Parameter            | Values (Range)   | Unit | Step | Default         | Description                         |
|----------------------|--|------|------|-----------------|-------------------------------------|
| Operation            | 1=on<br>5=off  |      |      | 1=on            | Operation Off / On                  |
| Phase voltage Meas   | 1=Accurate<br>2=Ph-to-ph without Uo                                    |      |      | 1=Accurate      | Phase voltage measurement principle |
| Select active zones  | 1=Zone 1<br>2=Zones 1-2<br>3=Zones 1-3<br>4=Zones 1-4<br>5=All 5 zones |      |      | 1=Zone 1        | Active zones selection              |
| System grounding GFC | 1=High impedance<br>2=Low impedance<br>3=From input                    |      |      | 2=Low impedance | Network neutral earthing method     |
| Ph Prf mode Lo Z GFC | 1=All loops<br>2=PE only   |      |      | 1=All loops     | Loop selection mode for             |

Table continues on the next page

| Parameter               | Values (Range)  | Unit | Step | Default         | Description  |
|-------------------------|---|------|------|-----------------|--|
|                         | 3=PP only<br>4=BLK leading PE<br>5=BLK lagging PE   |      |      |                 | low impedance earthed network                            |
| Ph Prf mode<br>Hi Z GFC | 1=No filter<br>2=No preference<br>3=Cyc A-B-C-A<br>4=Cyc A-C-B-A<br>5=Acyc A-B-C<br>6=Acyc A-C-B<br>7=Acyc B-A-C<br>8=Acyc B-C-A<br>9=Acyc C-A-B<br>10=Acyc C-B-A |      |      | 1=No filter     | Phase preference mode for high impedance earthed network |
| Impedance mode Zn       | 1=Rectangular<br>2=Polar  |      |      | 1=Rectangular   | Impedance characteristic, underimpedance, PSL            |
| Impedance Chr Gnd Zn    | 1=Quadrilateral<br>2=Mho (circular)<br>3=Mho Dir line<br>4=Offset Dir line<br>5=Bullet (combi)  |      |      | 1=Quadrilateral | Impedance characteristic for PE-loops, zones             |
| Impedance Chr PP Zn     | 1=Quadrilateral<br>2=Mho (circular)<br>3=Mho Dir line<br>4=Offset Dir line  |      |      | 1=Quadrilateral | Impedance characteristic for PP/3P-loops, zones          |

Table continues on the next page

| Parameter            | Values (Range)                                 | Unit | Step | Default           | Description   |
|----------------------|--|------|------|-------------------|---|
|                      | 5=Bullet (combi)                               |      |      |                   |   |
| Pol quantity zone    | 5=Cross pol<br>7=Pos. seq. volt.<br>1=Self pol |      |      | 7=Pos. seq. volt. | Mho polarization method for zones                     |
| Max phase angle zone | 0...45   | deg  | 1    | 15                | Angle from R-axis to right hand side directional line |
| Min phase angle zone | 90...135                                       | deg  | 1    | 115               | Angle from R-axis to left hand side directional line  |

#### DSTPDIS Non group settings (Advanced)

Table 540: DSTPDIS Non group settings (Advanced)

| Parameter            | Values (Range)            | Unit | Step  | Default       | Description   |
|----------------------|---------------------------|------|-------|---------------|---|
| EF Cur stabilization | 0=False<br>1=True         |      |       | 0=False       | EF current stabilization enabled                      |
| Fact EF current Bal  | 1.000...2.000             |      | 0.001 | 1.200         | Residual current ratio for parallel line compensation |
| Zone timer mode      | 1=Independent<br>2=Common |      |       | 1=Independent | Operate timer start mode, zones                       |
| Voltage Mem time     | 0...300000                | ms   | 10    | 40            | Voltage memory time                                   |

### 3.7.1.10

#### Monitored data

**DSTPDIS Monitored data****Table 541: DSTPDIS Monitored data**

| Name       | Type    | Values (Range)   | Unit | Description                                   |
|------------|---------|--|------|---|
| STARTS_GFC | Enum    | 4=AB Fault<br>5=BC Fault<br>6=CA Fault<br>7=ABC Fault<br>-5=No fault<br>1=AG Fault<br>2=BG Fault<br>3=CG Fault |      | Start signals for phases A, B and C, GFC      |
| RELEASE_PE | Enum    | -5=No fault<br>1=AG Fault<br>2=BG Fault<br>3=CG Fault<br>4=AB Fault<br>5=BC Fault<br>6=CA Fault<br>7=ABC Fault |      | Release signals for PE- loops, GFC            |
| RELEASE_PP | Enum    | 5=BC Fault<br>6=CA Fault<br>7=ABC Fault<br>4=AB Fault<br>-5=No fault   |      | Release signals for PP/3P loops, GFC          |
| EARTH_FLT  | BOOLEAN | 0=False<br>1=True  |      | Indication of a single phase earth-fault, GFC |
| DIR_E_FLT  | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both   |      | Earth-fault direction (low imp. earthed), GFC |
| STARTS_Z1  | INT32   | -5...31  |      | Start signals for phases A, B and C, zone 1   |
| STARTS_Z2  | INT32   | -5...31  |      | Start signals for phases A, B and C, zone 2   |

*Table continues on the next page*



| Name             | Type    | Values (Range)                                 | Unit | Description                                      |
|------------------|---------|--|------|--|
| STARTS_Z3        | INT32   | -5...31  |      | Start signals for phases A, B and C, zone 3      |
| STARTS_Z4        | INT32   | -5...31  |      | Start signals for phases A, B and C, zone 4      |
| STARTS_Z5        | INT32   | -5...31  |      | Start signals for phases A, B and C, zone 5      |
| DIRECTION        | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Direction of fault or load                       |
| DIR_LOOP_R       | FLOAT32 | -3000.00...3000.00                             | ohm  | Resistance used in dir. evaluation, zone 1       |
| DIR_LOOP_X       | FLOAT32 | -3000.00...3000.00                             | ohm  | Reactance used in dir. eval., zone 1             |
| FLTLOOP_RFST     | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop resistance, zone 1                 |
| FLTLOOP_XFST     | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop reactance, zone 1                  |
| FLTLOOP_RSND     | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop resistance, zone 1                |
| FLTLOOP_XSND     | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop reactance, zone 1                 |
| FLTLOOP_RPP      | FLOAT32 | -3000.00...3000.00                             | ohm  | PP/3P-loop resistance, zone 1                    |
| FLTLOOP_XPP      | FLOAT32 | -3000.00...3000.00                             | ohm  | PP/3P-loop reactance, zone 1                     |
| FLTPH_X          | FLOAT32 | -3000.00...3000.00                             | ohm  | Phase to earth reactance in phase domain, zone 1 |
| VMEM_USED        | BOOLEAN | 0=False<br>1=True                              |      | Voltage memory in use status                     |
| TLT_ANG_CONFLICT | INT32   | 0...1023                                       |      | Tilt angle conflict                              |
| DSTPDIS          | Enum    | 1=on<br>2=blocked<br>3=test                    |      | Status   |

*Table continues on the next page*

| Name                  | Type      | Values (Range)  | Unit | Description   |
|-----------------------|-----------|---|------|---|
|                       |           | 4=test/blocked<br>5=off   |      |   |
| Time                  | Timestamp |   |      | Time  |
| Release PE-loop       | Enum      | -5=No fault<br>-4=ABCG Fault<br>-3=CAG Fault<br>-2=BCG Fault<br>-1=ABG Fault<br>1=AG Fault<br>2=BG Fault<br>3=CG Fault<br>4=AB Fault<br>5=BC Fault<br>6=CA Fault<br>7=ABC Fault |      | Release signals for PE- loops, GFC                            |
| Release PP-loop       | Enum      | -5=No fault<br>-4=ABCG Fault<br>-3=CAG Fault<br>-2=BCG Fault<br>-1=ABG Fault<br>1=AG Fault<br>2=BG Fault<br>3=CG Fault<br>4=AB Fault<br>5=BC Fault<br>6=CA Fault<br>7=ABC Fault |      | Release signals for PP/3P loops. GFC                          |
| Cross country fault   | BOOLEAN   | 0=False<br>1=True   |      | Indication of a cross- country-fault (high imp. earthed), GFC |
| Earth fault detected  | BOOLEAN   | 0=False<br>1=True   |      | Indication of a single phase earth-fault, GFC                 |
| Earth-fault direction | Enum      | 0=unknown<br>1=forward<br>2=backward  |      | Earth-fault direction (low impedance earthed), GFC            |

*Table continues on the next page*

| Name                 | Type    | Values (Range)                                 | Unit | Description                                      |
|----------------------|---------|--|------|--|
|                      |         | 3=both   |      |  |
| Operate of all zones | INT32   | 0...31   |      | Operate signal of all zones                      |
| Fault/load Dir Zn1   | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Direction of fault or load zone 1                |
| Dir resistance Zn1   | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction resistance, zone 1                     |
| Dir reactance Zn1    | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction reactance, zone 1                      |
| Flt loop 1st Ris Zn1 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop resistance, zone 1                 |
| Flt loop 1st Rea Zn1 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop reactance, zone 1                  |
| Flt loop 2nd Ris Zn1 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop resistance, zone 1                |
| Flt loop 2nd Rea Zn1 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop reactance, zone 1                 |
| Flt PP-loop Ris Zn1  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop resistance, zone 1                       |
| Flt PP-loop Rea Zn1  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop reactance, zone 1                        |
| Phase reactance Zn1  | FLOAT32 | -3000.00...3000.00                             | ohm  | Phase to earth reactance in phase domain, zone 1 |
| Fault/load Dir Zn2   | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Direction of fault or load zone 2                |
| Dir resistance Zn2   | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction resistance, zone 2                     |
| Dir reactance Zn2    | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction reactance, zone 2                      |
| Flt loop 1st Ris Zn2 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop resistance, zone 2                 |
| Flt loop 1st Rea Zn2 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop reactance, zone 2                  |

*Table continues on the next page*

| Name                 | Type    | Values (Range)                                 | Unit | Description                                      |
|----------------------|---------|--|------|--|
| Flt loop 2nd Ris Zn2 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop resistance, zone 2                |
| Flt loop 2nd Rea Zn2 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop reactance, zone 2                 |
| Flt PP-loop Ris Zn2  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop resistance, zone 2                       |
| Flt PP-loop Rea Zn2  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop reactance, zone 2                        |
| Phase reactance Zn2  | FLOAT32 | -3000.00...3000.00                             | ohm  | Phase to earth reactance in phase domain, zone 2 |
| Fault/load Dir Zn3   | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both | ohm  | Direction of fault or load zone 3                |
| Dir resistance Zn3   | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction resistance, zone 3                     |
| Dir reactance Zn3    | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction reactance, zone 3                      |
| Flt loop 1st Ris Zn3 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop resistance, zone 3                 |
| Flt loop 1st Rea Zn3 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop reactance, zone 3                  |
| Flt loop 2nd Ris Zn3 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop resistance, zone 3                |
| Flt loop 2nd Rea Zn3 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop reactance, zone 3                 |
| Flt PP-loop Ris Zn3  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop resistance, zone 3                       |
| Flt PP-loop Rea Zn3  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop reactance, zone 3                        |
| Phase reactance Zn3  | FLOAT32 | -3000.00...3000.00                             | ohm  | Phase to earth reactance in phase domain, zone 3 |
| Fault/load Dir Zn4   | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Direction of fault or load zone 4                |

Table continues on the next page

| Name                 | Type    | Values (Range)                                 | Unit | Description                                      |
|----------------------|---------|--|------|--|
| Dir resistance Zn4   | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction resistance, zone 4                     |
| Dir reactance Zn4    | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction reactance, zone 4                      |
| Flt loop 1st Ris Zn4 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop resistance, zone 4                 |
| Flt loop 1st Rea Zn4 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop reactance, zone 4                  |
| Flt loop 2nd Ris Zn4 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop resistance, zone 4                |
| Flt loop 2nd Rea Zn4 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop reactance, zone 4                 |
| Flt PP-loop Ris Zn4  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop resistance, zone 4                       |
| Flt PP-loop Rea Zn4  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop reactance, zone 4                        |
| Phase reactance Zn4  | FLOAT32 | -3000.00...3000.00                             | ohm  | Phase to earth reactance in phase domain, zone 4 |
| Fault/load Dir Zn5   | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Direction of fault or load zone 5                |
| Dir resistance Zn5   | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction resistance, zone 5                     |
| Dir reactance Zn5    | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction reactance, zone 5                      |
| Flt loop 1st Ris Zn5 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop resistance, zone 5                 |
| Flt loop 1st Rea Zn5 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop reactance, zone 5                  |
| Flt loop 2nd Ris Zn5 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop resistance, zone 5                |
| Flt loop 2nd Rea Zn5 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop reactance, zone 5                 |
| Flt PP-loop Ris Zn5  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop resistance, zone 5                       |
| Flt PP-loop Rea Zn5  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop reactance, zone 5                        |

*Table continues on the next page*

| Name                  | Type      | Values (Range)  | Unit | Description   |
|-----------------------|-----------|---|------|---|
| Phase reactance Zn5   | FLOAT32   | -3000.00...3000.00  | ohm  | Phase to earth reactance in phase domain, zone 5              |
| Time                  | Timestamp |   |      | Time  |
| Release PE-loop       | Enum      | -5=No fault<br>-4=ABCG Fault<br>-3=CAG Fault<br>-2=BCG Fault<br>-1=ABG Fault<br>1=AG Fault<br>2=BG Fault<br>3=CG Fault<br>4=AB Fault<br>5=BC Fault<br>6=CA Fault<br>7=ABC Fault |      | Release signals for PE- loops, GFC                            |
| Release PP-loop       | Enum      | -5=No fault<br>-4=ABCG Fault<br>-3=CAG Fault<br>-2=BCG Fault<br>-1=ABG Fault<br>1=AG Fault<br>2=BG Fault<br>3=CG Fault<br>4=AB Fault<br>5=BC Fault<br>6=CA Fault<br>7=ABC Fault |      | Release signals for PP/3P loops. GFC                          |
| Cross country fault   | BOOLEAN   | 0=False<br>1=True   |      | Indication of a cross- country-fault (high imp. earthed), GFC |
| Earth fault detected  | BOOLEAN   | 0=False<br>1=True   |      | Indication of a single phase earth-fault, GFC                 |
| Earth-fault direction | Enum      | 0=unknown<br>1=forward  |      | Earth-fault direction (low impe-                              |

Table continues on the next page

| Name                 | Type    | Values (Range)                                 | Unit | Description                                      |
|----------------------|---------|--|------|--|
|                      |         | 2=backward<br>3=both                           |      | dance earthed),<br>GFC                           |
| Operate of all zones | INT32   | 0...31   |      | Operate signal of all zones                      |
| Fault/load Dir Zn1   | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Direction of fault or load zone 1                |
| Dir resistance Zn1   | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction resistance, zone 1                     |
| Dir reactance Zn1    | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction reactance, zone 1                      |
| Flt loop 1st Ris Zn1 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop resistance, zone 1                 |
| Flt loop 1st Rea Zn1 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop reactance, zone 1                  |
| Flt loop 2nd Ris Zn1 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop resistance, zone 1                |
| Flt loop 2nd Rea Zn1 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop reactance, zone 1                 |
| Flt PP-loop Ris Zn1  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop resistance, zone 1                       |
| Flt PP-loop Rea Zn1  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop reactance, zone 1                        |
| Phase reactance Zn1  | FLOAT32 | -3000.00...3000.00                             | ohm  | Phase to earth reactance in phase domain, zone 1 |
| Fault/load Dir Zn2   | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Direction of fault or load zone 2                |
| Dir resistance Zn2   | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction resistance, zone 2                     |
| Dir reactance Zn2    | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction reactance, zone 2                      |
| Flt loop 1st Ris Zn2 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop resistance, zone 2                 |
| Flt loop 1st Rea Zn2 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop reactance, zone 2                  |

*Table continues on the next page*

| Name                 | Type    | Values (Range)                                 | Unit | Description                                      |
|----------------------|---------|--|------|--|
| Flt loop 2nd Ris Zn2 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop resistance, zone 2                |
| Flt loop 2nd Rea Zn2 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop reactance, zone 2                 |
| Flt PP-loop Ris Zn2  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop resistance, zone 2                       |
| Flt PP-loop Rea Zn2  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop reactance, zone 2                        |
| Phase reactance Zn2  | FLOAT32 | -3000.00...3000.00                             | ohm  | Phase to earth reactance in phase domain, zone 2 |
| Fault/load Dir Zn3   | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Direction of fault or load zone 3                |
| Dir resistance Zn3   | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction resistance, zone 3                     |
| Dir reactance Zn3    | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction reactance, zone 3                      |
| Flt loop 1st Ris Zn3 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop resistance, zone 3                 |
| Flt loop 1st Rea Zn3 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop reactance, zone 3                  |
| Flt loop 2nd Ris Zn3 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop resistance, zone 3                |
| Flt loop 2nd Rea Zn3 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop reactance, zone 3                 |
| Flt PP-loop Ris Zn3  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop resistance, zone 3                       |
| Flt PP-loop Rea Zn3  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop reactance, zone 3                        |
| Phase reactance Zn3  | FLOAT32 | -3000.00...3000.00                             | ohm  | Phase to earth reactance in phase domain, zone 3 |
| Fault/load Dir Zn4   | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Direction of fault or load zone 4                |

Table continues on the next page



| Name                 | Type    | Values (Range)                                 | Unit | Description                                      |
|----------------------|---------|--|------|--|
| Dir resistance Zn4   | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction resistance, zone 4                     |
| Dir reactance Zn4    | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction reactance, zone 4                      |
| Flt loop 1st Ris Zn4 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop resistance, zone 4                 |
| Flt loop 1st Rea Zn4 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop reactance, zone 4                  |
| Flt loop 2nd Ris Zn4 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop resistance, zone 4                |
| Flt loop 2nd Rea Zn4 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop reactance, zone 4                 |
| Flt PP-loop Ris Zn4  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop resistance, zone 4                       |
| Flt PP-loop Rea Zn4  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop reactance, zone 4                        |
| Phase reactance Zn4  | FLOAT32 | -3000.00...3000.00                             | ohm  | Phase to earth reactance in phase domain, zone 4 |
| Fault/load Dir Zn5   | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Direction of fault or load zone 5                |
| Dir resistance Zn5   | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction resistance, zone 5                     |
| Dir reactance Zn5    | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction reactance, zone 5                      |
| Flt loop 1st Ris Zn5 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop resistance, zone 5                 |
| Flt loop 1st Rea Zn5 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop reactance, zone 5                  |
| Flt loop 2nd Ris Zn5 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop resistance, zone 5                |
| Flt loop 2nd Rea Zn5 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop reactance, zone 5                 |
| Flt PP-loop Ris Zn5  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop resistance, zone 5                       |
| Flt PP-loop Rea Zn5  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop reactance, zone 5                        |

*Table continues on the next page*

| Name                  | Type      | Values (Range)  | Unit | Description   |
|-----------------------|-----------|---|------|---|
| Phase reactance Zn5   | FLOAT32   | -3000.00...3000.00  | ohm  | Phase to earth reactance in phase domain, zone 5              |
| Time                  | Timestamp |   |      | Time  |
| Release PE-loop       | Enum      | -5=No fault<br>-4=ABCG Fault<br>-3=CAG Fault<br>-2=BCG Fault<br>-1=ABG Fault<br>1=AG Fault<br>2=BG Fault<br>3=CG Fault<br>4=AB Fault<br>5=BC Fault<br>6=CA Fault<br>7=ABC Fault |      | Release signals for PE- loops, GFC                            |
| Release PP-loop       | Enum      | -5=No fault<br>-4=ABCG Fault<br>-3=CAG Fault<br>-2=BCG Fault<br>-1=ABG Fault<br>1=AG Fault<br>2=BG Fault<br>3=CG Fault<br>4=AB Fault<br>5=BC Fault<br>6=CA Fault<br>7=ABC Fault |      | Release signals for PP/3P loops. GFC                          |
| Cross country fault   | BOOLEAN   | 0=False<br>1=True   |      | Indication of a cross- country-fault (high imp. earthed), GFC |
| Earth fault detected  | BOOLEAN   | 0=False<br>1=True   |      | Indication of a single phase earth-fault, GFC                 |
| Earth-fault direction | Enum      | 0=unknown<br>1=forward  |      | Earth-fault direction (low impe-                              |

Table continues on the next page

| Name                 | Type    | Values (Range)                                 | Unit | Description                                      |
|----------------------|---------|--|------|--|
|                      |         | 2=backward<br>3=both                           |      | dance earthed),<br>GFC                           |
| Operate of all zones | INT32   | 0...31   |      | Operate signal of all zones                      |
| Fault/load Dir Zn1   | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Direction of fault or load zone 1                |
| Dir resistance Zn1   | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction resistance, zone 1                     |
| Dir reactance Zn1    | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction reactance, zone 1                      |
| Flt loop 1st Ris Zn1 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop resistance, zone 1                 |
| Flt loop 1st Rea Zn1 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop reactance, zone 1                  |
| Flt loop 2nd Ris Zn1 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop resistance, zone 1                |
| Flt loop 2nd Rea Zn1 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop reactance, zone 1                 |
| Flt PP-loop Ris Zn1  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop resistance, zone 1                       |
| Flt PP-loop Rea Zn1  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop reactance, zone 1                        |
| Phase reactance Zn1  | FLOAT32 | -3000.00...3000.00                             | ohm  | Phase to earth reactance in phase domain, zone 1 |
| Fault/load Dir Zn2   | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Direction of fault or load zone 2                |
| Dir resistance Zn2   | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction resistance, zone 2                     |
| Dir reactance Zn2    | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction reactance, zone 2                      |
| Flt loop 1st Ris Zn2 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop resistance, zone 2                 |
| Flt loop 1st Rea Zn2 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop reactance, zone 2                  |

*Table continues on the next page*

| Name                 | Type    | Values (Range)                                 | Unit | Description                                      |
|----------------------|---------|--|------|--|
| Flt loop 2nd Ris Zn2 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop resistance, zone 2                |
| Flt loop 2nd Rea Zn2 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop reactance, zone 2                 |
| Flt PP-loop Ris Zn2  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop resistance, zone 2                       |
| Flt PP-loop Rea Zn2  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop reactance, zone 2                        |
| Phase reactance Zn2  | FLOAT32 | -3000.00...3000.00                             | ohm  | Phase to earth reactance in phase domain, zone 2 |
| Fault/load Dir Zn3   | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Direction of fault or load zone 3                |
| Dir resistance Zn3   | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction resistance, zone 3                     |
| Dir reactance Zn3    | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction reactance, zone 3                      |
| Flt loop 1st Ris Zn3 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop resistance, zone 3                 |
| Flt loop 1st Rea Zn3 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop reactance, zone 3                  |
| Flt loop 2nd Ris Zn3 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop resistance, zone 3                |
| Flt loop 2nd Rea Zn3 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop reactance, zone 3                 |
| Flt PP-loop Ris Zn3  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop resistance, zone 3                       |
| Flt PP-loop Rea Zn3  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop reactance, zone 3                        |
| Phase reactance Zn3  | FLOAT32 | -3000.00...3000.00                             | ohm  | Phase to earth reactance in phase domain, zone 3 |
| Fault/load Dir Zn4   | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Direction of fault or load zone 4                |

Table continues on the next page

| Name                 | Type    | Values (Range)                                 | Unit | Description                                      |
|----------------------|---------|--|------|--|
| Dir resistance Zn4   | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction resistance, zone 4                     |
| Dir reactance Zn4    | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction reactance, zone 4                      |
| Flt loop 1st Ris Zn4 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop resistance, zone 4                 |
| Flt loop 1st Rea Zn4 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop reactance, zone 4                  |
| Flt loop 2nd Ris Zn4 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop resistance, zone 4                |
| Flt loop 2nd Rea Zn4 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop reactance, zone 4                 |
| Flt PP-loop Ris Zn4  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop resistance, zone 4                       |
| Flt PP-loop Rea Zn4  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop reactance, zone 4                        |
| Phase reactance Zn4  | FLOAT32 | -3000.00...3000.00                             | ohm  | Phase to earth reactance in phase domain, zone 4 |
| Fault/load Dir Zn5   | Enum    | 0=unknown<br>1=forward<br>2=backward<br>3=both |      | Direction of fault or load zone 5                |
| Dir resistance Zn5   | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction resistance, zone 5                     |
| Dir reactance Zn5    | FLOAT32 | -3000.00...3000.00                             | ohm  | Direction reactance, zone 5                      |
| Flt loop 1st Ris Zn5 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop resistance, zone 5                 |
| Flt loop 1st Rea Zn5 | FLOAT32 | -3000.00...3000.00                             | ohm  | First PE-loop reactance, zone 5                  |
| Flt loop 2nd Ris Zn5 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop resistance, zone 5                |
| Flt loop 2nd Rea Zn5 | FLOAT32 | -3000.00...3000.00                             | ohm  | Second PE-loop reactance, zone 5                 |
| Flt PP-loop Ris Zn5  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop resistance, zone 5                       |
| Flt PP-loop Rea Zn5  | FLOAT32 | -3000.00...3000.00                             | ohm  | PP-loop reactance, zone 5                        |
| Phase reactance Zn5  | FLOAT32 | -3000.00...3000.00                             | ohm  | Phase to earth reactance in                      |

| Name | Type | Values (Range) | Unit | Description          |
|------|------|----------------|------|----------------------|
|      |      |                |      | phase domain, zone 5 |

### 3.7.1.11 Technical data

| Characteristic  | Value   |
|---|---|
| Operation accuracy                                      | At the frequency $f = f_n$<br>Current:<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$<br>Voltage:<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times U_n$<br>Impedance:<br>$\pm 2.5\%$ of the set value or $\pm 0.05 \Omega$<br>Phase angle: $\pm 2^\circ$ |
| Operate time <sup>77</sup> SIR <sup>78</sup> : 0.1...50 | 40 ms   |
| Transient overreach SIR = 0.1...50                      | <3%   |
| Reset time  | Typically 45 ms   |
| Reset ratio   | Typically 0.96/1.04   |
| Operate time accuracy                                   | $\pm 1.0\%$ of the set value or $\pm 20$ ms   |

## 3.7.2 Three-phase underimpedance protection UZPDIS

### 3.7.2.1 Identification

| Function description                  | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---------------------------------------|--------------------------|--------------------------|-------------------------------|
| Three-phase underimpedance protection | UZPDIS                   | Z<G                      | 21G                           |

<sup>77</sup> Measured with High-speed output (HSO)

<sup>78</sup> SIR = Source impedance ratio

### 3.7.2.2 Function block

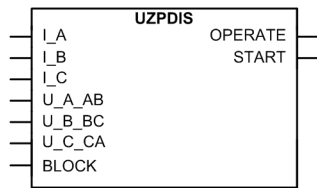


Figure 308: Function block

### 3.7.2.3 Functionality

The three-phase underimpedance protection UZPDIS is generally applied as a backup protection for generators and transformers against short circuit faults.

The protection is based on the origin-centric circular characteristics on the impedance plane. The function calculates the impedance value from the voltage and current phasors. If the impedance vector enters the origin-centric circle, the function produces the operating signal after a set delay. The operating time characteristics are according to definite time (DT).

This function contains a blocking functionality. It is possible to block the function outputs, reset timer or the function itself, if desired.

### 3.7.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the three-phase underimpedance protection can be described with a module diagram. All the modules in the diagram are explained in the next sections.

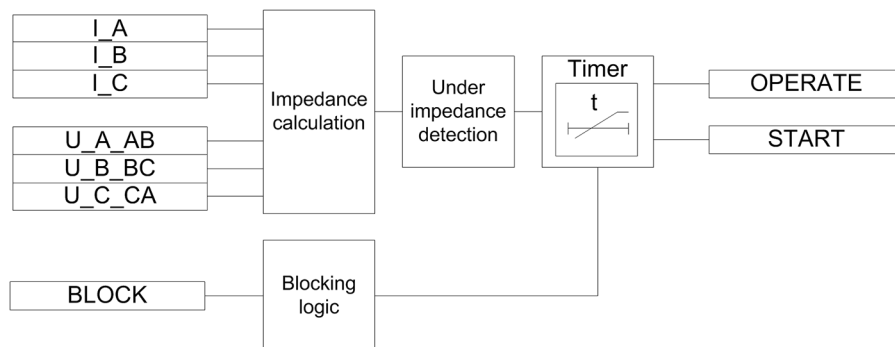


Figure 309: Functional module diagram

#### Impedance calculation

This module calculates the impedance based on the selected voltages and currents. The *Impedance Meas mode* and *Phase Sel for Z Clc* settings determine which voltages and currents are to be used. If *Impedance Meas mode* is set to "1Phase-phase", the *Phase Sel for Z Clc* setting is needed for determining which phase-phase voltages ("AB", "BC" and "CA") and currents should be used for calculating the impedance.

**Table 542: Voltages and currents used in impedance calculation**

| Impedance Meas mode | Phase Sel for Z Clc | Voltages and currents used in impedance calculation <sup>79</sup>  |
|---------------------|---------------------|--|
| 1Phase-phase        | AB                  | $\overline{Z_{AB}} = \frac{U_{AB}}{I_A - I_B}$   |
| 1Phase-phase        | BC                  | $\overline{Z_{BC}} = \frac{U_{BC}}{I_B - I_C}$   |
| 1Phase-phase        | CA                  | $\overline{Z_{CA}} = \frac{U_{CA}}{I_C - I_A}$   |
| 3Phase-phase        | N/A                 | $\overline{Z_{AB}} = \frac{U_{AB}}{I_A - I_B}$<br>$\overline{Z_{BC}} = \frac{U_{BC}}{I_B - I_C}$<br>$\overline{Z_{CA}} = \frac{U_{CA}}{I_C - I_A}$ |



If all three phase or phase-phase voltages and phase currents are fed to the IED, the "3Phase-phase" mode is recommended.

The current measurement of the function is based on two alternative measurement modes, "DFT" and "Peak-To-Peak". The measurement mode is selected using the *Measurement mode* setting.

If the current magnitude is below  $0.02 \cdot I_N$ , where  $I_N$  is the nominal phase current, the impedance value is not evaluated and the maximum impedance value (99.999 pu) is shown in the Monitored data view.



The calculated impedances are converted to a pu impedance as the operating characteristics are defined using the *Polar reach* setting in %Zb.

The calculated phase-phase impedance amplitudes ZAB\_AMPL, ZBC\_AMPL and ZCA\_AMPL are available as pu values in the Monitored data view.

### Underimpedance detection

The operating characteristic is an origin-centric circle on the impedance plane. The origin-centric circular characteristic is defined using the *Polar reach* setting. If the calculated impedance value enters the circle in the impedance plane, the module sends an enabling signal to start the Timer.

<sup>79</sup> Voltages and currents in the calculations are given in volts and amps.



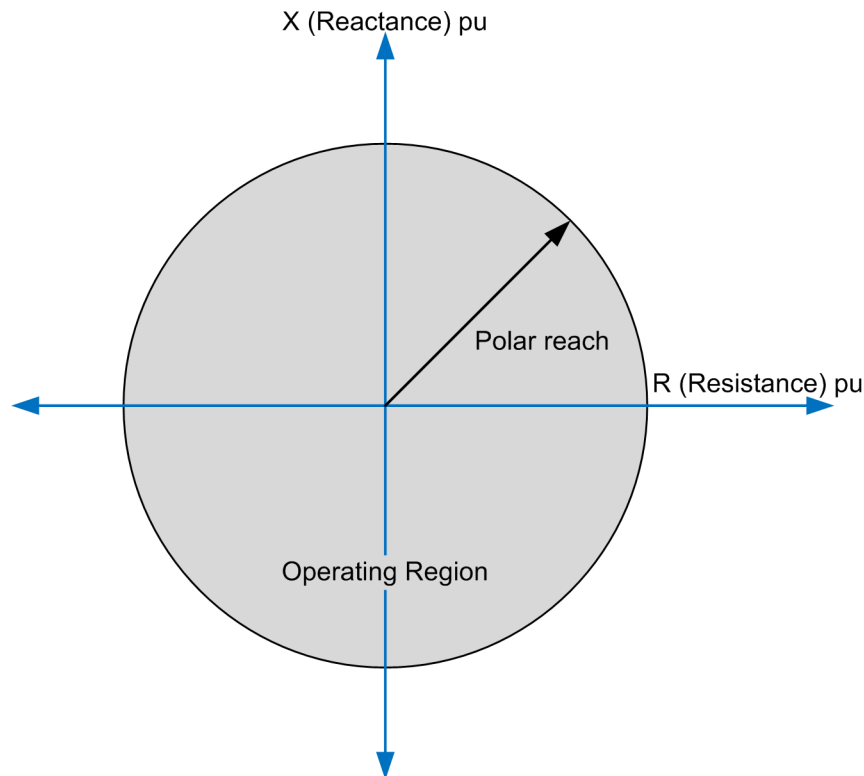


Figure 310: Origin-centric circular operating characteristics



More than one impedance value is available when *Impedance Meas mode* is set to "3Phase-phase", and the function considers the lowest impedance value for starting and operating.

### Timer

Once activated, the Timer activates `START` output. The time characteristic is according to `DT`. When the duration of the underimpedance condition exceeds the set definite *Operate delay time*, the `OPERATE` output is activated. If the impedance locus moves out of circular operating characteristics before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operating timer resets and the `START` output is deactivated.

The Timer calculates the start duration value `START_DUR`, which indicates the percentage ratio of the start situation and the set operating time (`DT`). The value is available in the Monitored data view.

### Blocking logic

There are three operation modes in the blocking functionality. The operation modes are controlled by the `BLOCK` input and the global setting **Configuration > System > Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

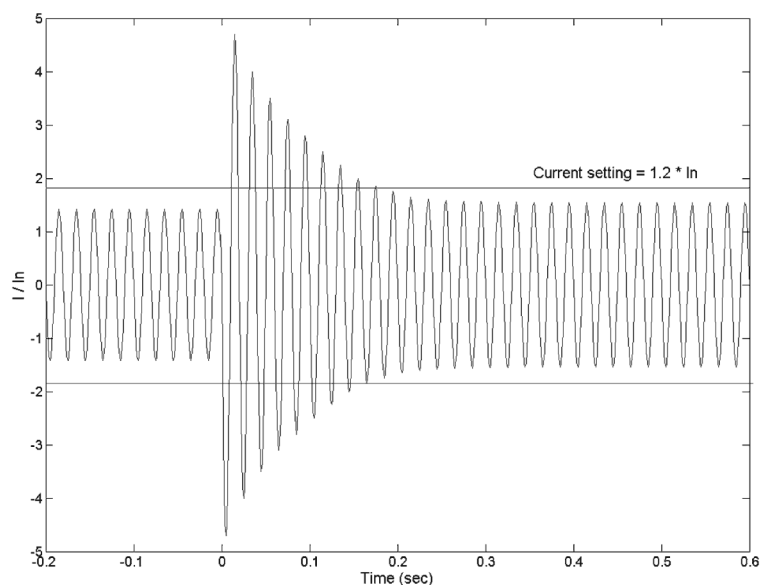
The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

### 3.7.2.5 Application

The three-phase underimpedance protection is used as a backup protection against short circuit faults at the generator terminals or on the high-voltage side of a step-up transformer. This function can be used either instead of the definite time voltage-dependent overcurrent protection or to obtain a limited protection zone and the optimum operating time instead of the non-directional overcurrent protection.

#### Comparison between overcurrent and underimpedance protection

Phase current for three-phase short circuit is shown in [Figure 311](#). In this case, with an ordinary over current relay having the current setting as  $1.2 \cdot I_n$ , the time setting should be less than 0.2 seconds, since with a higher value the short-circuit current decays below the set value and the relay drops off. The current setting can also be reduced to  $1.1 \cdot I_n$ , although this provides no substantial rise in the time setting. In some situations, either of the above current settings is appropriate, but if longer tripping times are required to maintain the time selectivity, the underimpedance protection is needed.



*Figure 311: Short circuit current waveform, fault occurs at time 0 seconds (Current setting limit is multiplied by the square root of 2)*

The phase voltage in a three-phase short circuit when a fault occurs at time = 0 s is shown in [Figure 312](#). The voltage drop caused by a three-phase fault provides more time for determining the fault by means of an underimpedance protection.

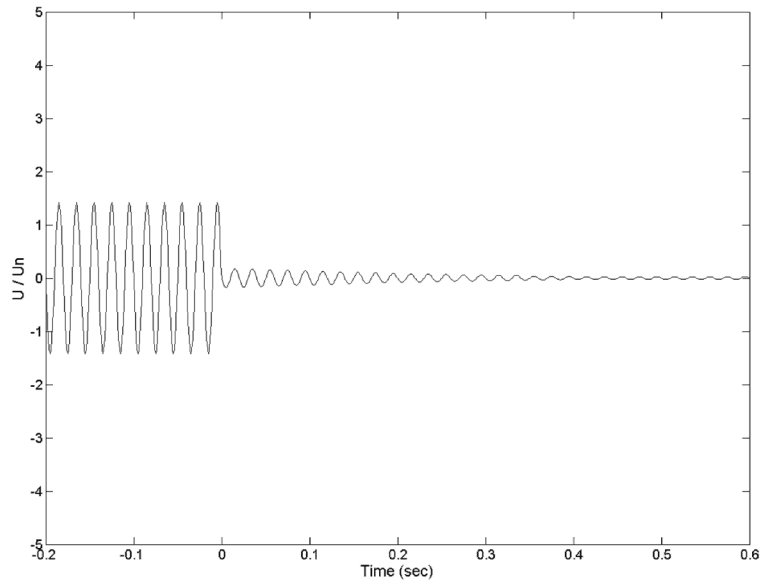


Figure 312: Short-circuit voltage waveform, fault occurs at time 0 seconds

In a typical impedance trajectory during a short circuit, the fault impedance remains inside the impedance circle for a longer time, in which case the underimpedance protection provides longer tripping delay times to maintain the time selectivity.

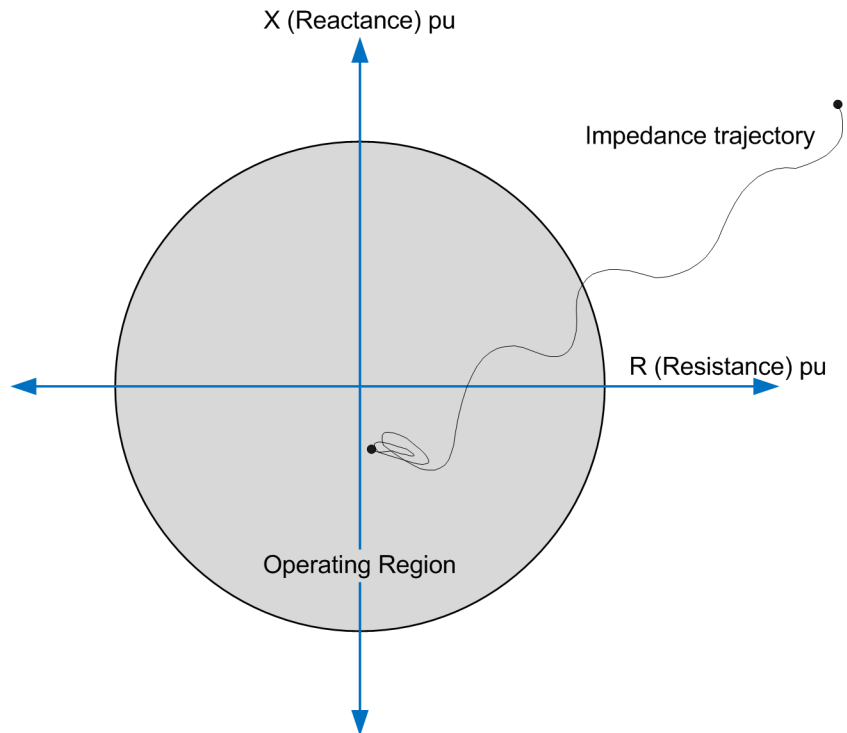


Figure 313: Typical impedance trajectory during a short circuit

**Underimpedance protection for transformers**

The underimpedance function is used as a short circuit protection instead of the overcurrent protection. It is also used as a backup to the differential protection of transformers.

The voltage and current phasors are measured with the VTs and CTs connected on the HV side of the transformer.



The phase and current shifts due to transformer D/Y connections and other factors complicate the settings for the faults in the secondary winding (as seen from the IED), and detailed calculations are necessary for a good coverage.

The *Polar reach* setting is set to a value equal to 150 percent of the transformer short circuit impedance. The setting also provides a backup protection for the busbar and feeder faults on the HV side.

**Underimpedance protection for generators**

The underimpedance protection is set to protect the zone between the generator windings and the generator side windings of the step-up transformer. The function mainly protects the generator bus, the low-voltage part of the step-up transformer and a part of the stator winding against any short circuits.

The voltages should be measured from the generator terminals and the phase currents from the neutral point of the generator.

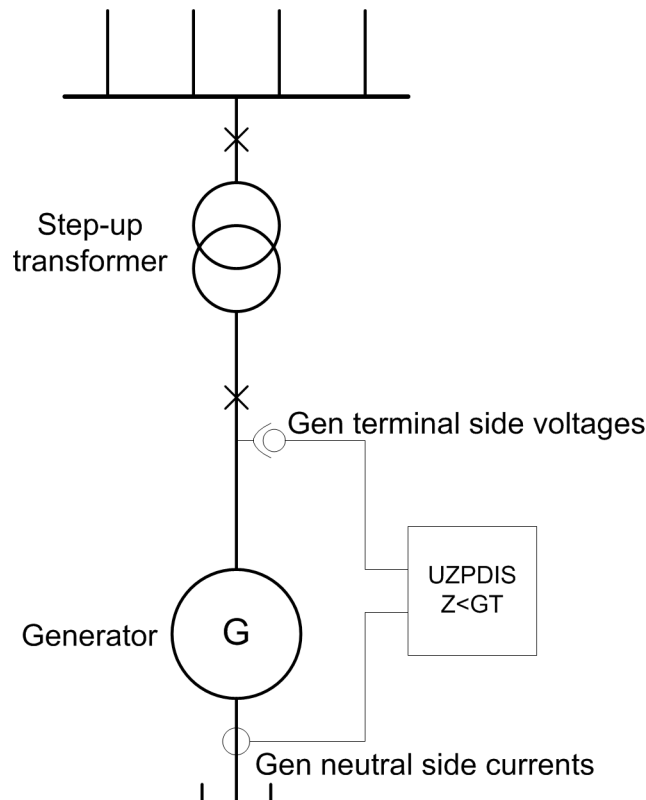


Figure 314: Current and voltage signals for underimpedance protection

To prevent malfunctioning of the underimpedance protection in case of nearby faults, the *Polar reach* setting is set to a value equal to 70 percent of the step-up transformer short circuit impedance.

In directly connected machines where the impedance towards the network is limited only by the lines or bus bars, it must be secured that the function does not cause any selectivity problems. In such cases, it is recommended to use the voltage-dependent overcurrent protection instead of the underimpedance protection.

#### Function blocking guidelines

The operation of the underimpedance protection must be restrained if the voltage in one or more phases suddenly drops close to zero without any significant change in the current observed at the same time. This situation is considered as a fuse failure or a miniature circuit breaker operation in the voltage transformer secondary circuit. The voltage drop could cause an unwanted operation of the function block since the calculated impedance could fall below the set operating limit even if there is no actual fault in the primary system.

The blocking operation is provided by an external function block, the fuse failure supervision SEQSPVC from the bay level Merging Unit or Relay, whose output is connected to the BLOCK input of UZPDIS.

### 3.7.2.6

## Signals

### UZPDIS Input signals

Table 543: UZPDIS Input signals

| Name   | Type    | Default | Description   |
|--------|---------|---------|---|
| I_A    | SIGNAL  | 0       | Phase A current                                       |
| I_B    | SIGNAL  | 0       | Phase B current                                       |
| I_C    | SIGNAL  | 0       | Phase C current                                       |
| U_A_AB | SIGNAL  | 0       | Phase-to-earth voltage A or phase-to-phase voltage AB |
| U_B_BC | SIGNAL  | 0       | Phase-to-earth voltage B or phase-to-phase voltage BC |
| U_C_CA | SIGNAL  | 0       | Phase-to-earth voltage C or phase-to-phase voltage CA |
| BLOCK  | BOOLEAN | 0=False | Block signal for activating the blocking mode         |

**UZPDIS Output signals****Table 544: UZPDIS Output signals**

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

**3.7.2.7****Settings****UZPDIS Settings****Table 545: UZPDIS Group settings (Basic)**

| Parameter          | Values (Range) | Unit | Step | Default | Description                         |
|--------------------|----------------|------|------|---------|-------------------------------------|
| Percentage reach   | 1...6000       | %Zn  | 1    | 7       | Radius of the origin centric circle |
| Operate delay time | 40...200000    | ms   | 10   | 200     | Operate delay time                  |

**Table 546: UZPDIS Non group settings (Basic)**

| Parameter           | Values (Range)                         | Unit | Step | Default           | Description  |
|---------------------|--|------|------|-------------------|--|
| Operation           | 1=on<br>5=off                          |      |      | 1=on              | Operation Off / On   |
| Measurement mode    | 2=DFT<br>3=Peak-to-Peak                |      |      | 2=DFT             | Selects used measurement mode                                |
| Impedance Meas mode | 2=1Phase-to-phase<br>4=3Phase-to-phase |      |      | 4=3Phase-to-phase | Select voltage and current signals for impedance calculation |
| Phase Sel for Z Clc | 1=AB<br>2=BC<br>3=CA                   |      |      | 1=AB              | Voltage phase selection                                      |

**Table 547: UZPDIS Non group settings (Advanced)**

| Parameter        | Values (Range) | Unit | Step | Default | Description      |
|------------------|----------------|------|------|---------|------------------|
| Reset delay time | 0...60000      | ms   | 10   | 20      | Reset delay time |

### 3.7.2.8 Monitored data

#### UZPDIS Monitored data

Table 548: UZPDIS Monitored data

| Name      | Type    | Values (Range)   | Unit | Description                               |
|-----------|---------|--|------|---|
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time (in %) |
| Z_AMPL_AB | FLOAT32 | 0.00...200.00  | xZn  | Phase-to-phase A-B impedance amplitude    |
| Z_AMPL_BC | FLOAT32 | 0.00...200.00  | xZn  | Phase-to-phase B-C impedance amplitude    |
| Z_AMPL_CA | FLOAT32 | 0.00...200.00  | xZn  | Phase-to-phase C-A impedance amplitude    |
| UZPDIS    | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                                    |

### 3.7.2.9 Technical data

Table 549: UZPDIS Technical data

| Characteristic                         | Value   |
|--|---|
| Operation accuracy                     | Depending on the frequency of the measured current and voltage: $f_n \pm 2$ Hz<br>$\pm 3.0\%$ of the set value or $\pm 0.2\% Z_b$ |
| Start time <sup>80</sup> <sub>81</sub> | Typically 50 ms   |
| Reset time                             | Typically 40 ms   |
| Reset ratio                            | Typically 1.04  |
| Retardation time                       | <40 ms  |
| Operate time accuracy                  | $\pm 1.0\%$ of the set value or $\pm 20$ ms   |

<sup>80</sup>  $f_n = 50$  Hz, results based on statistical distribution of 1000 measurements

<sup>81</sup> Includes the delay of the signal output contact

## 3.8 Power protection

### 3.8.1 Reverse power-directional overpower protection DOPPDPR

#### 3.8.1.1 Identification

| Function description                            | IEC 61850 identification | IEC 60617 identification | ANSI/IEE C37.2 device number |
|---|--------------------------|--------------------------|------------------------------|
| Reverse power/directional over-power protection | DOPPDPR                  | P>/Q>                    | 32R/32O                      |

#### 3.8.1.2 Function block

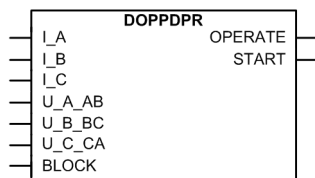


Figure 315: Function block

#### 3.8.1.3 Functionality

The reverse power/directional overpower protection function DOPPDPR can be used for generator protection against delivering an excessive power beyond the generator's capacity to the grid, against the generator running like a motor, and against the motor running like a generator and for protecting a motor which consumes more reactive power due to loss of field. It can also be used in feeder protection for indicating overload on the distribution system, to indicate that a customer is supplying power into the grid and for protecting the transformer from delivering an excessive load.

The function starts and operates when the measured power exceeds the set limit and in a specified direction. The operate time characteristics are according to definite time (DT).

This function contains a blocking functionality. It is possible to block the function outputs, timer or the function itself, if desired.

#### 3.8.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of DOPPDPR can be described using a module diagram. All the modules in the diagram are explained in the next sections.



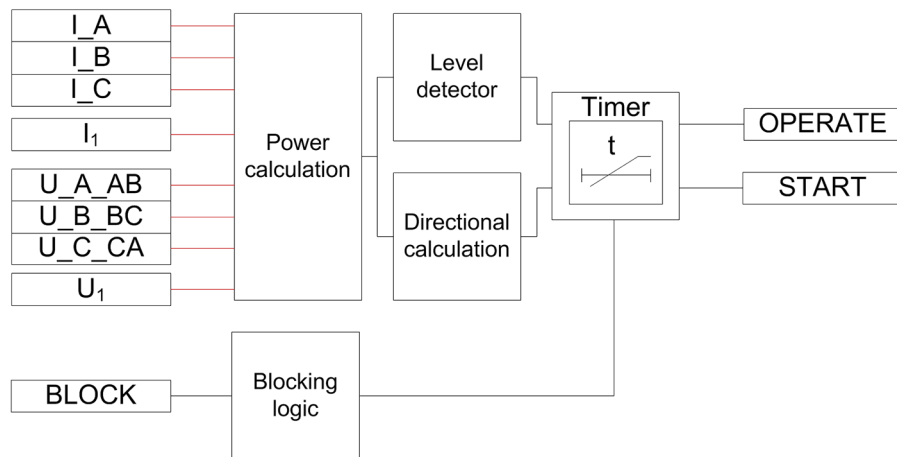


Figure 316: Functional module diagram

**Power calculation**

This module calculates the apparent power based on the selected voltages and currents. The *Measurement mode* setting determines which voltages and currents are used. It is also possible to use positive-sequence components for calculating the apparent power which makes the determination of power insensitive to a possible asymmetry in currents or voltages and corresponds to the real load on the prime mover of the generator.

**Table 550: Power calculation**

| Measurement mode setting | Power calculation   |
|--------------------------|---|
| PhsA, PhsB, PhsC         | $\bar{S} = \bar{U}_a \cdot \bar{I}_a^* + \bar{U}_b \cdot \bar{I}_b^* + \bar{U}_c \cdot \bar{I}_c^*$ $P = Re(\bar{S})$ |
| Arone                    | $\bar{S} = \bar{U}_{ab} \cdot \bar{I}_a^* - \bar{U}_{bc} \cdot \bar{I}_c^*$ $P = Re(\bar{S})$                         |
| Pos Seq                  | $\bar{S} = 3 \cdot \bar{U}_1 \cdot \bar{I}_1^*$ $P = Re(\bar{S})$   |
| PhsAB                    | $\bar{S} = \sqrt{3} \cdot \bar{U}_{ab} \cdot (\bar{I}_a^* - \bar{I}_b^*)$ $P = Re(\bar{S})$                           |
| PhsBC                    | $\bar{S} = \sqrt{3} \cdot \bar{U}_{bc} \cdot (\bar{I}_b^* - \bar{I}_c^*)$   |

Table continues on the next page

| Measurement mode setting | Power calculation  |
|--------------------------|--|
|                          | $P = \operatorname{Re}(\bar{S})$   |
| PhsCA                    | $\bar{S} = \sqrt{3} \cdot \bar{U}_{ca} \cdot (\bar{I}_c^* - \bar{I}_a^*)$ $P = \operatorname{Re}(\bar{S})$ |
| PhsA                     | $\bar{S} = 3 \cdot \bar{U}_a \cdot \bar{I}_a^*$ $P = \operatorname{Re}(\bar{S})$                           |
| PhsB                     | $\bar{S} = 3 \cdot \bar{U}_b \cdot \bar{I}_b^*$ $P = \operatorname{Re}(\bar{S})$                           |
| PhsC                     | $\bar{S} = 3 \cdot \bar{U}_c \cdot \bar{I}_c^*$ $P = \operatorname{Re}(\bar{S})$                           |



If all three phase voltages and phase currents are fed to the IED, the positive-sequence alternative is recommended.

The calculated powers S, P, Q and the power factor angle PF\_ANGL are available in the Monitored data view.

### Level detector

The Level detector compares the magnitude of the measured apparent power to the set *Start value*. If the measured value exceeds the set *Start value*, the Level detector sends an enabling signal to the Timer module.

### Directional calculation

The Directional calculation module monitors the direction of the apparent power. When the apparent power flow is in the operating area, the module sends the enabling signal to the Timer module. The directional operation can be selected with the combination of the settings *Directional mode* and *Power angle*. The selectable options for the *Directional mode* setting are "Forward" and "Reverse". The *Power angle* setting can be used to set the power direction between the reactive and active power.



A typical error is, for example, that the VT or CT poles are wrongly connected. This is seen as a power flow opposite to that of the intended direction. The *Pol Reversal* setting can be used to correct the situation. By setting the value to "True", the measured apparent power is turned 180 degrees.

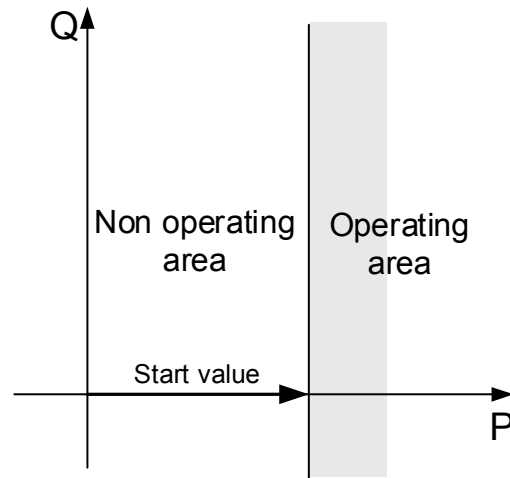


Figure 317: Operating characteristics with the Start Value setting, the Power angle setting being 0 and Directional mode "Forward"

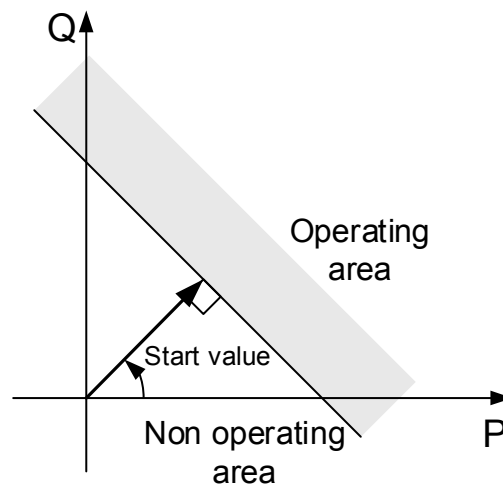


Figure 318: Operating characteristics with the Start Value setting, Power angle ( $\alpha$ ) being +45 and Directional mode "Forward"

### Timer

Once activated, the Timer activates the `START` output. The time characteristics are according to `DT`. When the operation timer has reached the value of *Operate delay time*, the `OPERATE` output is activated. If a drop-off situation happens, that is, the value of power drops below *Start value* before the operate delay is exceeded, the

timer reset state is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the `START` output is deactivated.

The Timer calculates the start duration value `START_DUR`, which indicates the percentage ratio of the start situation and the set operating time (DT). The value is available in the Monitored data view.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting **Configuration > System > Blocking mode**, which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the `OPERATE` output is not activated.

### 3.8.1.5

#### Application

DOPPDPR is used to provide protection against an excessive power flow in the set operating direction. The main application is the protection of generators and turbines. It can also be used in feeder protection applications, for example, the ring network.

DOPPDPR in the forward direction can be used to protect the generators or motors from delivering or consuming excess power. For example, the generator overpower protection can be used to shed a noncritical feeder load or to start parallel generators. A synchronous motor may start consuming more reactive power in case of loss of excitation, in which case the forward overpower protection is used to detect such condition.

The DOPPDPR function has many applications when used as reverse power protection. A generator in a power plant converts mechanical energy to electrical energy. Sometimes the mechanical power from a prime mover may decrease to a limit that it does not cover the internal losses. The synchronous generator becomes a synchronous motor and starts importing power from the system. The effect of a generator acting as a motor implies no risk to the machine but can cause damage to the prime mover. The extent of the damage depends on the type of the prime mover.

Steam turbines become overheated easily if the steam flow drops too low or if the steam ceases to flow through the turbine. The break of a main steam pipe, damage to one or more blades in the steam turbine or an inadvertent closing of the main stop valves are typical causes for the low steam flow. The steam turbines of turbo generators can be protected during a low steam flow with the overpower protection operating in reverse direction. Hydroturbines tolerate reverse power much better than steam turbines do. There is a risk that the turbine runner moves axially and touches stationary parts. They are not always strong enough to withstand the associated stresses.

A hydroturbine that rotates in water with the closed wicket gates draws about 10% of the rated power from the rest of the power system if the intake is blocked due to ice, snow, branches or leaves. A complete blockage of the intake may cause cavitations. If there is only air in the hydroturbine, the power demand drops

to about 3%. The risk of damages to the hydroturbines can justify the reverse operation of the overpower protection in unattended plants.



Whenever a low value of the reverse power setting is required, an underpower protection should also be used in conjunction with DOPDPDR. The limit depends on the CT and VT accuracy.

Diesel engines should have overpower protection in reverse direction. The generator takes about 15% or more of its rated power from the system. A stiff engine may require 25% of the rated power to motor it. A well run engine may need no more than 5%. It is necessary to obtain information from the engine manufacturer and to measure the reverse power during commissioning.

Reverse overpower can also act as an alternative for an under excitation protection in case of small generators. If the field excitation is reduced, the generator may start importing the reactive power, making the generator run as an asynchronous generator. A synchronous generator is not designed to work asynchronously and may become damaged due to heating in the damper windings or heating in the rotor due to slip frequency current.

When operated in reverse power direction, DOPDPDR can be used as an alarm if the power flowing from the industry is feeding the grid, which may not be desired as per the rules and regulations of the utility owning the grid.

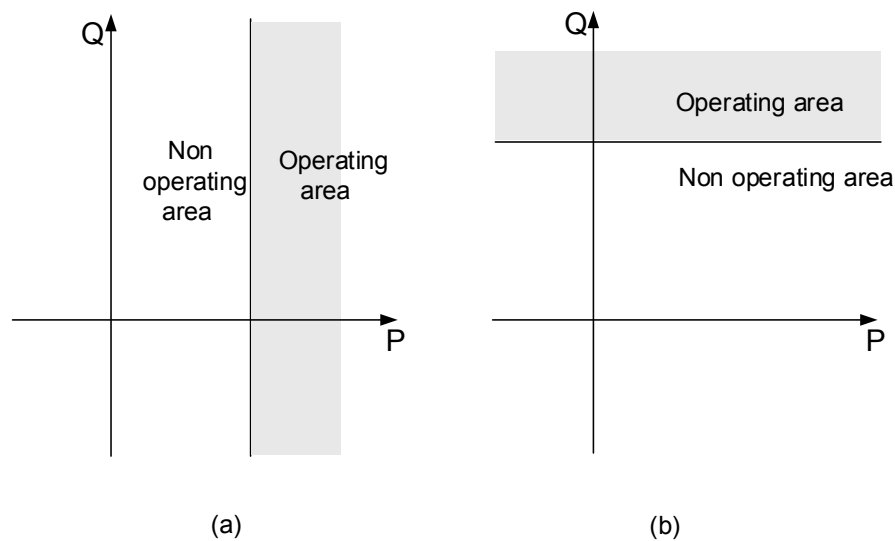


Figure 319: Forward active overpower characteristics (a) and forward reactive overpower characteristics (b)

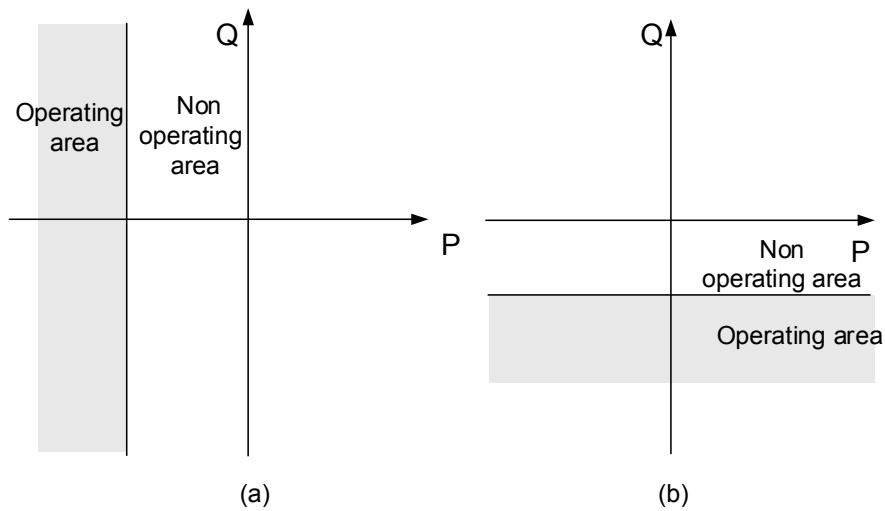


Figure 320: Reverse active overpower characteristics (a) and reverse reactive overpower characteristics (b)

3.8.1.6

Signals

DOPPDPR Input signals

Table 551: DOPPDPR Input signals

| Name   | Type    | Default | Description   |
|--------|---------|---------|---|
| I_A    | SIGNAL  | 0       | Phase A current                                       |
| I_B    | SIGNAL  | 0       | Phase B current                                       |
| I_C    | SIGNAL  | 0       | Phase C current                                       |
| U_A_AB | SIGNAL  | 0       | Phase-to-earth voltage A or phase-to-phase voltage AB |
| U_A_BC | SIGNAL  | 0       | Phase-to-earth voltage B or phase-to-phase voltage BC |
| U_A_CA | SIGNAL  | 0       | Phase-to-earth voltage C or phase-to-phase voltage CA |
| BLOCK  | BOOLEAN | 0=False | Block signal for activating the blocking mode         |

**DOPPDPR Output signals****Table 552: DOPPDPR Output signals**

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

**3.8.1.7****Settings****DOPPDPR Settings****Table 553: DOPPDPR Group settings (Basic)**

| Parameter          | Values (Range)         | Unit | Step | Default   | Description                |
|--------------------|------------------------|------|------|-----------|----------------------------|
| Start value        | 0.01...2.00            | xSn  | 0.01 | 1.00      | Start value                |
| Operate delay time | 40...300000            | ms   | 10   | 40        | Operate delay time         |
| Directional mode   | 2=Forward<br>3=Reverse |      |      | 2=Forward | Directional mode           |
| Power angle        | -90...90               | deg  | 1    | 0         | Adjustable angle for power |

**Table 554: DOPPDPR Non group settings (Basic)**

| Parameter        | Values (Range)  | Unit | Step | Default   | Description                           |
|------------------|---|------|------|-----------|---------------------------------------|
| Operation        | 1=on<br>5=off   |      |      | 1=on      | Operation On/Off                      |
| Measurement mode | 1=PhsA, PhsB, PhsC<br>2=Arone<br>3=Pos Seq<br>4=PhsAB<br>5=PhsBC<br>6=PhsCA<br>7=PhsA<br>8=PhsB<br>9=PhsC |      |      | 3=Pos Seq | Selection of power calculation method |

**Table 555: DOPPDPR Non group settings (Advanced)**

| Parameter        | Values (Range)    | Unit | Step | Default | Description                                   |
|------------------|-------------------|------|------|---------|---|
| Reset delay time | 0...60000         | ms   | 10   | 20      | Reset delay time                              |
| Pol reversal     | 0=False<br>1=True |      |      | 0=False | Reverse the definition of the power direction |

**3.8.1.8****Monitored data****DOPPDPR Monitored data****Table 556: DOPPDPR Monitored data**

| Name      | Type    | Values (Range)   | Unit | Description                        |
|-----------|---------|--|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time |
| P         | FLOAT32 | -160.000...160.00<br>0                                 | xSn  | Active power                       |
| Q         | FLOAT32 | -160.000...160.00<br>0                                 | xSn  | Reactive power                     |
| S         | FLOAT32 | 0.000...160.000  | xSn  | Apparent power                     |
| PF_ANGLE  | FLOAT32 | -180.00...180.00                                       | deg  | Power factor angle                 |
| DOPPDPR   | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                             |

**3.8.1.9****Technical data****Table 557: DOPPDPR Technical data**

| Characteristic                   | Value   |
|----------------------------------|---|
| Operation accuracy <sup>82</sup> | Depending on the frequency of the measured current and voltage: |

*Table continues on the next page*

<sup>82</sup> Measurement mode = "Pos Seq" (default)



| Characteristic             | Value   |
|----------------------------|---|
|                            | $f = f_n \pm 2 \text{ Hz}$  |
|                            | Power measurement accuracy $\pm 3\%$ of the set value or $\pm 0.002 \times S_n$ |
|                            | Phase angle: $\pm 2^\circ$  |
| Start time <sup>8384</sup> | Typically 45 ms   |
| Reset time                 | Typically 30 ms   |
| Reset ratio                | Typically 0.94  |
| Operate time accuracy      | $\pm 1.0\%$ of the set value of $\pm 20 \text{ ms}$                             |
| Suppression of harmonics   | -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$                    |

## 3.8.2 Directional reactive power undervoltage protection DQPTUV

### 3.8.2.1 Identification

| Description  | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--|--------------------------|--------------------------|-------------------------------|
| Directional reactive power undervoltage protection | DQPTUV                   | $Q > \rightarrow, 3U <$  | 32Q,27                        |

### 3.8.2.2 Function block

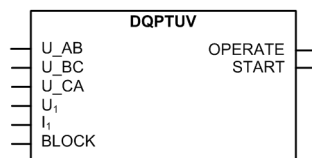


Figure 321: Function block

### 3.8.2.3 Functionality

The directional reactive power undervoltage protection function DQPTUV is used at the grid connection point of distributed power generating units as stipulated by various grid codes to prevent voltage collapse of the grid due to network faults. DQPTUV measures phase voltages and current at the grid connection point. The generating facility is disconnected from the network with a specific time delay if all phase voltages decrease and remain at or below the specified limit and if reactive power is simultaneously consumed (that is, under-excitation operation).

DQPTUV contains a blocking functionality to block function outputs, timer or the function itself.

<sup>83</sup>  $U = U_n$ ,  $f_n = 50 \text{ Hz}$ , results based on statistical distribution of 1000 measurements

<sup>84</sup> Includes the delay of the signal output contact

### 3.8.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of DQPTUV can be described using a module diagram. All the modules in the diagram are explained in the next sections.

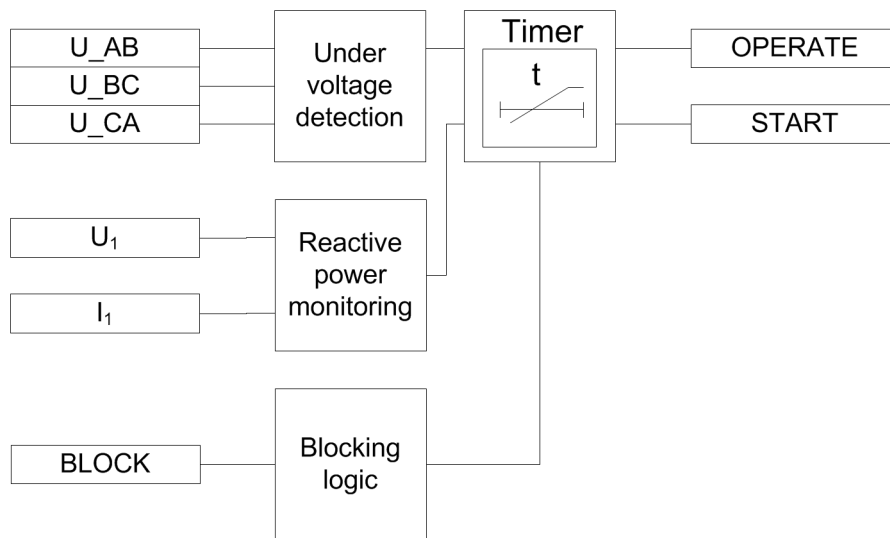


Figure 322: Functional module diagram

#### Under voltage detection

Under voltage detection compares the fundamental frequency component of all three phase-to-phase voltages with the set *Voltage start value*. When all three phase-to-phase voltages are lower than the set *Voltage start value*, the Under voltage detection module sends an enable signal to the Timer indicating an undervoltage condition at the grid connection point.

#### Reactive power monitoring

This module calculates and monitors the reactive power based on positive sequence current and voltage. The use of a positive sequence component makes the determination of power insensitive to a possible asymmetry in current and voltages. When the reactive power exceeds *Min reactive power* and flows in the operating area, the module sends an enable signal to the Timer indicating that the reactive power is being consumed at the grid connection point. A slight tilt in the curve can be obtained by the setting *Pwr sector reduction*.

To avoid false tripping, reactive power calculation is blocked if the magnitude of positive sequence current is less than the set *Min PS current*.

The magnitude of calculated reactive power  $Q$  is available in the Monitored data view.

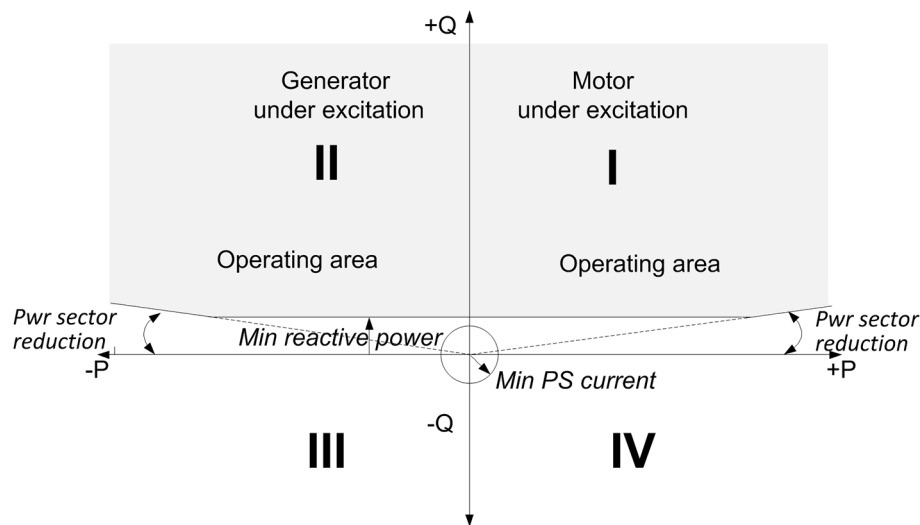


Figure 323: Operating area of DQPTUV function

|              |   |
|--------------|---|
| Quadrant II  | Generator produces active power, but draws reactive power (under-excited) |
| Quadrant III | Generator produces both active and reactive power                         |



The power direction can be reversed by setting *Pol reversal* to "True".

### Timer

Once activated by both Under voltage detection and Reactive power monitoring module, the Timer activates the *START* output. The Timer characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the *OPERATE* output is activated. If the fault disappears before the module operates, the Timer is reset instantaneously.

The Timer calculates the start duration value *START\_DUR* which indicates the percentage ratio of the start situation and the set operating time. The value is available through the Monitored data view.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the *BLOCK* input and the global setting **Configuration > System > Blocking mode** which selects the blocking mode. The *BLOCK* input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED program. The influence of the *BLOCK* signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode setting* has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the *OPERATE* output is not activated.

### 3.8.2.5 Application

Use of distributed power generating units ( PGU) is rapidly increasing due to liberalized markets (deregulation) and the global trend to use more renewable sources of energy. As the capacity of these generating units increase, they are connected directly to medium voltage networks. Until recent years it had been a practice by grid operators to disconnect the distributed power generator from the network in case of fault in the network.

If there is a considerable loss in the power generation, it may affect the system's ability to recover. To ensure power system stability, various grid codes have revised their requirements and therefore require that the distributed PGUs have to make a contribution to network support. In case of network faults, the distributed power generator should not be immediately disconnected from the network. Instead, as a matter of principle, generating plants connected to the medium-voltage network must be capable of participating in steady-state voltage control and dynamic network support. However, if the generators stay connected, it must be ensured that they do not take reactive power from the network because this may lead to collapse of the grid. DQPTUV is used for detecting such situations, that is, simultaneous undervoltage and reactive power (under excited generators) and trip the generators.

The protection function DQPTUV is developed considering various grid codes. For example, in the BDEW Technical Guideline "Generating Plants Connected to the Medium-Voltage Network" (June 2008 issue, Germany), it is stated that if all three phase-to-phase voltages at the grid connection point decrease and remain at and below a value of 85% of the rated and if reactive power is simultaneously consumed at the grid connection point (under-excited operation), the generating facility must be disconnected from the network with a time delay of 0.5 s.

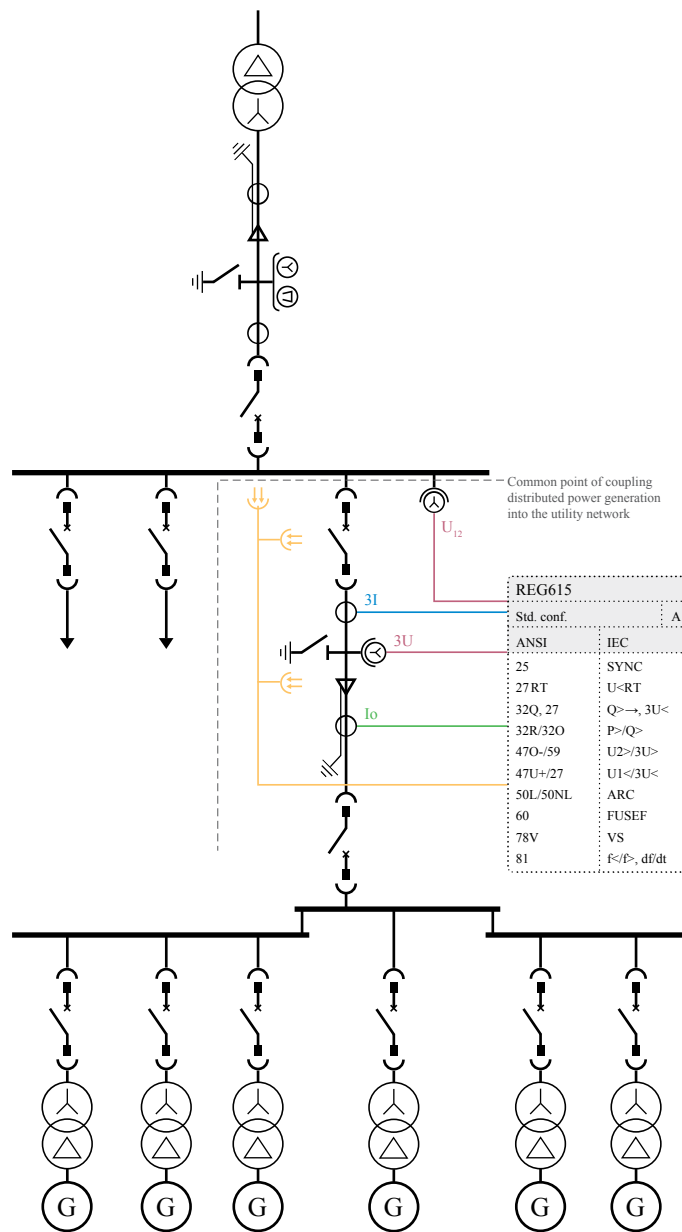


Figure 324: Application example of wind power plant as distributed power generation coupled into the utility network

### 3.8.2.6 Signals

**DQPTUV Input signals****Table 558: DQPTUV Input signals**

| Name           | Type    | Default | Description                                   |
|----------------|---------|---------|---|
| U_AB           | SIGNAL  | 0       | Phase-to-phase voltage AB                     |
| U_BC           | SIGNAL  | 0       | Phase-to-phase voltage BC                     |
| U_CA           | SIGNAL  | 0       | Phase-to-phase voltage CA                     |
| U <sub>1</sub> | SIGNAL  | 0       | Positive phase sequence voltage               |
| I <sub>1</sub> | SIGNAL  | 0       | Positive sequence current                     |
| BLOCK          | BOOLEAN | 0=False | Block signal for activating the blocking mode |

**DQPTUV Output signals****Table 559: DQPTUV Output signals**

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

**3.8.2.7****Settings****DQPTUV Settings****Table 560: DQPTUV Group settings (Basic)**

| Parameter           | Values (Range) | Unit | Step | Default | Description                             |
|---------------------|----------------|------|------|---------|---|
| Voltage start value | 0.20...1.20    | xUn  | 0.01 | 0.85    | Start value for under voltage detection |
| Operate delay time  | 100...300000   | ms   | 10   | 500     | Operate delay time                      |

**Table 561: DQPTUV Non group settings (Basic)**

| Parameter | Values (Range) | Unit | Step | Default | Description      |
|-----------|----------------|------|------|---------|------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation On/Off |

**Table 562: DQPTUV Non group settings (Advanced)**

| Parameter            | Values (Range)    | Unit | Step | Default | Description   |
|----------------------|-------------------|------|------|---------|---|
| Min reactive power   | 0.01...0.50       | xSn  | 0.01 | 0.05    | Minimum reactive power needed for function to operate           |
| Min Ps Seq current   | 0.02...0.20       | xIn  | 0.01 | 0.05    | Minimum positive sequence current                               |
| Pwr sector reduction | 0...10            | deg  | 1    | 3       | Power sector reduction  |
| Pol reversal         | 0=False<br>1=True |      |      | 0=False | Reverse the definition of the positive reactive power direction |

**3.8.2.8****Monitored data****DQPTUV Monitored data****Table 563: DQPTUV Monitored data**

| Name      | Type    | Values (Range)   | Unit | Description                        |
|-----------|---------|--|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time |
| Q         | FLOAT32 | -160.000...160.00<br>0                                 | xSn  | Reactive power                     |
| DQPTUV    | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                             |

**3.8.2.9****Technical data****Table 564: DQPTUV Technical data**

| Characteristic     | Value   |
|--------------------|---|
| Operation accuracy | Depending on the frequency of the measured current and voltage: |

*Table continues on the next page*

| Characteristic             | Value   |
|----------------------------|---|
|                            | $f_n \pm 2 \text{ Hz}$<br>Reactive power range $ PF  < 0.71$  |
|                            | Power:<br>$\pm 3.0\%$ or $\pm 0.002 \times Q_n$<br>Voltage:<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times U_n$ |
| Start time <sup>8586</sup> | Typically 46 ms   |
| Reset time                 | <50 ms  |
| Reset ratio                | Typically 0.96  |
| Operate time accuracy      | $\pm 1.0\%$ of the set value or $\pm 20 \text{ ms}$   |
| Suppression of harmonics   | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$   |

### 3.9 Arc protection ARCSARC

#### 3.9.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|----------------------|--------------------------|--------------------------|-------------------------------|
| Arc protection       | ARCSARC                  | ARC                      | 50L/50NL                      |

#### 3.9.2 Function block

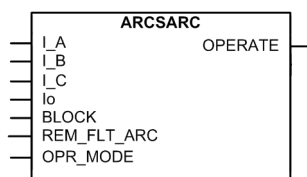


Figure 325: Function block

#### 3.9.3 Functionality

The arc protection function ARCSARC detects arc situations in air insulated metal-clad switchgears caused by, for example, human errors during maintenance or insulation breakdown during operation.

<sup>85</sup> Start value =  $0.05 \times S_n$ , reactive power before fault =  $0.8 \times \text{Start value}$ , reactive power overshoot 2 times, results based on statistical distribution of 1000 measurements

<sup>86</sup> Includes the delay of the signal output contact



The function detects light from an arc via a remote light signal. The function also monitors phase and residual currents to be able to make accurate decisions on ongoing arcing situations.

The function contains a blocking functionality. Blocking deactivates all outputs and resets timers.

### 3.9.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of ARCSARC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

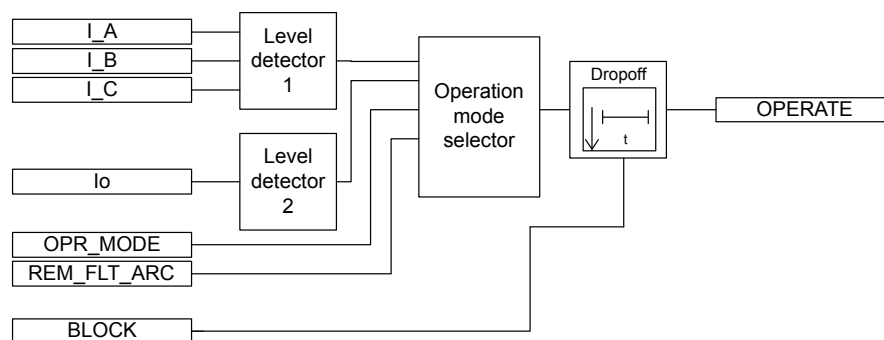


Figure 326: Functional module diagram

#### Level detector 1

The measured phase currents are compared phase-wise to the set *Phase start value*. If the measured value exceeds the set *Phase start value*, the level detector reports the exceeding of the value to the operation mode selector.

#### Level detector 2

The measured residual currents are compared to the set *Ground start value*. If the measured value exceeds the set *Ground start value*, the level detector reports the exceeding of the value to the operation mode selector.

#### Operation mode selector

Depending on the *Operation mode* setting, the operation mode selector makes sure that all required criteria are fulfilled for a reliable decision of an arc fault situation. The user can select either "Light+current", "Light only" or "BI controlled" operation mode. The operation is based on both current and light information in "Light+current" mode, on light information only in "Light only" mode or on remotely controlled information in "BI controlled" mode. When the "BI controlled" mode is in use and the `OPR_MODE` input is activated, the operation of the function is based on light information only. When the `OPR_MODE` input is deactivated, the operation of the function is based on both light and current information. When the required criteria are met, the drop-off timer is activated.

### Drop-off timer

Once activated, the drop-off timer remains active until the input is deactivated or at least during the drop-off time. The `BLOCK` signal can be used to block the `OPERATE` signal.

## 3.9.5 Application

The arc protection in SSC600 is a station-wide arc protection, processing current measurements and light indications received from several bay level relays or merging units. Current measurements are received as SMV measurements via IEC 61850-9-2LE and light indications as GOOSE messaged. Different tripping schemes can be selected for the operation of the circuit breakers of the incoming and outgoing feeders, when SSC600 is configured to send the trip signal to relays. Consequently, the relays in the station can, for example, be set to trip the circuit breaker of either the incoming or the outgoing feeder, depending on the fault location in the switchgear. For maximum safety, the relays can be set to always trip both the circuit breaker of the incoming feeder and that of the outgoing feeder.

The arc protection consists of:

- Optional arc light detection logic, when light information is available from bay level merging units or relays type sensors
- Protection stage with phase- and earth-fault current measurement.

The function detects light from an arc via a remote light signal. The lens sensors can be placed, for example, in the busbar compartment, the breaker compartment, and the cable compartment of the metal-clad cubicle.

When the light has been detected remotely and, depending on the operation mode, if one or several phase currents exceed the set *Phase start value* limit, or the earth-fault current the set *Ground start value* limit, the arc protection stage generates an operation signal. The stage is reset in 30 ms, after all three-phase currents and the earth-fault current have fallen below the set current limits.

A station-wide arc protection is realized by processing centrally the light indications from multiple protection relays or merging units.

It is possible to block the tripping of the arc protection stage with a binary input or a signal from another function block.

### Arc protection with several IEDs or Merging Units

When using several IEDs or Merging Units (MU), the MU connected to the outgoing feeder is used for tripping the circuit breaker of the outgoing feeder when detecting an arc at the cable terminations. If the MU connected to the outgoing feeder detects an arc on the busbar or in the breaker compartment via one of the other lens sensors, a logic can be created to send a signal to the MU connected to the incoming feeder and MUs connected to other outgoing feeders. When detecting the signal, the MU connected to the incoming feeder is used for tripping the circuit breaker of the incoming feeder, and all MUs connected to the outgoing feeders for tripping also all circuit breakers of the outgoing feeders. For maximum safety, the MUs can be configured to trip all the circuit breakers regardless of where the arc is detected.

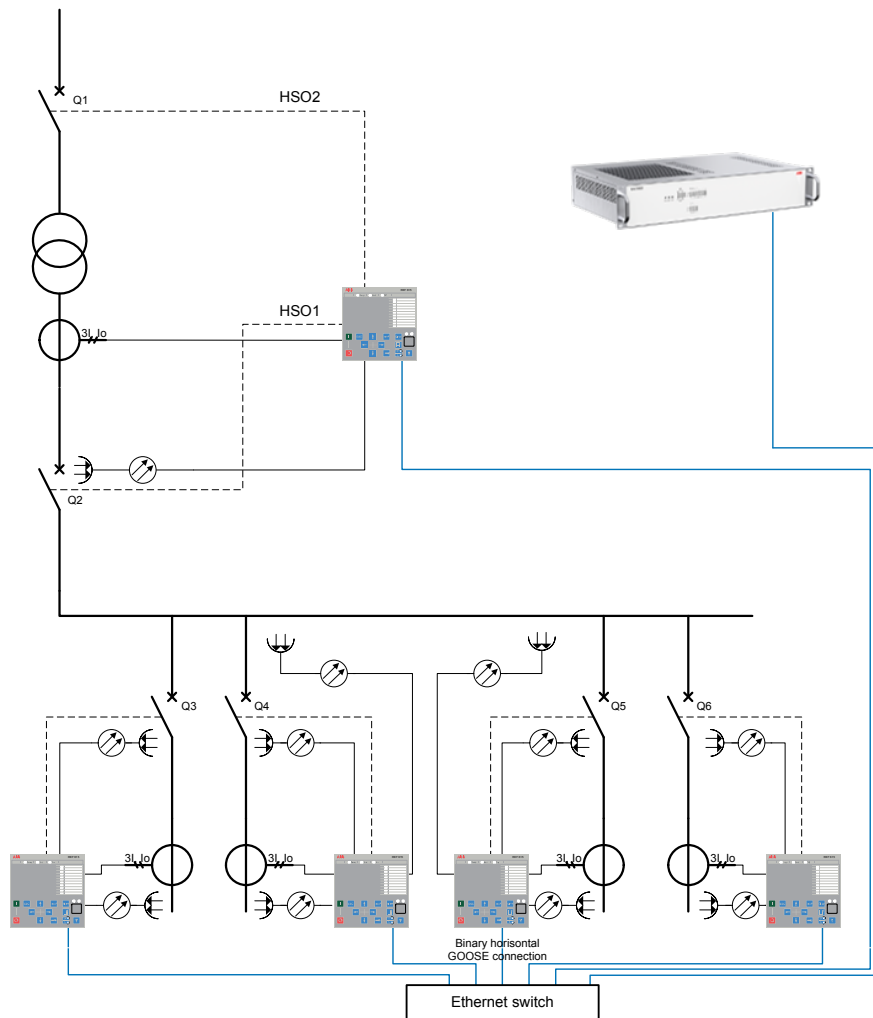


Figure 327: Arc protection with several MUs and high-speed outputs and GOOSE

### 3.9.6 Signals

#### 3.9.6.1 ARCSARC Input signals

Table 565: ARCSARC Input signals

| Name | Type   | Default | Description      |
|------|--------|---------|------------------|
| I_A  | SIGNAL | 0       | Phase A current  |
| I_B  | SIGNAL | 0       | Phase B current  |
| I_C  | SIGNAL | 0       | Phase C current  |
| Io   | SIGNAL | 0       | Residual current |

Table continues on the next page

| Name        | Type    | Default | Description                         |
|-------------|---------|---------|-------------------------------------|
| BLOCK       | BOOLEAN | 0=False | Block signal for all binary outputs |
| REM_FLT_ARC | BOOLEAN | 0=False | Remote Fault arc detected           |
| OPR_MODE    | BOOLEAN | 0=False | Operation mode input                |

### 3.9.6.2 ARCSARC Output signals

Table 566: ARCSARC Output signals

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |

## 3.9.7 Settings

### 3.9.7.1 ARCSARC Settings

Table 567: ARCSARC Group settings (Basic)

| Parameter          | Values (Range)                                     | Unit | Step | Default         | Description                |
|--------------------|--|------|------|-----------------|----------------------------|
| Phase start value  | 0.50...40.00                                       | xIn  | 0.01 | 2.50            | Operating phase current    |
| Ground start value | 0.05...8.00  | xIn  | 0.01 | 0.20            | Operating residual current |
| Operation mode     | 1=Light+current<br>2=Light only<br>3=BI controlled |      |      | 1=Light+current | Operation mode             |

Table 568: ARCSARC Non group settings (Basic)

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

## 3.9.8 Monitored data

### 3.9.8.1 ARCSARC Monitored data

Table 569: ARCSARC Monitored data

| Name    | Type | Values (Range)   | Unit | Description |
|---------|------|--|------|-------------|
| ARCSARC | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status      |

### 3.9.9 Technical data

Table 570: ARCSARC Technical data

| Characteristic     |  | Value   |  |  |
|--------------------|--|---|--|--|
| Operation accuracy |  | $\pm 3\%$ of the set value or $\pm 0.01 \times I_n$ |  |  |
| Operate time       |  | Minimum   | Typical                                      | Maximum                                      |
|                    | <i>Operation mode = "Light+current"</i> <sup>87 88</sup> | 12 ms <sup>89</sup><br>8 ms <sup>90</sup>           | 13 ms <sup>108</sup><br>10 ms <sup>109</sup> | 15 ms <sup>108</sup><br>12 ms <sup>109</sup> |
|                    | <i>Operation mode = "Light only"</i> <sup>98</sup>       | 12 ms <sup>108</sup><br>7 ms <sup>109</sup>         | 14 ms <sup>108</sup><br>7 ms <sup>109</sup>  | 17 ms <sup>108</sup><br>8 ms <sup>109</sup>  |
| Reset time         |  | Typically 40 ms                                     |  |  |
| Reset ratio        |  | Typically 0.96                                      |  |  |

### 3.9.10 Technical revision history

Table 571: ARCSARC Technical revision history

| Technical revision | Change                |
|--------------------|-----------------------|
| B                  | Internal improvement. |
| C                  | Modified for SSC600   |

<sup>87</sup> *Phase start value* =  $1.0 \times I_n$ , current before fault =  $2.0 \times$  set *Phase start value*,  $f_n = 50$  Hz, fault with nominal frequency, results based on statistical distribution of 200 measurements

<sup>88</sup> Includes the delay of the heavy-duty output contact

<sup>89</sup> Normal power output

<sup>90</sup> High-speed output

## 3.10 Motor start-up supervision STTPMSU

### 3.10.1 Identification

| Function description       | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|----------------------------|--------------------------|--------------------------|-------------------------------|
| Motor start-up supervision | STTPMSU                  | Is2t n<                  | 49,66,48,51LR                 |

### 3.10.2 Function block

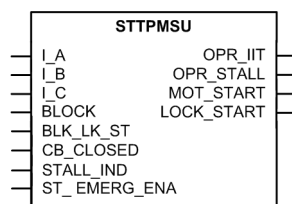


Figure 328: Function block

### 3.10.3 Functionality

The motor start-up supervision function STTPMSU is designed for protection against excessive starting time and locked rotor conditions of the motor during starting. For a good and reliable operation of the motor, the thermal stress during the motor starting is maintained within the allowed limits.

The starting of the motor is supervised by monitoring the TRMS magnitude of all the phase currents or by monitoring the status of the circuit breaker connected to the motor.

During the start-up period of the motor, STTPMSU calculates the integral of the  $I^2t$  value. If the calculated value exceeds the set value, the operate signal is activated.

STTPMSU has the provision to check the locked rotor condition of the motor using the speed switch, which means checking if the rotor is able to rotate or not. This feature operates after a predefined operating time.

STTPMSU also protects the motor from an excessive number of start-ups. Upon exceeding the specified number of start-ups within certain duration, STTPMSU blocks further starts. The restart of the motor is also inhibited after each start and continues to be inhibited for a set duration. When the lock of start of motor is enabled, STTPMSU gives the time remaining until the restart of the motor.

STTPMSU contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

### 3.10.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of STTPMSU can be described with a module diagram. All the modules in the diagram are explained in the next sections.

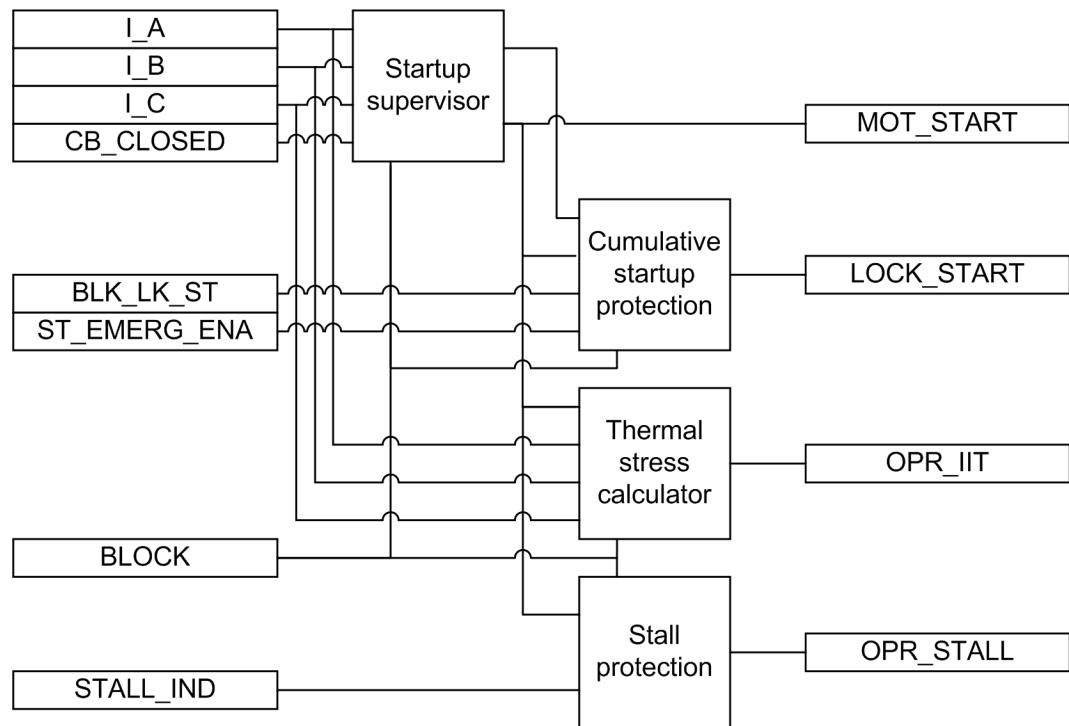


Figure 329: Functional module diagram

### Startup supervisor

This module detects the starting of the motor. The starting and stalling motor conditions are detected in four different modes of operation. This is done through the *Operation mode* setting.

When the *Operation mode* setting is operated in the "IIt" mode, the function calculates the value of the thermal stress of the motor during the start-up condition. In this mode, the start-up condition is detected by monitoring the TRMS currents.

The *Operation mode* setting in the "IIt, CB" mode enables the function to calculate the value of the thermal stress when a start-up is monitored in addition to the CB\_CLOSED input.

In the "IIt & stall" mode, the function calculates the thermal stress of the motor during the start-up condition. The start-up condition is detected by monitoring the TRMS currents.

In the "IIt & stall, CB" mode, the function calculates the thermal stress of the motor during the start-up condition but the start-up condition is detected by monitoring the TRMS current as well as the circuit breaker status.

In both the "IIt & stall" and "IIt & stall, CB" mode, the function also checks for motor stalling by monitoring the speed switch.

When the measured current value is used for start-up supervision in the "IIt" and "IIt & stall" modes, the module initially recognizes the de-energized condition of the motor when the values of all three phase currents are less than *Motor standstill A* for longer than 100 milliseconds. If any of the phase currents of the de-energized

condition rises to a value equal to or greater than *Motor standstill A*, the `MOT_START` output signal is activated indicating that the motor start-up is in progress. The `MOT_START` output remains active until the values of all three phase currents drop below 90 percent of the set value of *Start detection A* and remain below that level for a time of *Str over delay time*, that is, until the start-up situation is over.

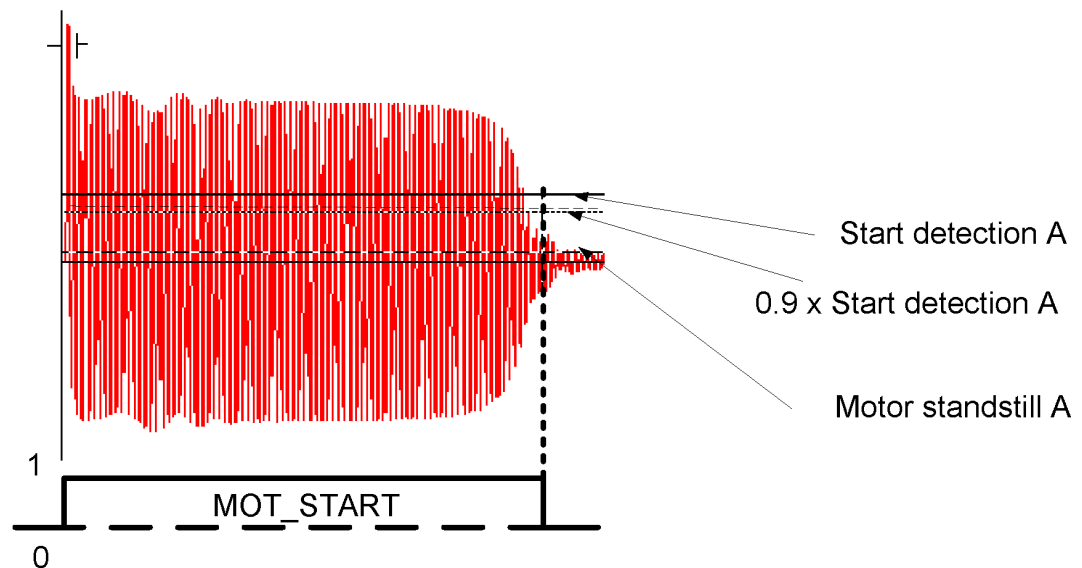


Figure 330: Functionality of start-up supervision in the "Ilt and Ilt&stall" mode

In case of the "Ilt, CB" or "Ilt & stall, CB" modes, the function initially recognizes the de-energized condition of the motor when the value of all three phase currents is below the value of the *Motor standstill A* setting for 100 milliseconds. The beginning of the motor start-up is recognized when CB is closed, that is, when the `CB_CLOSED` input is activated and at least one phase current value exceeds the *Motor standstill A* setting.

These two events do not take place at the same instant, that is, the CB main contact is closed first, in which case the phase current value rises above 0.1 pu and after some delay the CB auxiliary contact gives the information of the `CB_CLOSED` input. In some cases, the `CB_CLOSED` input can be active but the value of current may not be greater than the value of the *Motor standstill A* setting. To allow both possibilities, a time slot of 200 milliseconds is provided for current and the `CB_CLOSED` input. If both events occur during this time, the motor start-up is recognized.

The motor start-up ends either within the value of the *Str over delay time* setting from the beginning of the start-up or the opening of CB or when the `CB_CLOSED` input is deactivated. The operation of the `MOT_START` output signal in this operation mode is as illustrated in [Figure 331](#).

This CB mode can be used in soft-started or slip ring motors for protection against a large starting current, that is, a problem in starting and so on.



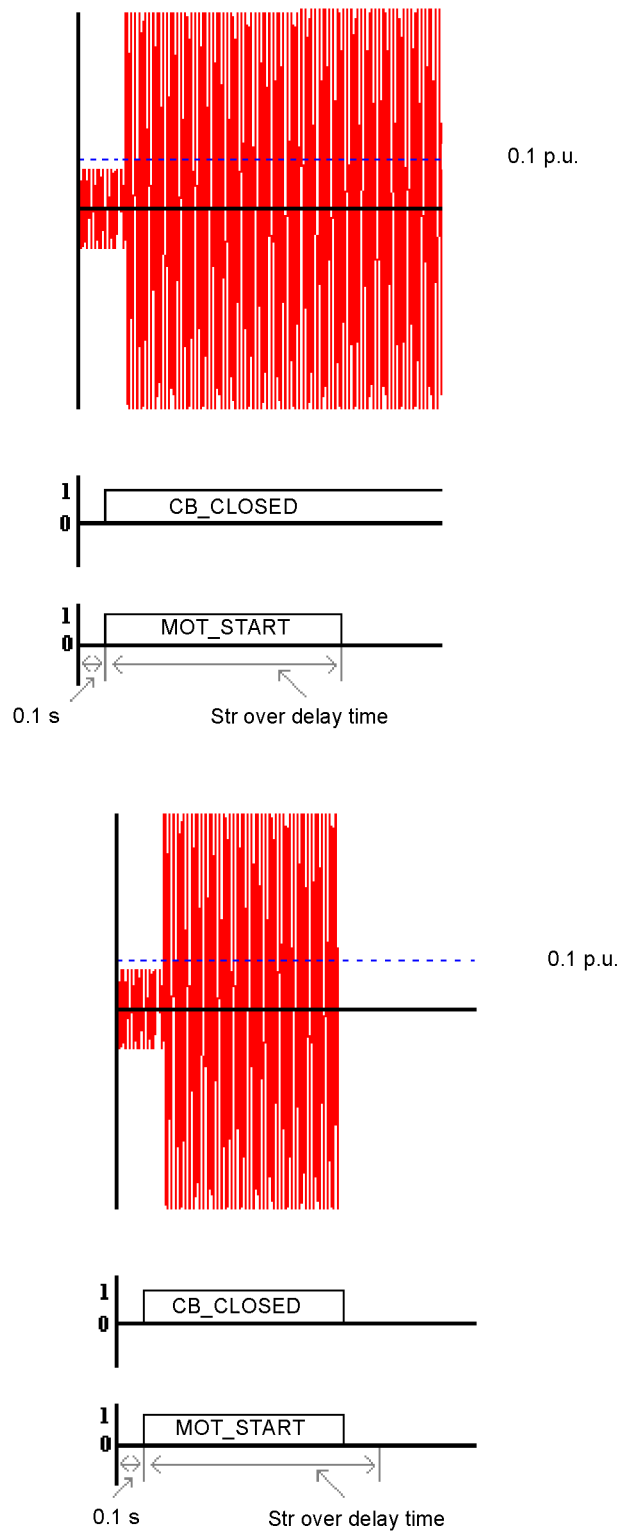


Figure 331: Functionality of start-up supervision in the "Ilt, CB" mode and the "Ilt and stall, CB" mode

The *Str over delay time* setting has different purposes in different modes of operation.

- In the "Ilt" or "Ilt & stall" modes, the aim of this setting is to check for the completion of the motor start-up period. The purpose of this time delay setting is to allow for short interruptions in the current without changing the state of the MOT\_START output. In this mode of operation, the value of the setting is in the range of around 100 milliseconds.
- In the "Ilt, CB" or "Ilt & stall, CB" modes, the purpose of this setting is to check for the life of the protection scheme after the CB\_CLOSED input has been activated. Based on the values of the phase currents, the completion of the start-up period cannot be judged. So in this mode of operation, the value of the time delay setting can even be as high as within the range of seconds, for example around 30 seconds.

The activation of the BLOCK input signal deactivates the MOT\_START output.

### Thermal stress calculator

Because of the high current surges during the start-up period, a thermal stress is imposed on the rotor. With less air circulation in the ventilation of the rotor before it reaches its full speed, the situation becomes even worse. Consequently, a long start-up causes a rapid heating of the rotor.

This module calculates the thermal stress developed in the motor during start-up. The heat developed during the starting can be calculated with the equation.

$$W = R_s \int_0^t i_s^2(t) dt$$

|       |                                      |
|-------|--------------------------------------|
| $R_s$ | combined rotor and stator resistance |
| $i_s$ | starting current of the motor        |
| $t$   | starting time of the motor           |

This equation is normally represented as the integral of  $I^2t$ . It is a commonly used method in protective IEDs to protect the motor from thermal stress during starting. The advantage of this method over the traditional definite time overcurrent protection is that when the motor is started with a reduced voltage as in the star-delta starting method, the starting current is lower. This allows more starting time for the motor since the module is monitoring the integral of  $I^2t$ .

The module calculates the accumulated heat continuously and compares it to the limiting value obtained from the product of the square of the values of the *Motor start-up A* and *Motor start-up time* settings. When the calculated value of the thermal stress exceeds this limit, the OPR\_IIT output is activated.

The module also measures the time START\_TIME required by the motor to attain the rated speed and the relative thermal stress IIT\_RL. The values are available in the Monitored data view.

The activation of the BLOCK input signal resets the thermal stress calculator and deactivates the OPR\_IIT output.

### Stall protection

This module is activated only when the selected *Operation mode* setting value is "Ilt & stall" or "Ilt & stall, CB".

The start-up current is specific to each motor and depends on the start-up method used, such as direct online, autotransformer and rotor resistance insertion. The start-up time is dependent on the load connected to the motor.

Based on the motor characteristics supplied by the manufacturer, this module is required if the stalling time is shorter than or too close to the starting time. In such cases, a speed switch must be used to indicate whether a motor is accelerating during start-up or not.

At motor standstill, the `STALL_IND` input is active. It indicates that the rotor is not rotating. When the motor is started, at certain revolution the deactivation of the `STALL_IND` by the speed switch indicates that the rotor is rotating. If the input is not deactivated within *Lock rotor time*, the `OPR_STALL` output is activated.

The module calculates the duration of the motor in stalling condition, the `STALL_RL` output indicating the percent ratio of the start situation and the set value of *Lock rotor time*. The value is available in the Monitored data view.

The activation of the `BLOCK` input signal resets the operation time and deactivates the `OPR_STALL` output.

### Cumulative start-up protection

This module protects the motor from an excessive number of start-ups.

Whenever the motor is started, the latest value of `START_TIME` is added to the existing value of `T_ST_CNT` and the updated cumulative start-up time is available at `T_ST_CNT`. If the value of `T_ST_CNT` is greater than the value of *Cumulative time Lim*, the `LOCK_START` output is activated and lockout condition for the restart of motor is enabled during the time the output is active. The `LOCK_START` output remains high until the `T_ST_CNT` value reduces to a value less than the value of *Cumulative time Lim*. The start time counter reduces at the rate of the value of *Counter Red rate*.

The `LOCK_START` output becomes activated at the start of `MOT_START`. The output remains active for a period of *Restart inhibit time*.

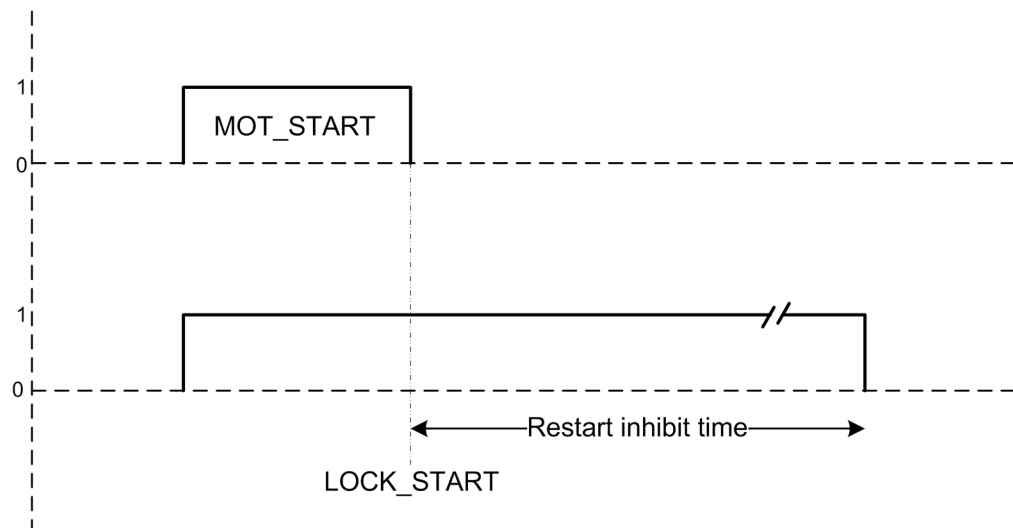


Figure 332: Time delay for cumulative start

This module also protects the motor from consecutive start-ups. When the `LOCK_START` output is active, `T_RST_ENA` shows the possible time for next restart.

The value of  $T\_RST\_ENA$  is calculated by the difference of *Restart inhibit time* and the elapsed time from the instant  $LOCK\_START$  is enabled.

When the  $ST\_EMERG\_ENA$  emergency start is set high, the value of the cumulative start-up time counter is set to *Cumulative time Lim - 60s · Emg start Red rate*. This disables  $LOCK\_START$  and in turn makes the restart of the motor possible.

This module also calculates the total number of start-ups occurred,  $START\_CNT$ . The value can be reset from the Clear menu.

The old *Number of motor start-ups occurred* counter value ( $START\_CNT$ ) can be taken into use by writing the value to the *Ini start up counter* parameter and resetting the value via the Clear menu from WHMI .

The calculated values of  $T\_RST\_ENA$ ,  $T\_ST\_CNT$  and  $START\_CNT$  are available in the Monitored data view.

The activation of the  $BLK\_LK\_ST$  input signal deactivates the  $LOCK\_START$  output. The activation of the  $BLOCK$  input signal resets the cumulative start-up counter module.

### 3.10.5 Application

When a motor is started, it draws a current well in excess of the motor's full-load rating throughout the period it takes for the motor to run up to the rated speed. The motor starting current decreases as the motor speed increases and the value of current remains close to the rotor-locked value for most of the acceleration period.

The full-voltage starting or the direct-on-line starting method is used out of the many methods used for starting the induction motor. If there is either an electrical or mechanical constraint, this starting method is not suitable. The full-voltage starting produces the highest starting torque. A high starting torque is generally required to start a high-inertia load to limit the acceleration time. In this method, full voltage is applied to the motor when the switch is in the "On" position. This method of starting results in a large initial current surge, which is typically four to eight times that of the full-load current drawn by the motor. If a star-delta starter is used, the value of the line current will only be about one-third of the direct-on-line starting current.

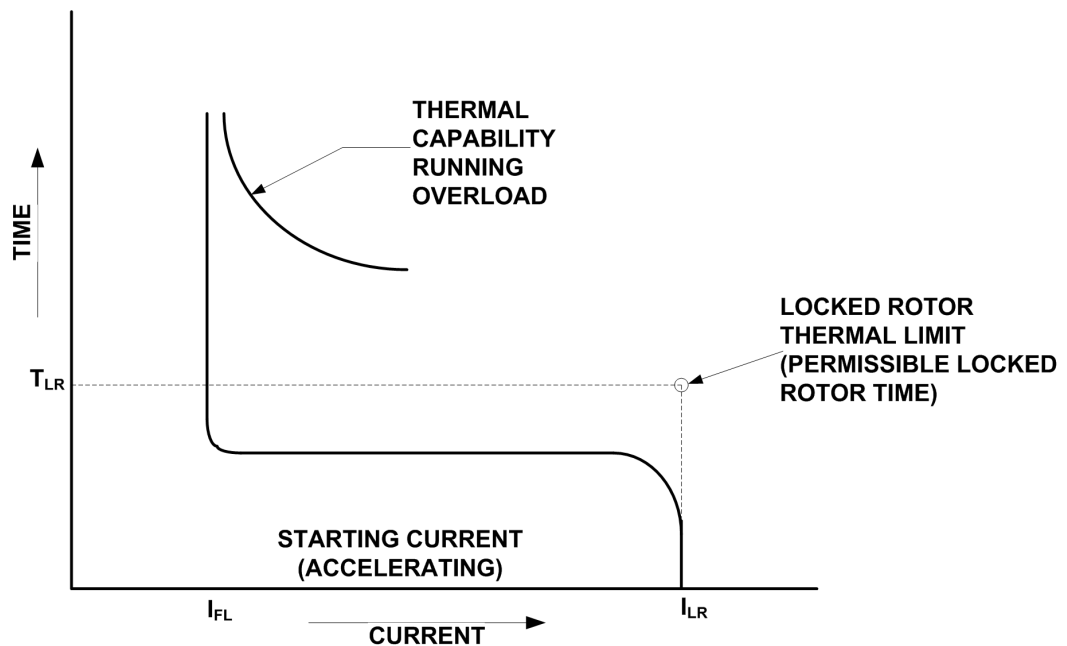


Figure 333: Typical motor starting and capability curves

The start-up supervision of a motor is an important function because of the higher thermal stress developed during starting. During the start-up, the current surge imposes a thermal strain on the rotor. This is exaggerated as the air flow for cooling is less because the fans do not rotate in their full speed. Moreover, the difference of speed between the rotating magnetic field and the rotor during the start-up time induces a high magnitude of slip current in the rotor at frequencies higher than when the motor is at full speed. The skin effect is stronger at higher frequencies and all these factors increase the losses and the generated heat. This is worse when the rotor is locked.

The starting current for slip-ring motors is less than the full load current and therefore it is advisable to use the circuit breaker in the closed position to indicate the starting for such type of motors.

The starting times vary depending on motor design and load torque characteristics. The time taken may vary from less than two seconds to more than 60 seconds. The starting time is determined for each application.

When the permissible stall time is less than the starting time of the motor, the stalling protection is used and the value of the time delay setting should be set slightly less than the permissible stall time. The speed switch on the motor shaft must be used for detecting whether the motor begins to accelerate or not. However, if the safe stall time is longer than the start-up time of the motor, the speed switch is not required.

The failure of a motor to accelerate or to reach its full nominal speed in an acceptable time when the stator is energized is caused by several types of abnormal conditions, including a mechanical failure of the motor or load bearings, low supply voltage, open circuit in one phase of a three-phase voltage supply or too high starting voltage. All these abnormal conditions result in overheating.

Repeated starts increase the temperature to a high value in the stator or rotor windings, or both, unless enough time is allowed for the heat to dissipate. To ensure a safe operation it is necessary to provide a fixed-time interval between starts or limit the number of starts within a period of time. This is why the motor

manufacturers have restrictions on how many starts are allowed in a defined time interval. This function does not allow starting of the motor if the number of starts exceeds the set level in the register that calculates them. This insures that the thermal effects on the motor for consecutive starts stay within permissible levels.

For example, the motor manufacturer may state that three starts at the maximum are allowed within 4 hours and the start-up situation time is 60 seconds. By initiating three successive starts we reach the situation as illustrated. As a result, the value of the register adds up to a total of 180 seconds. Right after the third start has been initiated, the output lock of start of motor is activated and the fourth start will not be allowed, provided the time limit has been set to 121 seconds.

Furthermore, a maximum of three starts in 4 hours means that the value of the register should reach the set start time counter limit within 4 hours to allow a new start. Accordingly, the start time counter reduction should be 60 seconds in 4 hours and should thus be set to  $60\text{ s} / 4\text{ h} = 15\text{ s} / \text{h}$ .

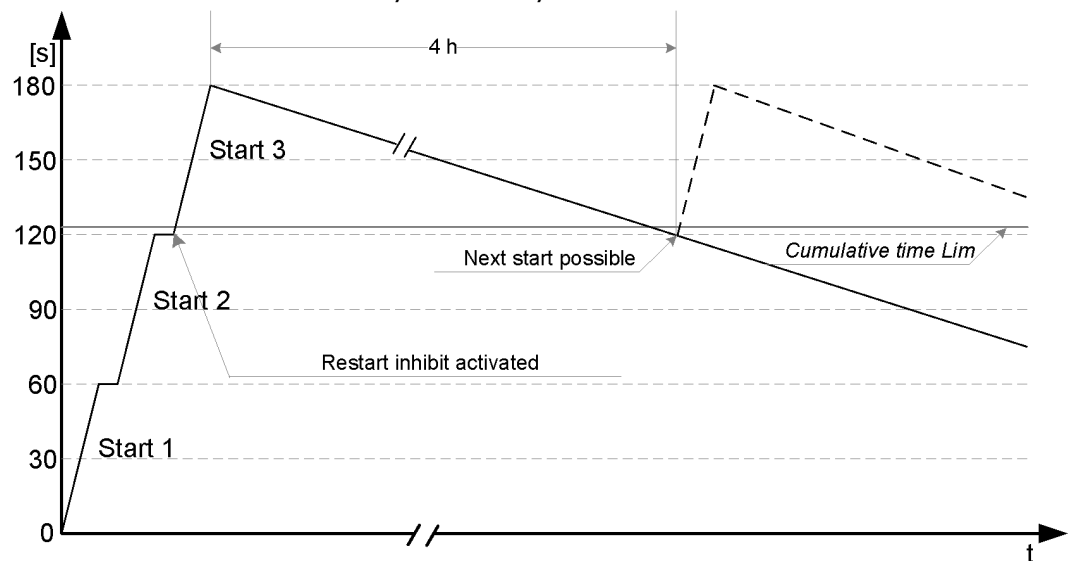


Figure 334: Typical motor-starting and capability curves

Setting of *Cumulative time Lim*

*Cumulative time Lim* is calculated by

$$\sum t_{si} = (n-1) \times t + margin$$

- n specified maximum allowed number of motor start-ups
- t start-up time of the motor (in seconds)
- margin safety margin (~10...20 percent)

Setting of *Counter Red rate*

*Counter Red rate* is calculated by

$$\Delta \sum t_s = \frac{t}{t_{reset}}$$

- t specified start time of the motor in seconds
- t<sub>reset</sub> duration during which the maximum number of motor start-ups stated by the manufacturer can be made; time in hours

## 3.10.6 Signals

### 3.10.6.1 STTPMSU Input signals

Table 572: STTPMSU Input signals

| Name         | Type    | Default | Description  |
|--------------|---------|---------|--|
| I_A          | SIGNAL  | 0       | Phase A current  |
| I_B          | SIGNAL  | 0       | Phase B current  |
| I_C          | SIGNAL  | 0       | Phase C current  |
| BLOCK        | BOOLEAN | 0=False | Block of function  |
| BLK_LK_ST    | BOOLEAN | 0=False | Blocks lock out condition for restart of motor           |
| CB_CLOSED    | BOOLEAN | 0=False | Input showing the status of motor circuit breaker        |
| STALL_IND    | BOOLEAN | 0=False | Input signal for showing the motor is not stalling       |
| ST_EMERG_ENA | BOOLEAN | 0=False | Enable emergency start to disable lock of start of motor |

### 3.10.6.2 STTPMSU Output signals

Table 573: STTPMSU Output signals

| Name       | Type    | Description                                      |
|------------|---------|--|
| OPR_IIT    | BOOLEAN | Operate/trip signal for thermal stress.          |
| OPR_STALL  | BOOLEAN | Operate/trip signal for stalling protection.     |
| MOT_START  | BOOLEAN | Signal to show that motor startup is in progress |
| LOCK_START | BOOLEAN | Lock out condition for restart of motor.         |

## 3.10.7 Settings

### 3.10.7.1 STTPMSU Settings

**Table 574: STTPMSU Group settings (Basic)**

| Parameter           | Values (Range) | Unit | Step | Default | Description  |
|---------------------|----------------|------|------|---------|--|
| Motor start-up A    | 1.0...10.0     | xIn  | 0.1  | 2.0     | Motor starting current                                     |
| Motor start-up time | 1...80         | s    | 1    | 5       | Motor starting time  |
| Lock rotor time     | 2...120        | s    | 1    | 10      | Permitted stalling time                                    |
| Str over delay time | 0...60000      | ms   | 1    | 100     | Time delay to check for completion of motor startup period |

**Table 575: STTPMSU Group settings (Advanced)**

| Parameter         | Values (Range) | Unit | Step | Default | Description                                    |
|-------------------|----------------|------|------|---------|--|
| Start detection A | 0.1...10.0     | xIn  | 0.1  | 1.5     | Current value for detecting starting of motor. |

**Table 576: STTPMSU Non group settings (Basic)**

| Parameter           | Values (Range)   | Unit | Step | Default | Description                                 |
|---------------------|--|------|------|---------|---|
| Operation           | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On                          |
| Operation mode      | 1=Ilt<br>2=Ilt, CB<br>3=Ilt + stall<br>4=Ilt + stall, CB |      |      | 1=Ilt   | Motor start-up operation mode               |
| Counter Red rate    | 2.0...250.0  | s/h  | 0.1  | 60.0    | Start time counter reduction rate           |
| Cumulative time Lim | 1...500  | s    | 1    | 10      | Cumulative time based restart inhibit limit |
| Emg start Red rate  | 0.00...100.00  | %    | 0.01 | 20.00   | Start time reduction fac-                   |

*Table continues on the next page*



| Parameter            | Values (Range) | Unit | Step | Default | Description                             |
|----------------------|----------------|------|------|---------|---|
|                      |                |      |      |         | tor when emergency start is On          |
| Restart inhibit time | 0...250        | min  | 1    | 30      | Time delay between consecutive startups |
| Ini start up counter | 0...999999     |      | 1    | 0       | Initial value for the START_CNT         |

Table 577: STTPMSU Non group settings (Advanced)

| Parameter          | Values (Range) | Unit | Step | Default | Description   |
|--------------------|----------------|------|------|---------|---|
| Motor standstill A | 0.05...0.20    | xIn  | 0.01 | 0.12    | Current limit to check for motor standstill condition |

## 3.10.8 Monitored data

### 3.10.8.1 STTPMSU Monitored data

Table 578: STTPMSU Monitored data

| Name       | Type    | Values (Range) | Unit | Description   |
|------------|---------|----------------|------|---|
| START_CNT  | INT32   | 0...999999     |      | Number of motor start-ups occurred                          |
| START_TIME | FLOAT32 | 0.0...999.9    | s    | Measured motor latest startup time in sec                   |
| T_ST_CNT   | FLOAT32 | 0.0...99999.9  | s    | Cumulated start-up time in sec                              |
| T_RST_ENA  | INT32   | 0...999        | min  | Time left for restart when lock-start is enabled in minutes |
| IIT_RL     | FLOAT32 | 0.00...100.00  | %    | Thermal stress relative to set maximum thermal stress       |

*Table continues on the next page*

| Name     | Type    | Values (Range)   | Unit | Description   |
|----------|---------|--|------|---|
| STALL_RL | FLOAT32 | 0.00...100.00  | %    | Start time relative to the operate time for stall condition |
| STTPMSU  | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status  |

### 3.10.9 Technical data

Table 579: STTPMSU Technical data

| Characteristic             |   | Value  |         |         |
|----------------------------|---|--|---------|---------|
| Operation accuracy         |   | Depending on the frequency of the measured current: $f_n \pm 2 \text{ Hz}$<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$ |         |         |
| Start time <sup>9192</sup> |   | Minimum  | Typical | Maximum |
|                            | $I_{\text{Fault}} = 1.1 \times \text{set Start detection } A$ | 29 ms  | 30 ms   | 34 ms   |
| Operate time accuracy      |   | $\pm 1.0\%$ of the set value or $\pm 20 \text{ ms}$  |         |         |
| Reset ratio                |   | Typically 0.90   |         |         |

### 3.10.10 Technical revision history

Table 580: STTPMSU Technical revision history

| Technical revision | Change                                      |
|--------------------|---|
| B                  | Internal improvement.                       |
| C                  | Added setting <i>Ini start up counter</i> . |

## 3.11 Multipurpose protection MAPGAPC

<sup>91</sup> Current before =  $0.0 \times I_n$ ,  $f_n = 50 \text{ Hz}$ , overcurrent in one phase, results based on statistical distribution of 1000 measurements

<sup>92</sup> Includes the delay of the signal output contact

### 3.11.1 Identification

| Function description    | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|-------------------------|--------------------------|--------------------------|-------------------------------|
| Multipurpose protection | MAPGAPC                  | MAP                      | MAP                           |

### 3.11.2 Function block

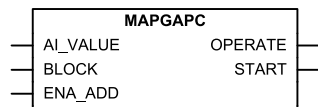


Figure 335: Function block

### 3.11.3 Functionality

The multipurpose protection function MAPGAPC is used as a general protection with many possible application areas as it has flexible measuring and setting facilities. The function can be used as an under- or overprotection with a settable absolute hysteresis limit. The function operates with the definite time (DT) characteristics.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

### 3.11.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of MAPGAPC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

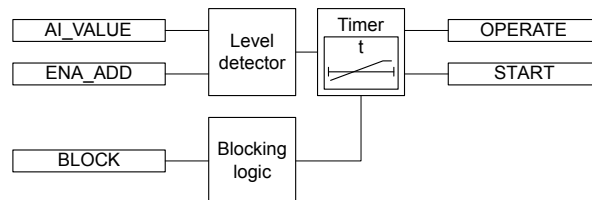


Figure 336: Functional module diagram

#### Level detector

The level detector compares `AI_VALUE` to the *Start value* setting. The *Operation mode* setting defines the direction of the level detector.

| Operation Mode | Description   |
|----------------|---|
| "Under"        | If the input signal AI_VALUE is lower than the set value of the Start value setting, the level detector enables the timer module. |
| "Over"         | If the input signal AI_VALUE exceeds the set value of the Start value setting, the level detector enables the timer module.       |

The *Absolute hysteresis* setting can be used for preventing unnecessary oscillations if the input signal is slightly above or below the *Start value* setting. After leaving the hysteresis area, the start condition has to be fulfilled again and it is not sufficient for the signal to only return to the hysteresis area. If the ENA\_ADD input is activated, the threshold value of the internal comparator is the sum of the *Start value Add* and *Start value* settings. The resulting threshold value for the comparator can be increased or decreased depending on the sign and value of the *Start value Add* setting.

### Timer

Once activated, the timer activates the START output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the OPERATE output is activated. If the starting condition disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operation timer resets and the START output is deactivated.

The timer calculates the start duration value START\_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration > System > Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

## 3.11.5 Application

The function block can be used for any general analog signal protection, either underprotection or overprotection. The setting range is wide, allowing various protection schemes for the function. Thus, the absolute hysteresis can be set to a value that suits the application.

The temperature protection using the RTD sensors can be done using the function block. The measured temperature can be fed from the RTD sensor in bay level relay or merging unit, sent to protective device via GOOSE message, to the function input

that detects too high temperatures in the motor bearings or windings, for example. When the `ENA_ADD` input is enabled, the threshold value of the internal comparator is the sum of the *Start value Add* and *Start value* settings. This allows a temporal increase or decrease of the level detector depending on the sign and value of the *Start value Add* setting, for example, when the emergency start is activated. If, for example, *Start value* is 100, *Start value Add* is 20 and the `ENA_ADD` input is active, the input signal needs to rise above 120 before MAPGAPC operates.

## 3.11.6 Signals

### 3.11.6.1 MAPGAPC Input signals

Table 581: MAPGAPC Input signals

| Name     | Type    | Default | Description                                   |
|----------|---------|---------|---|
| AI_VALUE | FLOAT32 | 0.0     | Analogue input value                          |
| BLOCK    | BOOLEAN | 0=False | Block signal for activating the blocking mode |
| ENA_ADD  | BOOLEAN | 0=False | Enable start added                            |

### 3.11.6.2 MAPGAPC Output signals

Table 582: MAPGAPC Output signals

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |

## 3.11.7 Settings

### 3.11.7.1 MAPGAPC Settings

Table 583: MAPGAPC Group settings (Basic)

| Parameter          | Values (Range)     | Unit | Step | Default | Description        |
|--------------------|--------------------|------|------|---------|--------------------|
| Start value        | -10000.0...10000.0 |      | 0.1  | 0.0     | Start value        |
| Start value Add    | -100.0...100.0     |      | 0.1  | 0.0     | Start value Add    |
| Operate delay time | 0...200000         | ms   | 100  | 0       | Operate delay time |

**Table 584: MAPGAPC Non group settings (Basic)**

| Parameter      | Values (Range)    | Unit | Step | Default | Description        |
|----------------|-------------------|------|------|---------|--------------------|
| Operation      | 1=on<br>5=off     |      |      | 1=on    | Operation Off / On |
| Operation mode | 1=Over<br>2=Under |      |      | 1=Over  | Operation mode     |

**Table 585: MAPGAPC Non group settings (Advanced)**

| Parameter           | Values (Range) | Unit | Step | Default | Description                       |
|---------------------|----------------|------|------|---------|-----------------------------------|
| Reset delay time    | 0...60000      | ms   | 100  | 0       | Reset delay time                  |
| Absolute hysteresis | 0.01...100.00  |      | 0.01 | 0.10    | Absolute hysteresis for operation |

## 3.11.8 Monitored data

### 3.11.8.1 MAPGAPC Monitored data

**Table 586: MAPGAPC Monitored data**

| Name      | Type    | Values (Range)   | Unit | Description                        |
|-----------|---------|--|------|------------------------------------|
| START_DUR | FLOAT32 | 0.00...100.00  | %    | Ratio of start time / operate time |
| MAPGAPC   | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                             |

## 3.11.9 Technical data

**Table 587: MAPGAPC Technical data**

| Characteristic     | Value                            |
|--------------------|----------------------------------|
| Operation accuracy | ±1.0% of the set value or ±20 ms |

### 3.11.10 Technical revision history

Table 588: MAPGAPC Technical revision history

| Technical revision | Change                |
|--------------------|-----------------------|
| B                  | Internal improvement. |
| C                  | Internal improvement. |

## 3.12 Capacitor bank protection

### 3.12.1 Three-phase overload protection for shunt capacitor banks COLPTOC (ANSI 51,37,86C)

#### 3.12.1.1 Identification

| Function description                                      | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---|--------------------------|--------------------------|-------------------------------|
| Three-phase overload protection for shunt capacitor banks | COLPTOC                  | 3I> 3I<                  | 51,37,86C                     |

#### 3.12.1.2 Function block

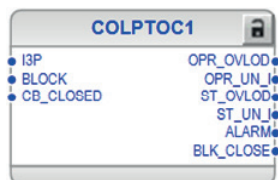


Figure 337: Function block symbol

#### 3.12.1.3 Functionality

The three-phase overload protection for shunt capacitor banks function COLPTOC provides single-phase, two-phase and three-phase protection against overloads caused by harmonic currents and overvoltages in shunt capacitor banks. The operation of overload and alarm is based on the peak value of the integrated current which is proportional to the voltage across the capacitor.

The overload function operates with IDMT characteristic and an alarm function operates with DT characteristic.

COLPTOC provides undercurrent protection to detect disconnection of the capacitor. COLPTOC has breaker reclosing inhibit feature to enable complete capacitor discharging before breaker reclosing after it has operated.

COLPTOC contains blocking functionality. It is possible to block the function outputs, timers or the function itself.

### 3.12.1.4 Analog channel configuration

COLPTOC has one analog group input which must be properly configured.

**Table 589: Analog inputs**

| Input | Description          |
|-------|----------------------|
| I3P   | Three-phase currents |



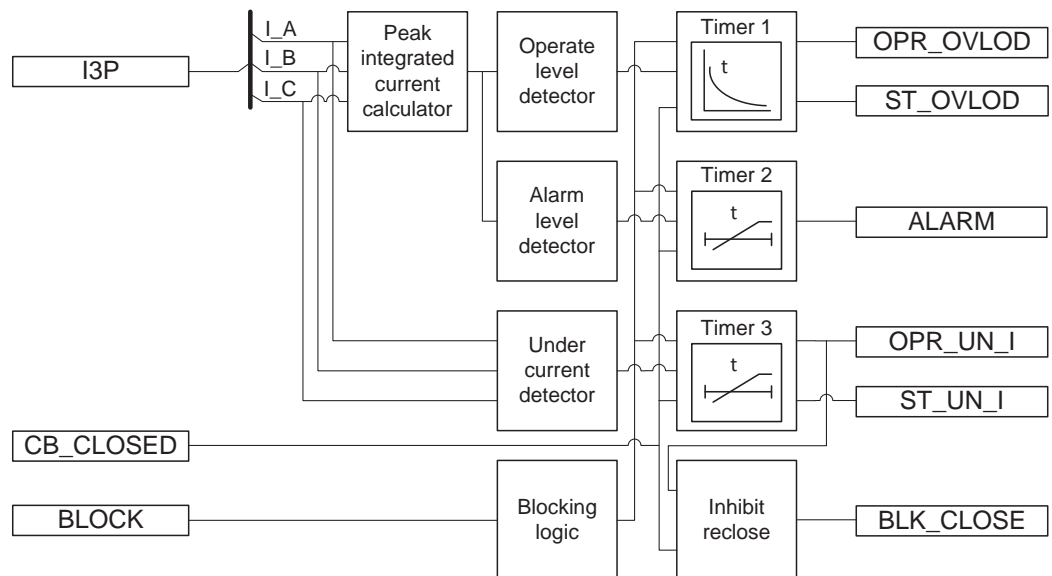
See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

### 3.12.1.5 Operation principle

The function can be enabled and disabled with the Operation setting. The corresponding parameter values are “On” and “Off”.

The operation of COLPTOC can be described using a module diagram. All the modules in the diagram are explained in the next sections.



*Figure 338: Functional module diagram*



### Peak integrated current calculator

The peak integrated current calculator calculates peak value of integrated current ( $I\_PEAK\_INT\_A$ ,  $I\_PEAK\_INT\_B$  and  $I\_PEAK\_INT\_C$ ) which is proportional to the voltage over capacitor. The  $I\_PEAK\_INT\_A$ ,  $I\_PEAK\_INT\_B$  and  $I\_PEAK\_INT\_C$  values are available in monitored data view. The frequency response of the peak integrated current calculator can be seen in [Figure 339](#).

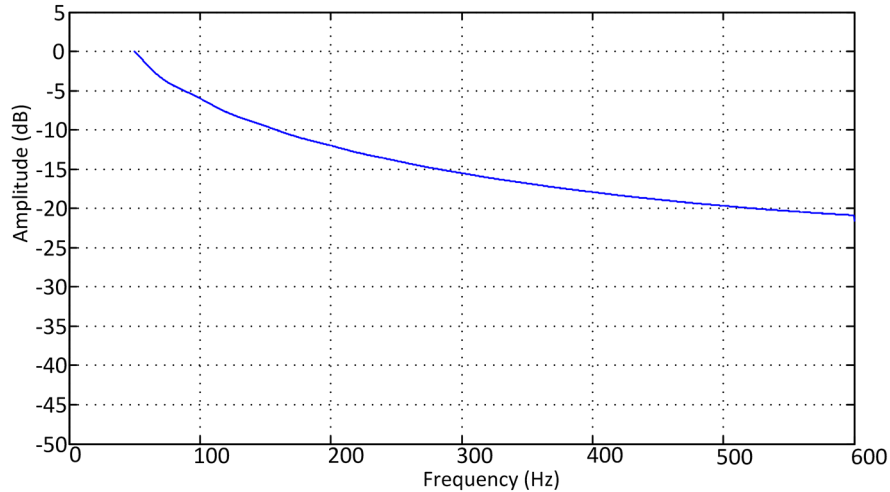


Figure 339: Frequency response of the peak integrated current calculator

### Operate level detector

The Operate level detector compares  $I\_PEAK\_INT\_x$  value to *Start value overload*. If the phase or phases in which  $I\_PEAK\_INT\_x$  exceeds the setting matches the *Num of start phases* setting, the Operate level detector module activates the Timer 1 module.

#### Timer 1

Once activated, the Timer 1 module activates the  $ST\_OVL0D$  output. The operation time depends on the overload level and *Time multiplier*. The operation time under standard characteristics is based on ANSI/IEEE 37.99 and IEC 60871-1 recommendations.

Table 590: Standard Curve characteristics for IDMT Curve

| Overload value | IED operate time(s) with k = 1 | Standard                  |
|----------------|--------------------------------|---------------------------|
| 1.10           | 43200                          | IEC60871-1                |
| 1.15           | 1800                           | IEC60871-1                |
| 1.20           | 300                            | IEC60871-1                |
| 1.30           | 60                             | ANSI/IEEE37.99,IEC60871-1 |
| 1.40           | 15                             | ANSI/IEEE37.99            |
| 1.70           | 1                              | ANSI/IEEE37.99            |
| 2.20           | 0.120                          | ANSI/IEEE37.99            |

Operate time is based on maximum value of I\_PEAK\_INT\_A, I\_PEAK\_INT\_B and I\_PEAK\_INT\_C. From maximum value calculated, operate time between any two consecutive points in the standard table is based on logarithmic interpolation.

The operate time can be scaled using the *Time multiplier* setting. The OPR\_OVL0D output is activated if the overload situation lasts long enough to exceed the operation time.



The operate time for the operation overload stage is limited between 0.1 s to 43200 s (12 hours) if *Time multiplier* is used.

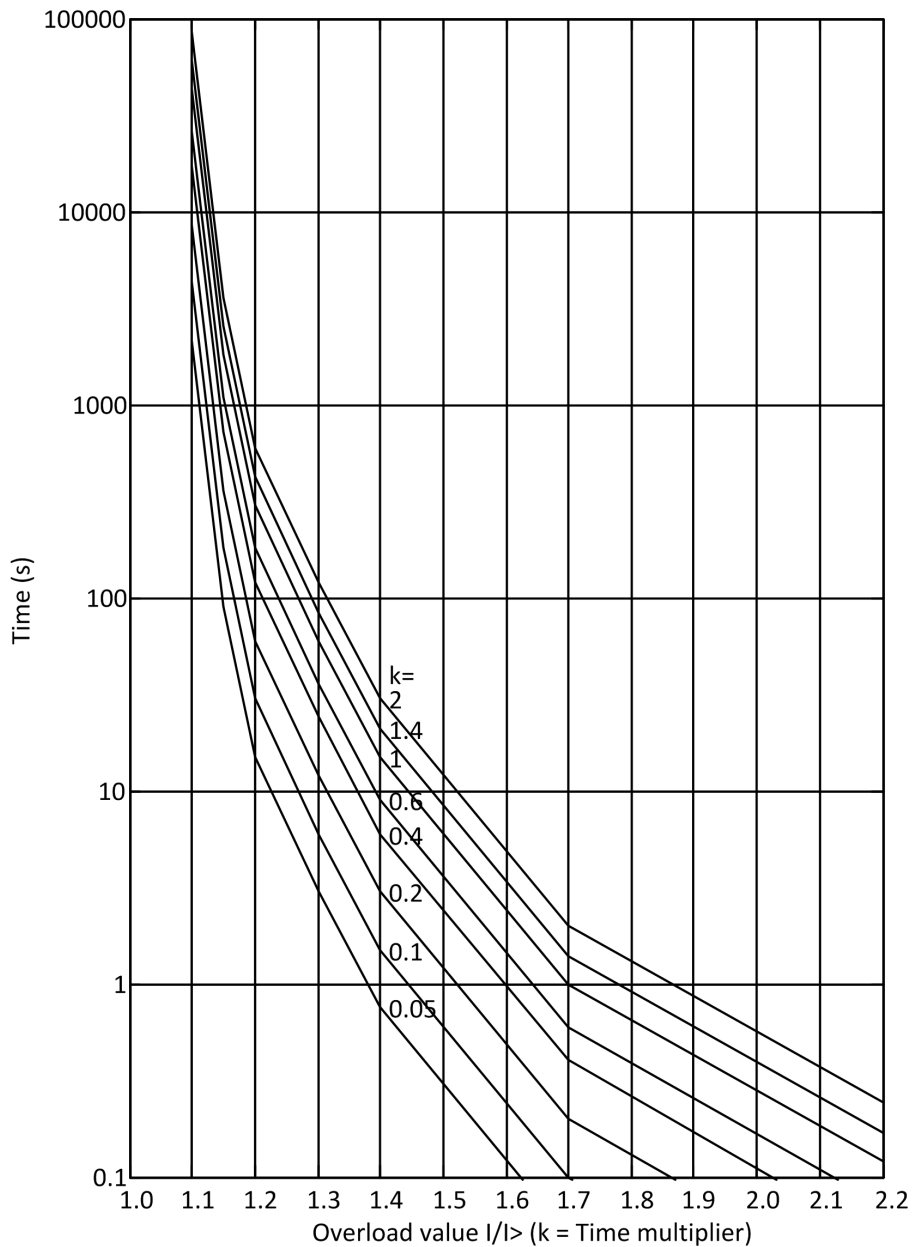


Figure 340: Inverse-time characteristic curves for overload stage

If the integrated current exceeds 1.1 times the setting *Start value overload* for a short period but does not operate as the current decreases within *Start value overload*, the output ST\_OVL0D is kept active but the operation timer is frozen.

However, if the integrated current exceeds 1.1 times the *Start value overload* setting value again, the operation timer continue from the freezing point. Thus, the operation timer is cumulative. If the integrated current exceeds 1.1 times the setting *Start value overload* only once and remains within the *Start value overload* area for 24 hours, the operation timer and the output `ST_OVL0D` are reset.

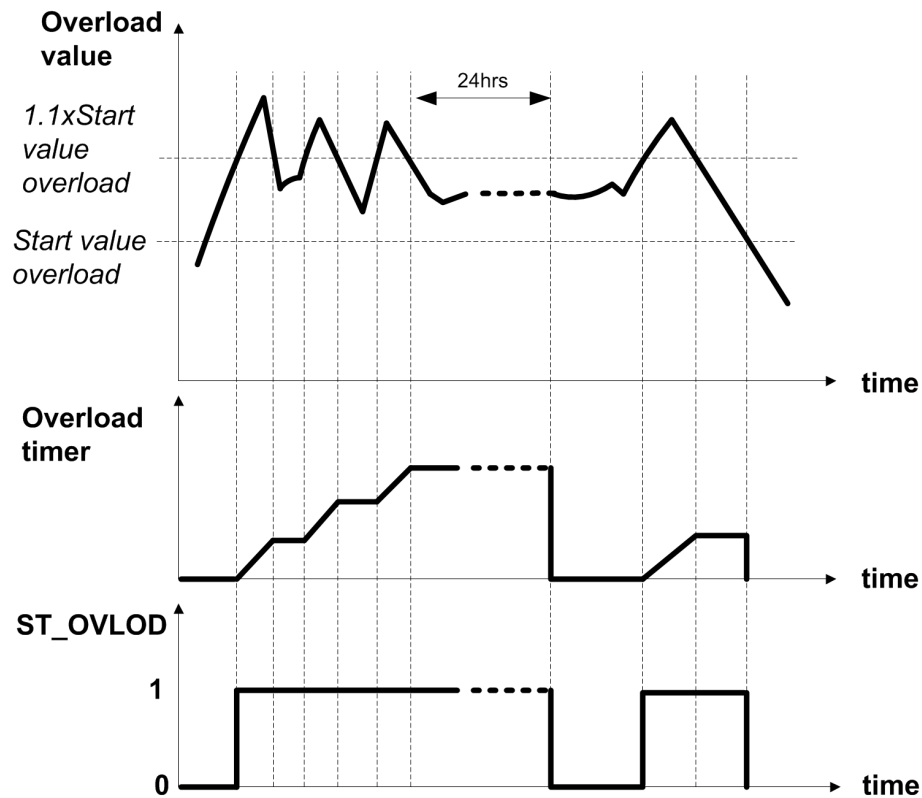


Figure 341: The behavior of the IDMT timer and the output `ST_OVL0D`

The `ST_DUR_OVL0D` output indicates the percentage ratio of the start situation and the operation time in the Timer 1 module and is available in the monitored data view.



The Timer 1 module is internally blocked for one second after the capacitor bank is connected by detecting the rising edge of the `CB_CLOSED` signal. The `CB_CLOSED` signal is True when the CB position is closed.

#### Alarm level detector

The Alarm level detector compares `I_PEAK_INT_x` value to *Alarm start value*. If the phase or phases in which `I_PEAK_INT_x` exceeds the setting matches the *Num of start phases* setting, the Alarm level detector module activates the Timer 2 module.



The *Num of start phases* setting is a common setting for both Operate level detector and Alarm level detector.

#### Timer 2

The Timer 2 characteristics are according to Definite Time (DT). When the operation timer has reached the value of *Alarm delay time*, the `ALARM` output is activated.

If a drop-off situation happens, the timer is reset.



The Timer 2 module is internally blocked for one second after the capacitor bank is connected by detecting the rising edge of the `CB_CLOSED` signal. The `CB_CLOSED` signal is True when the CB position is closed.

### Under current detector

The Under current detector module can be enabled by setting *Enable under current* to “Enable” and disabled by setting it to “Disable”. The Under current detector module is also disabled when `CB_CLOSED` is FALSE, that is, when circuit breaker is open.

The fundamental frequency component of phase currents is compared to the setting *Start value Un Cur*. If all the three-phase currents are below the setting *Start value Un Cur*, the Under current detector module enables the Timer 3 module.

### Timer 3

Once activated, the Timer 3 module activates the `ST_UN_I` output. The operation is based on DT characteristics. When the operation timer has reached the value of *Un Cur delay time*, the `OPR_UN_I` output is activated.

If the undercurrent situation disappears, the operation timer is reset. The `ST_DUR_UN_I` output indicates the percentage ratio of the undercurrent start situation and the set operation time in the Timer 3 module and is available in the monitored data view.

The `OPR_UN_I` output is of pulse type and remains TRUE for 150 ms. After that, `ST_DUR_UN_I` and `OPR_UN_I` are deactivated and `ST_DUR_UN_I` is reset.



If the circuit breaker closed status signal is not detected, the constant value TRUE has to be connected to `CB_CLOSED` input to enable the undercurrent detector.



If the circuit breaker status signal is not connected to `CB_CLOSED` input, the `OPR_UN_I` output is activated even if the circuit breaker is open and undercurrent is detected.

### Inhibit reclose

When the output `OPR_UN_I` becomes active or when the `CB_CLOSED` state changes from TRUE to FALSE, that is, when circuit breaker opens, the reclosing inhibition module activates output `BLK_CLOSE`.



If *Enable under current* is set to “Disable”, the reclosing inhibition operation is based purely on the `CB_CLOSED` input.

When the relay powers up after a reboot or software reset, or if the Operation of COLPTOC function is switched from off to on, the `BLK_CLOSE` output is activated defined by the *Reclose inhibit time*, regardless the *Reclose inhibit mode*.

The behavior of the `BLK_CLOSE` output depends on *Reclose inhibit mode*. If *Reclose inhibit mode* is set to “Lockout”, the `BLK_CLOSE` output needs to be reset manually from the clearing menu parameter *COLPTOC inhibit recl*. If *Reclose inhibit mode* is set to “Non-latched”, the `BLK_CLOSE` output resets after the set *Reclose inhibit time* has elapsed.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting **Configuration > System > Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the “Freeze timers” mode, the operation timer is frozen to the prevailing value. In the “Block all” mode, the whole function is blocked and the timers are reset. In the “Block OPERATE output” mode, `COLPTOC` is executed normally but the `OPR_OVL` and `OPR_UN_I` outputs are not allowed to activate.



The `BLOCK` input does not block the `BLK_CLOSE` signal.

### 3.12.1.6

#### Application

The application area for three-phase overload protection function of shunt capacitor bank is the protection of power capacitor banks intended for reactive power compensation and filtering of the harmonics. Shunt capacitor banks provide a low-impedance path to harmonic currents and hence attract harmonic currents flowing in the system. Increased harmonic currents result in excessive voltage stress across the capacitor bank. According to the standards, a high-voltage capacitor shall be able to withstand 10% overload. Loading beyond that can cause damage to the capacitor bank and in turn to the system. Hence, `COLPTOC` is specially designed for the protection against overloads produced by harmonic currents and overvoltage.

Undercurrent protection is used to disconnect the capacitor bank from the rest of the power system when the voltage at the capacitor bank terminals is too low for too long a period of time. To avoid an undercurrent trip operation when the capacitor bank is disconnected from the power system, the undercurrent functionality is blocked by using the capacitor bank circuit breaker status signal.

Furthermore, the reclosing inhibition feature provides protection against the reconnection of a charged capacitor to a live network. Whenever the capacitor bank circuit breaker is opened, the reclosing is inhibited for the duration of the discharge time of the capacitor. The reclosing inhibition functionality can be disabled manually or automatically. In the manual mode, the inhibition reclosing has to be manually reset and in automatic mode, the reclosing inhibition resets automatically after the set time.

### 3.12.1.7 Signals

**Table 591: COLPTOC Input signals**

| Name      | Type    | Default | Description   |
|-----------|---------|---------|---|
| I3P       | SIGNAL  | –       | Three-phase currents                                  |
| BLOCK     | BOOLEAN | 0=False | Block signal for activating the blocking mode         |
| CB_CLOSED | BOOLEAN | 0=False | Input showing the status of capacitor circuit breaker |

**Table 592: COLPTOC Output signals**

| Name      | Type    | Description                        |
|-----------|---------|------------------------------------|
| OPR_OVL0D | BOOLEAN | Overload operated                  |
| OPR_UN_I  | BOOLEAN | Operate under current              |
| ST_OVL0D  | BOOLEAN | Overload started                   |
| ST_UN_I   | BOOLEAN | Under current started              |
| ALARM     | BOOLEAN | Alarm                              |
| BLK_CLOSE | BOOLEAN | Inhibit re-close of capacitor bank |

### 3.12.1.8 Settings

**Table 593: COLPTOC Group settings (Basic)**

| Parameter             | Values (Range) | Unit | Step | Default | Description  |
|-----------------------|----------------|------|------|---------|--|
| Start value over-load | 0.30...1.50    | xIn  | 0.01 | 1.00    | Start value for over-load stage                      |
| Alarm start value     | 80...120       | %    | 1    | 105     | Alarm start value (% of Start value overload)        |
| Start value Un Cur    | 0.10...0.70    | xIn  | 0.01 | 0.50    | Start value for under current operation              |
| Time multiplier       | 0.05...2.00    |      | 0.01 | 1.00    | Time multiplier for Capacitor Bank protection curves |
| Alarm delay time      | 500...6000000  | ms   | 100  | 300000  | Alarm delay time                                     |
| Un Cur delay time     | 100...120000   | ms   | 100  | 1000    | Delay time for under current operation               |

**Table 594: COLPTOC Group settings (Advanced)**

| Parameter            | Values (Range) | Unit | Step | Default | Description          |
|----------------------|----------------|------|------|---------|----------------------|
| Reclose inhibit time | 1...6000       | s    | 1    | 1       | Reclose inhibit time |

**Table 595: COLPTOC Non group settings (Basic)**

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on           |      |      | 1=on    | Operation Off / On |

*Table continues on the next page*

| Parameter            | Values (Range)                               | Unit | Step | Default       | Description                                      |
|----------------------|--|------|------|---------------|--|
|                      | 5=off  |      |      |               |  |
| Reclose inhibit mode | 1=Non-latched<br>3=Lockout                   |      |      | 1=Non-latched | Reclose inhibit mode                             |
| Num of start phases  | 1=1 out of 3<br>2=2 out of 3<br>3=3 out of 3 |      |      | 1=1 out of 3  | Number of phases required for operate activation |

**Table 596: COLPTOC Non group settings (Advanced)**

| Parameter            | Values (Range)        | Unit | Step | Default  | Description                        |
|----------------------|-----------------------|------|------|----------|------------------------------------|
| Enable under current | 0=Disable<br>1=Enable |      |      | 1=Enable | Enable under current functionality |

### 3.12.1.9 Monitored data

**Table 597: COLPTOC Monitored data**

| Name         | Type    | Values (Range)   | Unit | Description   |
|--------------|---------|--|------|---|
| ST_DUR_OVLOD | FLOAT32 | 0.00...100.00  | %    | Start duration for overload stage                             |
| ST_DUR_UN_I  | FLOAT32 | 0.00...100.00  | %    | Start duration for under current operation                    |
| I_PEAK_INT_A | FLOAT32 | 0.00...40.00   |      | Phase A peak value of the integrated current of the capacitor |
| I_PEAK_INT_B | FLOAT32 | 0.00...40.00   |      | Phase B peak value of the integrated current of the capacitor |
| I_PEAK_INT_C | FLOAT32 | 0.00...40.00   |      | Phase C peak value of the integrated current of the capacitor |
| COLPTOC      | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status  |

### 3.12.1.10 Technical data

**Table 598: COLPTOC Technical data**

| Characteristic                                     | Value   |
|--|---|
| Operation accuracy                                 | Depending on the frequency of the measured current:<br>$f_n \pm 2$ Hz, and no harmonics<br>5 % of the set value or $0.002 \times I_n$ |
| Start time for overload stage <sup>1, 2</sup>      | Typically 75 ms   |
| Start time for under current stage <sup>2, 3</sup> | Typically 26 ms   |
| Reset time for overload and alarm stage            | Typically 60 ms   |
| Reset ratio  | Typically 0.96  |
| Operate time accuracy in definite time mode        | 1 % of the set value or $\pm 20$ ms   |
| Operate time accuracy in inverse time mode         | 10 % of the theoretical value or $\pm 20$ ms  |
| Suppression of harmonics for under current stage   | DFT: -50 dB at $f = n \times f_n$ , where $n = 2,3,4,5,..$  |

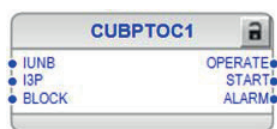
## 3.12.2 Current unbalance protection for capacitor banks CUBPTOC (ANSI 60N)

### 3.12.2.1 Identification

**Table 599: Function identification**

| Function description                                   | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--|--------------------------|--------------------------|-------------------------------|
| Current unbalance protection for shunt capacitor banks | CUBPTOC                  | dI>C                     | 60N                           |

### 3.12.2.2 Function block



*Figure 342: Function block symbol*

<sup>1</sup> Harmonics current before fault =  $0.5 \times I_n$ , harmonics fault current  $1.5 \times \text{Start value}$ , results based on statistical distribution of 1000 measurements

<sup>2</sup> Includes the delay of the signal output contact

<sup>3</sup> Harmonics current before fault =  $1.2 \times I_n$ , harmonics fault current  $0.8 \times \text{Start value}$ , results based on statistical distribution of 1000 measurements



### 3.12.2.3 Functionality

The current unbalance protection for shunt capacitor banks function CUBPTOC is used to protect the double-Y-connected capacitor banks from internal faults. CUBPTOC is suitable for the protection of internally fused, externally fused and fuseless applications.

CUBPTOC has two stages of operation, that is, operation stage and alarm stage. In the operating stage, CUBPTOC starts when the measured unbalance current exceeds the set limit. The operation time characteristics can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). The operation under alarm stage is either based on the DT characteristics or the faulty element counter of a capacitor bank.

CUBPTOC has a blocking functionality. It is possible to block the function outputs, timers or the function itself.

### 3.12.2.4 Analog channel configuration

CUBPTOC has two analog group inputs which must be properly configured.

**Table 600: Analog inputs**

| Input | Description                  |
|-------|------------------------------|
| IUNB  | Unbalance current (measured) |
| I3P   | Three-phase currents         |



See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

**Table 601: Special conditions**

| Condition        | Description  |
|------------------|--|
| IUNB measurement | The function requires that the unbalance current measurement is connected to the RESTCTR function block. |

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

### 3.12.2.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “On” and “Off”. The current unbalance protection for shunt capacitor banks operates on the DFT measurement mode.

The operation of CUBPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

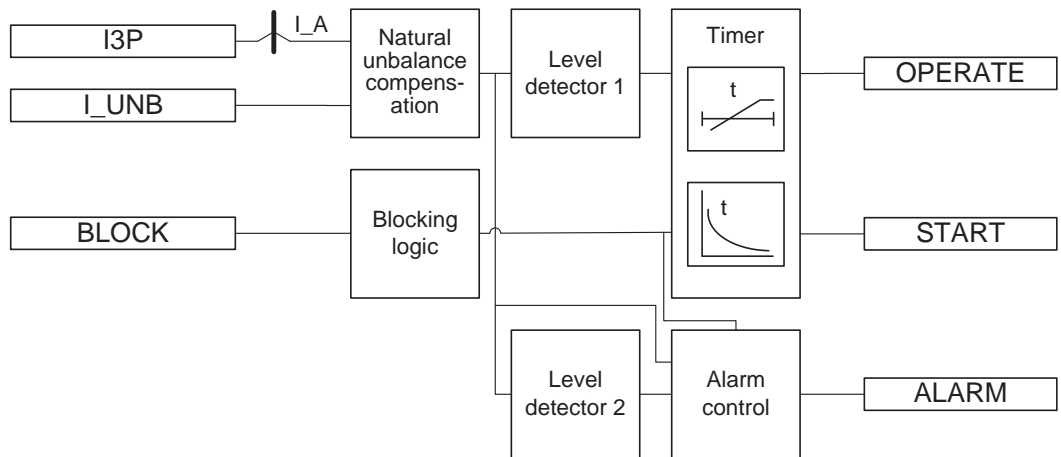


Figure 343: Functional module diagram

**Natural unbalance Compensation**

A standard double-Y-connected shunt capacitor bank configuration is shown in Figure 344. The fundamental frequency component of an unbalance current is measured on the common neutral connecting the two balanced parts of a shunt capacitor bank, that is, between star point 1 and star point 2.

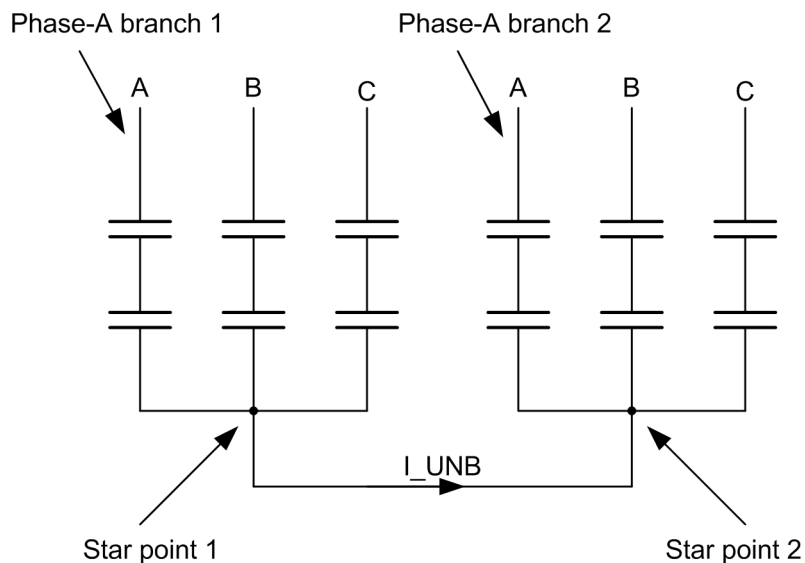


Figure 344: Double-Y-connected capacitor bank

The phase angle of the measured fundamental frequency component of the unbalance current I\_UNB is synchronized by using the phase current I\_A as a reference.

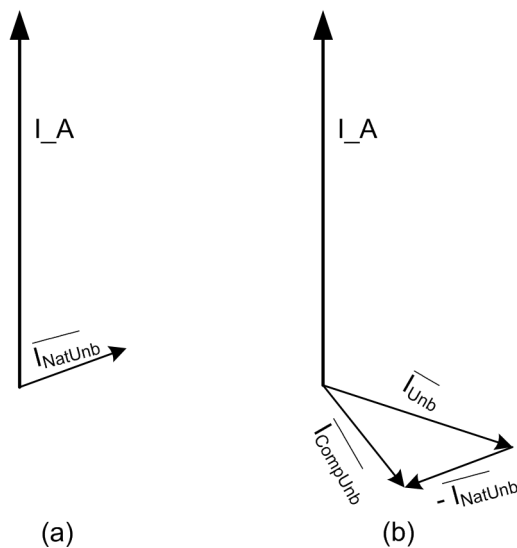
$$\angle I_{unb} = \angle I_{UNB} - \angle I_A$$

(Equation 34)

In a three-phase star-connected capacitor bank circuit, there may be some amount of natural unbalance current flowing through the neutral, which is primarily due

to capacitor manufacturing tolerances. The natural unbalance current must be compensated for before using the measured unbalance current for the function operation. The natural unbalance current needs to be recorded when there is no fault in the capacitor banks, and it is initiated through the command *Record unbalance*, available under menu path **Control** > **CUBPTOC**. By selecting *Record unbalance* with value “Record”, the measured unbalance current  $\bar{I}_{Unb}$  is considered as the natural unbalance current  $\bar{I}_{NatUnb}$  and is stored as a reference. The amplitude and angle of the recorded natural unbalance current I\_AMPL\_NAT and I\_ANGL\_NAT are available in the monitored data view.

Once the natural unbalance current is recorded during further executions of the function, the natural unbalance current is subtracted from the measured unbalance current  $\bar{I}_{Unb}$  to obtain the compensated unbalance current  $\bar{I}_{CompUnb}$  as shown in [Figure 345](#).



*Figure 345: Natural unbalance compensation. (a) Healthy condition when the natural unbalance is recorded (b) Unbalance compensation during faulty conditions*

The natural unbalance current compensation is enabled using the setting *Natural Comp Enable*. If *Natural Comp Enable* is set to “FALSE”, the unbalance current is not compensated. If *Natural Comp Enable* is set to “TRUE”, the compensated unbalance current is calculated based on the equation.

$$\bar{I}_{CompUnb} = \bar{I}_{Unb} - \bar{I}_{NatUnb}$$

(Equation 35)

The amplitude I\_AMPL\_COMP and the angle I\_ANGL\_COMP of the compensated unbalance current  $\bar{I}_{CompUnb}$  are available in the monitored data view.

### Level detector 1

The calculated compensated unbalance current  $I_{AMPL\_COMP}$  is compared to the set "Start value". If  $I_{AMPL\_COMP}$  exceeds the set "Start value", the Level detector 1 sends an enabling signal to the Timer 1 module.

### Timer 1

Once activated, the Timer 1 module activates the `START` output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the `OPERATE` output is activated. When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C* and *Curve parameter E*.

In a drop-off situation, that is when a fault suddenly disappears before the operate delay is exceeded, the Timer 1 reset state is activated. The functionality of the Timer 1 in the reset state depends on the combination of the Operating curve type and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, an immediate reset occurs. The `START` output is deactivated when the reset timer has elapsed.

The setting *Time multiplier* is used for scaling the IDMT operation and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operation time for IDMT. The setting is applicable only when the IDMT curves are used.



The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve but always at least the value of the *Minimum operate time* setting.

The Timer 1 module calculates the start duration value `START_DUR`, which indicates the percentile ratio of the start situation and the set operation time. The value is available in the monitored data view.

In a typical double-Y-connected configuration ( [Figure 344](#)), there are two branches in every phase and hence six individual counters `COUNT_BR1_A`, `COUNT_BR2_A`, `COUNT_BR1_B`, `COUNT_BR2_B`, `COUNT_BR1_C` and `COUNT_BR2_C` are maintained. Based on the phase angle of the compensated unbalance current  $I_{ANGL\_COMP}$ , the phase and the branch of the element failure location is detected. However, the element failure location also depends on the type of capacitor banks, that is, whether internal or external fuses are used. The setting *Fuse location* is used to set the capacitor bank type as "External" or "Internal".

For an external fuse capacitor bank, the element failure location and corresponding counters to be incremented are determined based on the phase angle of the compensated unbalance current.

**Table 602: Element failure location and counters to be incremented for external fuse case**

| Phase angle of the compensated unbalance current (degrees) | Phase and branch of the element failure | Counters to be incremented |
|--|---|----------------------------|
| -15...+15  | Phase-A branch 1                        | COUNT_BR1_A                |
| -15...-45  | Phase-A branch 1<br>Phase-C branch 2    | COUNT_BR1_A<br>COUNT_BR2_C |
| -45...-75  | Phase-C branch 2                        | COUNT_BR2_C                |
| -75...-105   | Phase-B branch 1<br>Phase-C branch 2    | COUNT_BR1_B<br>COUNT_BR2_C |
| -105...-135  | Phase-B branch 1                        | COUNT_BR1_B                |
| -135...-165  | Phase-B branch 1<br>Phase-A branch 2    | COUNT_BR1_B<br>COUNT_BR2_A |
| -165...-180  | Phase-A branch 2                        | COUNT_BR2_A                |
| +165...+180  | Phase-A branch2                         | COUNT_BR2_A                |
| +135...+165  | Phase-C branch 1<br>Phase-A branch 2    | COUNT_BR1_C<br>COUNT_BR2_A |
| +105...+135  | Phase-C branch 1                        | COUNT_BR1_C                |
| +75...+105   | Phase-C branch1<br>Phase-B branch2      | COUNT_BR1_C<br>COUNT_BR2_B |
| +45...+75  | Phase-B branch2                         | COUNT_BR2_B                |
| +15...+45  | Phase-A branch1<br>Phase-B branch2      | COUNT_BR1_A<br>COUNT_BR2_B |



If the capacitor bank is fuseless, then the setting *Fuse location* should be set to “External” and [Table 602](#) can be used to determine the element failure location.

If the compensated unbalance current  $I_{AMPL\_COMP}$  is greater than three times the set *Alarm value*, it is considered to be a case of blown external fuse. For the internal fuse and blown fuse cases, the element failure location and corresponding counters to be incremented are determined based on the phase angle of the compensated unbalance current.

**Table 603: Element failure location and counters to be incremented for internal fuse and blown fuse case**

| Phase angle of the compensated unbalance current (degrees) | Phase and branch of the element failure | Counters to be incremented |
|--|---|----------------------------|
| -15...+15  | Phase-A branch 2                        | COUNT_BR2_A                |
| -15... -45   | Phase-A branch 2                        | COUNT_BR2_A                |

*Table continues on the next page*

| Phase angle of the compensated unbalance current (degrees) | Phase and branch of the element failure | Counters to be incremented |
|--|---|----------------------------|
|  | Phase-C branch 1                        | COUNT_BR1_C                |
| -45...-75  | Phase-C branch 1                        | COUNT_BR1_C                |
| -75...-105   | Phase-B branch 2<br>Phase-C branch 1    | COUNT_BR2_B<br>COUNT_BR1_C |
| -105...-135  | Phase-B branch 2                        | COUNT_BR2_B                |
| -135...-165  | Phase-B branch 2<br>Phase-A branch 1    | COUNT_BR2_B<br>COUNT_BR1_A |
| -165...-180  | Phase-A branch 1                        | COUNT_BR1_A                |
| +165...+180  | Phase-A branch 1                        | COUNT_BR1_A                |
| +135...+165  | Phase-C branch 2<br>Phase-A branch 1    | COUNT_BR2_C<br>COUNT_BR1_A |
| +105...+135  | Phase-C branch 2                        | COUNT_BR2_C                |
| +75...+105   | Phase-C branch 2<br>Phase-B branch 1    | COUNT_BR2_C<br>COUNT_BR1_B |
| +45...+75  | Phase-B branch 1                        | COUNT_BR1_B                |
| +15...+45  | Phase-A branch 2<br>Phase-B branch 1    | COUNT_BR2_A<br>COUNT_BR1_B |

After *Alarm delay time* has elapsed, the corresponding counter value is incremented based on the magnitude of the unbalance current. If  $I\_AMPL\_COMP$  is less than 1.5 times the set *Alarm value*, the counter is incremented by one. Furthermore, if  $I\_AMPL\_COMP$  is between 1.5 and 2.5 times the set *Alarm value*, the counter is incremented by two and so on.



Normally, the setting *Alarm value* is about 0.1 percent lower than the value of the unbalance current which is caused by one faulty element. This setting value has to be chosen carefully because a slightly lower value may lead to a situation where the counters show more failures than the actual. Too high setting leads to a situation where a fault is not detected.

The counter values COUNT\_BR1\_A, COUNT\_BR2\_A, COUNT\_BR1\_B, COUNT\_BR2\_B, COUNT\_BR1\_C and COUNT\_BR2\_C are available in the monitoring data view. The total number of element failures in double-Y-connected capacitor banks, FAIL\_COUNT, is available in the monitored data view.

The ALARM output is activated, when the value of FAIL\_COUNT exceeds the setting *Element failure limit*.

The counter values can be reset via *CUBPTOC counters* which is located under the Clear menu.

### Level detector 2

The calculated compensated unbalance current  $I_{AMPL\_COMP}$  is compared to the set *Alarm start value*. If the  $I_{AMPL\_COMP}$  exceeds the set *Alarm value* the Level detector 2 sends enabling signal to the Alarm control module.

### Alarm control

Depending on the *Alarm mode* setting, the alarm stage operation is according to "Normal mode" or "Element counter mode".

In the "Normal mode" the time characteristic is according to DT. When the alarm timer has reached the value set by *Alarm delay time*, the ALARM output is activated. If the fault disappears before the alarm activates, the alarm timer is reset immediately.

The "Element counter mode" is used to detect faulty elements of the capacitor bank and count the number of element failures in each branch and line. On activation, this module increments the corresponding element failure counters after the set *Alarm delay time* has elapsed.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting **Configuration > System > Blocking mode**, which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, CUBPTOC operates normally but the OPERATE output is not activated.

## 3.12.2.6

### Application

CUBPTOC is designed for the protection against internal faults in double-Y-connected capacitor banks. This unbalance protection detects an asymmetry in the capacitor bank caused by blown fuses or short circuits across bushings or between capacitor units and the racks in which they are mounted.

Normally, the capacitor units are designed to withstand 110 percent of the nominal voltage continuously. When an element inside a capacitor bank fails, the remaining healthier elements experience an increase in voltage across them. If the voltage exceeds the 110 percent value of the nominal voltage, it can lead to a failure of the healthier elements of the bank and in turn fail the entire capacitor bank. Since the capacitor unbalance current is directly proportional to the element failures, unbalance protection is an effective way of detecting capacitor element failures. The current unbalance protection function is usually used with the three-phase capacitor bank overload protection function to increase the sensitivity of protection for capacitor banks.

Due to the two-stage (operation and alarm stage) unbalance protection and the natural unbalance compensation facility, the protection of capacitor banks with internal fuses can be implemented with a very high degree of sensitivity.

Furthermore, CUBPTOC provides a sophisticated method of detecting the number of faulty elements in each phase by calculating the differential unbalance current.

The unbalance protection function can be used for internally fused, externally fused and fuseless shunt capacitor banks. Since a fuseless capacitor bank lacks the individual capacitor unit fuses, current unbalance protection becomes even more critical for fuseless applications.

When an individual element fails, it causes unbalance current. With an increasing number of element failures, the unbalance current increases and CUBPTOC gives an alarm. The alarm level is normally set to 50 percent of the maximum permitted level. The capacitor bank needs to be taken out of service to replace the faulty units. If this is not done, the capacitor bank is tripped when the maximum allowed unbalance current level is exceeded.



If two simultaneous faults occur in the same phase but in different branches, there is no change in the unbalance current and CUBPTOC does not detect this type of faults.



If two simultaneous faults occur in the same branch but in different phases, it may cause a phase angle equal to a situation where there is only one fault in the branch. Therefore, the element failure counters show only one fault instead of two.

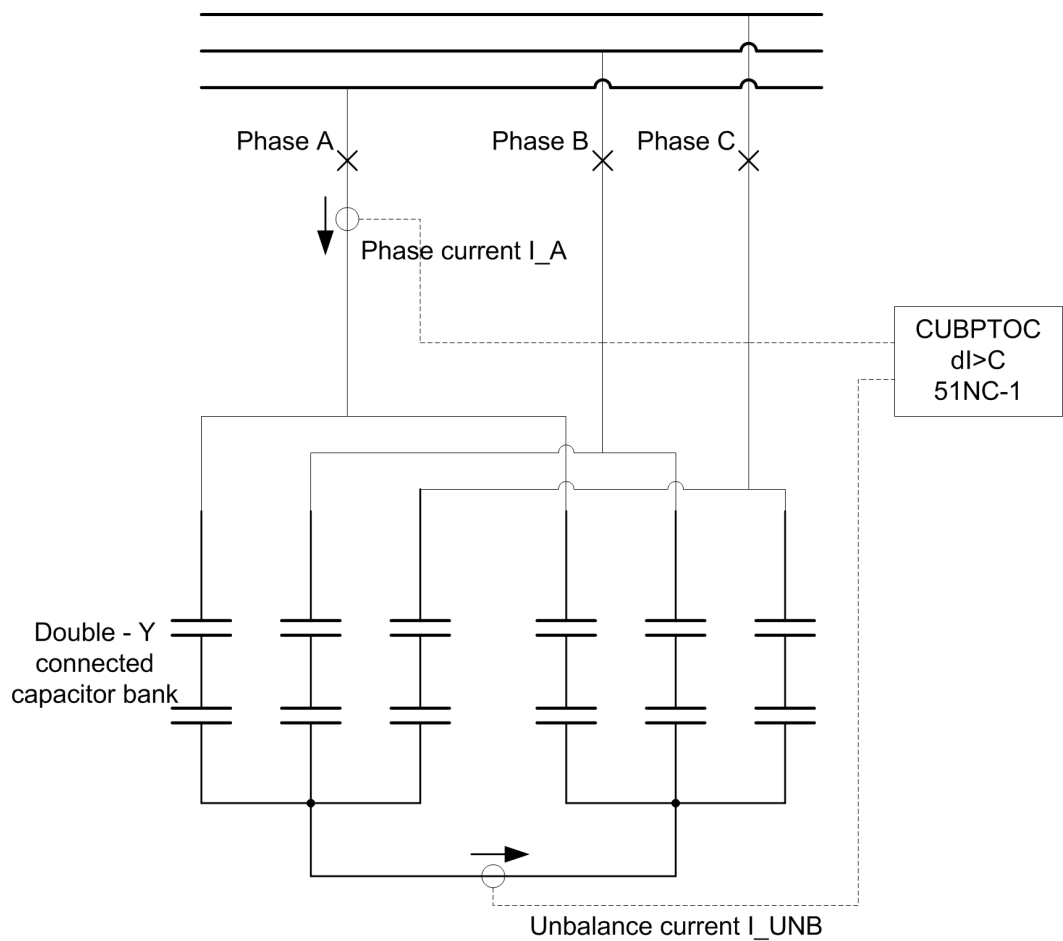


Figure 346: Example of double-Y-connected shunt capacitor bank unbalance protection





Connect the phase current analog input  $I\_A$  and unbalance current  $I\_UNB$  to the protection relay for the CUBPTOC function to start working.

#### Steps to measure natural unbalance current

1. The setting *Natural Comp Enable* must be set to “TRUE”.
2. The capacitor bank must be energized.
3. The capacitor bank compensated unbalance current  $I\_COM\_AMPL$  is observed from Monitored data.
4. The command *Record unbalance* must be activated by selecting the value “Record” which stores the unbalance reference for future unbalance calculations.
5. The compensated unbalance current ( $I\_COM\_AMPL$ ) is re-checked to be approximately zero.



The natural unbalance recording should be made only during the steady-state condition and when all the capacitor bank elements are assumed to be in service.

### 3.12.2.7

#### Signals

Table 604: CUBPTOC Input signals

| Name     | Type    | Default | Description                                   |
|----------|---------|---------|---|
| $I\_UNB$ | SIGNAL  | –       | Analog input                                  |
| I3P      | SIGNAL  | –       | Three-phase currents                          |
| BLOCK    | BOOLEAN | 0=False | Block signal for activating the blocking mode |

Table 605: CUBPTOC Output signals

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |
| ALARM   | BOOLEAN | Alarm       |

### 3.12.2.8

#### Settings

Table 606: CUBPTOC Group settings (Basic)

| Parameter         | Values (Range)                | Unit | Step | Default  | Description                             |
|-------------------|-------------------------------|------|------|----------|---|
| Alarm mode        | 1=Normal<br>2=Element counter |      |      | 1=Normal | Mode of operation for Alarm stage       |
| Start value       | 0.01...1.00                   | xIn  | 0.01 | 0.10     | Start value                             |
| Alarm start value | 0.01...1.00                   | xIn  | 0.01 | 0.05     | Alarm start value                       |
| Time multiplier   | 0.05...15.00                  |      | 0.01 | 1.00     | Time multiplier in IEC/ANSI IDMT curves |

Table continues on the next page

| Parameter            | Values (Range)   | Unit | Step | Default          | Description                        |
|----------------------|--|------|------|------------------|------------------------------------|
| Operating curve type | 1=ANSI Ext. inv.<br>2=ANSI Very inv.<br>3=ANSI Norm. inv.<br>4=ANSI Mod. inv.<br>5=ANSI Def. Time<br>6=L.T.E. inv.<br>7=L.T.V. inv.<br>8=L.T. inv.<br>9=IEC Norm. inv.<br>10=IEC Very inv.<br>11=IEC inv.<br>12=IEC Ext. inv.<br>13=IEC S.T. inv.<br>14=IEC L.T. inv.<br>15=IEC Def. Time<br>17=Programmable<br>18=RI type<br>19=RD type |      |      | 15=IEC Def. Time | Selection of time delay curve type |
| Operate delay time   | 50...200000  | ms   | 10   | 5000             | Operate delay time                 |
| Alarm delay time     | 50...200000  | ms   | 10   | 200000           | Alarm delay time                   |

**Table 607: CUBPTOC Group settings (Advanced)**

| Parameter            | Values (Range)           | Unit | Step | Default    | Description                                       |
|----------------------|--------------------------|------|------|------------|---|
| Fuse location        | 1=Internal<br>2=External |      |      | 1=Internal | Location of capacitor fuse                        |
| Element fail limit   | 1...100                  |      | 1    | 3          | Element failure limit above which alarm is active |
| Natural Compensation | 0=False<br>1=True        |      |      | 0=False    | Enable natural unbalance compensation             |

**Table 608: CUBPTOC Non group settings (Basic)**

| Parameter         | Values (Range)          | Unit | Step | Default  | Description                                 |
|-------------------|-------------------------|------|------|----------|---|
| Operation         | 1=on<br>5=off           |      |      | 1=on     | Operation Off / On                          |
| Curve parameter A | 0.00860...120.0000<br>0 |      | 1    | 28.20000 | Parameter A for customer programmable curve |
| Curve parameter B | 0.00000...0.71200       |      | 1    | 0.12170  | Parameter B for customer programmable curve |
| Curve parameter C | 0.02...2.00             |      | 1    | 2.00     | Parameter C for customer programmable curve |
| Curve parameter E | 0.0...1.0               |      | 1    | 1.0      | Parameter E for customer programmable curve |

**Table 609: CUBPTOC Non group settings (Advanced)**

| Parameter            | Values (Range) | Unit | Step | Default | Description                          |
|----------------------|----------------|------|------|---------|--------------------------------------|
| Reset delay time     | 0...60000      | ms   | 1    | 20      | Reset delay time                     |
| Minimum operate time | 20...60000     | ms   | 1    | 20      | Minimum operate time for IDMT curves |

### 3.12.2.9 Monitored data

**Table 610: CUBPTOC Monitored data**

| Name        | Type    | Values (Range)   | Unit | Description                                   |
|-------------|---------|------------------|------|---|
| START_DUR   | FLOAT32 | 0.00...100.00    | %    | Ratio of start time / operate time            |
| I_NAT_AMPL  | FLOAT32 | 0.00...5.00      | xIn  | Recorded natural unbalance current amplitude  |
| I_NAT_ANGL  | FLOAT32 | -179.00...179.00 | deg  | Recorded natural unbalance current angle      |
| I_COM_AMPL  | FLOAT32 | 0.00...5.00      | xIn  | Compensated unbalance current amplitude       |
| I_COM_ANGL  | FLOAT32 | -179.00...179.00 | deg  | Compensated unbalance current angle           |
| COUNT_BR1_A | INT32   | 0...2147483647   |      | Number of element failures in branch1 phase-A |
| COUNT_BR2_A | INT32   | 0...2147483647   |      | Number of element failures in branch2 phase-A |
| COUNT_BR1_B | INT32   | 0...2147483647   |      | Number of element failures in branch1 phase-B |
| COUNT_BR2_B | INT32   | 0...2147483647   |      | Number of element failures in branch2 phase-B |
| COUNT_BR1_C | INT32   | 0...2147483647   |      | Number of element failures in branch1 phase-C |
| COUNT_BR2_C | INT32   | 0...2147483647   |      | Number of element failures in branch2 phase-C |
| FAIL_COUNT  | INT32   | 0...2147483647   |      | Total number of element failures              |

*Table continues on the next page*

| Name        | Type    | Values (Range)   | Unit | Description                                  |
|-------------|---------|--|------|--|
| CUBPTOC     | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                                       |
| I-unb-xIn:1 | FLOAT32 | 0.00...5.00  | xIn  | Measured neutral unbalance current amplitude |

### 3.12.2.10 Technical data

Table 611: CUBPTOC Technical data

| Characteristic  | Value   |
|---|---|
| Operation accuracy  | Depending on the frequency of the measured current:<br>$f_n \pm 2$ Hz<br>1.5 % of the set value or $0.002 \times I_n$ |
| Start time <sup>1, 2</sup>                                  | Typically 26 ms   |
| Reset time  | Typically 40 ms   |
| Reset ratio   | Typically 0.96  |
| Operate time accuracy in definite time mode                 | 1 % of the theoretical value or $\pm 20$ ms   |
| Operate time accuracy in inverse definite minimum time mode | 5 % of the theoretical value or $\pm 20$ ms   |
| Suppression of harmonics                                    | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$   |

## 3.12.3 Three-phase current unbalance protection for shunt capacitor banks HCUBPTOC (ANSI 60P)

### 3.12.3.1 Identification

| Function description   | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--|--------------------------|--------------------------|-------------------------------|
| Three-phase current unbalance protection for shunt capacitor banks | HCUBPTOC                 | 3dI>C                    | 60P                           |

<sup>1</sup> Fundamental frequency current =  $1.0 \times I_n$ , current before fault =  $0.0 \times I_n$ , fault current =  $2.0 \times \text{Start value}$ , results based on statistical distribution of 1000 measurements

<sup>2</sup> Includes the delay of the signal output contact

### 3.12.3.2 Function block

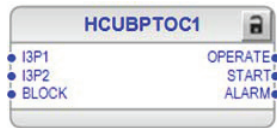


Figure 347: Function block symbol

### 3.12.3.3 Functionality

The three-phase current unbalance protection function for shunt capacitor banks HCUBPTOC is used to protect the H-bridge capacitor banks against internal faults. HCUBPTOC is suitable for protection of internally fused, externally fused and fuse-less capacitor bank applications.

HCUBPTOC has two stages of operation, the operation stage and alarm stage. In the operation stage, HCUBPTOC starts when the measured unbalance current exceeds the set limit. The operating time characteristics can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). In the alarm stage, the alarm starts when the measured unbalance current exceeds the set alarm limit. The alarm time characteristics are based on DT.

HCUBPTOC contains blocking functionality. It is possible to block the function outputs, timers or the function itself.

### 3.12.3.4 Analog channel configuration

HCUBPTOC has two analog group inputs which must be properly configured.

Table 612: Analog inputs

| Input | Description                    |
|-------|--------------------------------|
| I3P1  | Three-phase currents           |
| I3P2  | Three-phase unbalance currents |



See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

### 3.12.3.5 Operation principle

The function can be enabled and disabled with the Operation setting. The corresponding parameter values are “On” and “Off”.

The three-phase current unbalance protection for shunt capacitor banks operates on the DFT measurement mode. The operation of HCUBPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

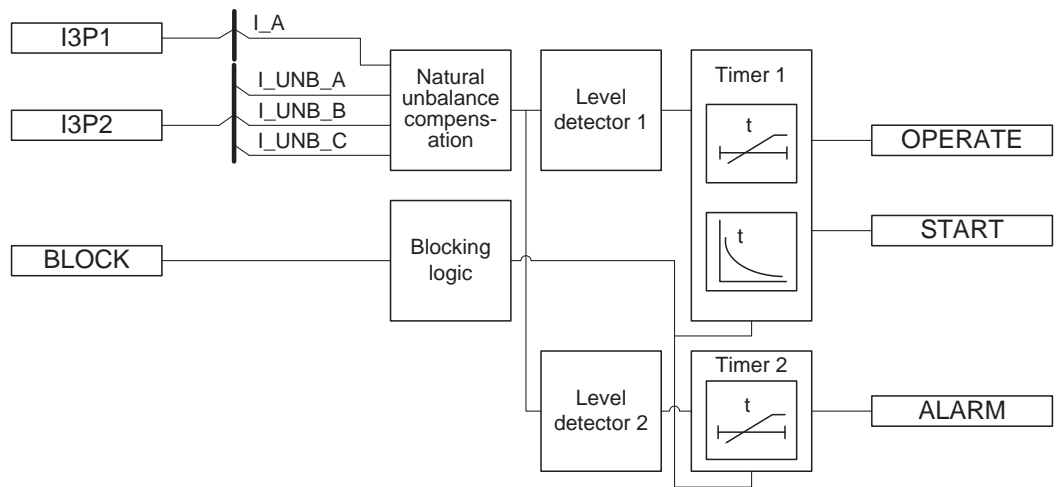


Figure 348: Function module diagram

**Natural unbalance compensation**

In the three-phase H-bridge-connected shunt capacitor bank configuration, the unbalance currents  $I_{UNB\_A}$ ,  $I_{UNB\_B}$  and  $I_{UNB\_C}$  are measured at the common points of the H-bridge.

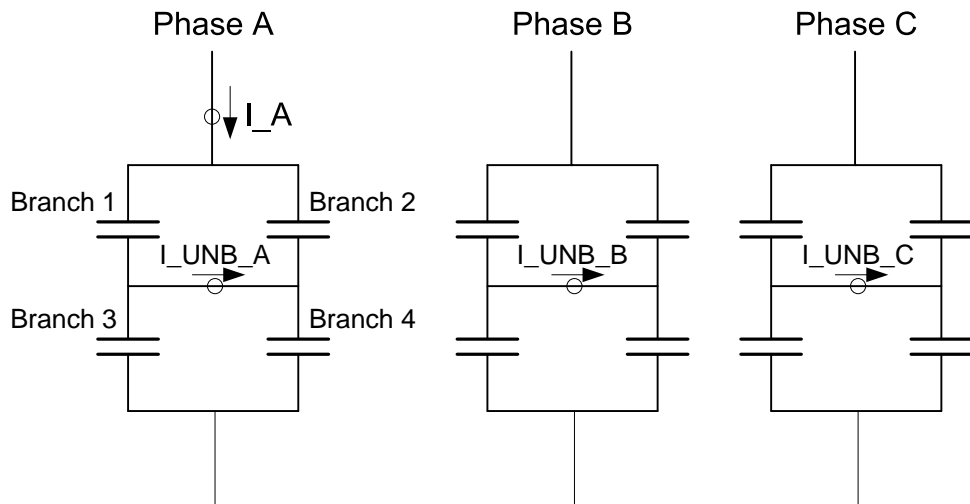


Figure 349: H-Bridge-connected capacitor bank

The phase angles of three-phase measured unbalance currents are synchronized using the phase current  $I_A$  as reference. The phase-A unbalance current phase angle can be calculated with the equation.

$$\angle \overline{I_{Unb\_A}} = \angle \overline{I_{UNB\_A}} - \angle \overline{I_A}$$

(Equation 36)

A three-phase H-bridge-connected capacitor bank circuit may have some amount of natural unbalance current flowing through the common points of H-bridge, which may primarily be due to capacitor manufacturing tolerances. Therefore, the natural

unbalance current must be compensated for before using the measured unbalance current for function operation.

The natural unbalance current needs to be recorded when there is no fault in the capacitor banks, and it is initiated through the command *Record unbalance* available under menu path **Control > HCUBPTOC**. The natural unbalance currents are recorded for all the phases at the same time by setting command *Record unbalance* to “Record all phases” or each natural unbalance current can be recorded separately for individual phases by setting command *Record unbalance* to “Record phase A” or “Record phase B” or “Record phase C”. By selecting *Record unbalance* with value “Record”, the measured three-phase unbalance currents

(  $\overline{I_{Unb\_A}}, \overline{I_{Unb\_B}}, \overline{I_{Unb\_C}}$  ) are considered the natural unbalance currents for each phase respectively and stored as a reference. The amplitude and angle of the phasewise-recorded natural unbalance currents  $I\_NAT\_AMPL\_A, I\_NAT\_ANGL\_A, I\_NAT\_AMPL\_B, I\_NAT\_ANGL\_B, I\_NAT\_AMPL\_C$  and  $I\_NAT\_ANGL\_C$  are available in the monitored data view.

Once a natural unbalance current is recorded, the phasewise natural unbalance current is subtracted from the corresponding phase-measured unbalance current (  $\overline{I_{Unb}}$  ) during further executions of the function to obtain the compensated unbalance current (  $\overline{I_{CompUnb}}$  ).

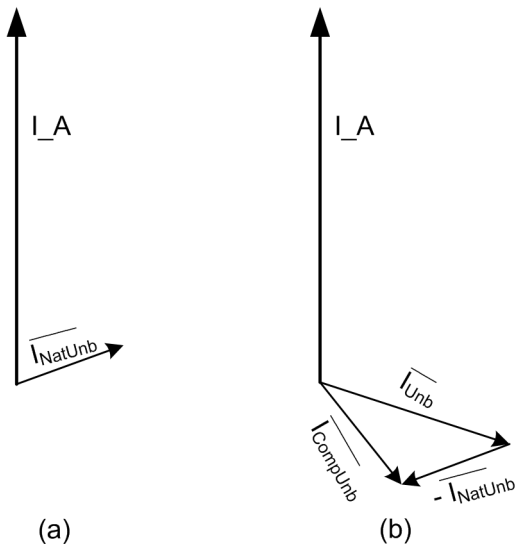


Figure 350: Natural unbalance compensation. (a) Healthy condition when the natural unbalance is recorded (b) Unbalance compensation during faulty conditions

The natural unbalance compensation for each phase is enabled based on the settings *Natural Comp Ena PhA, Natural Comp Ena PhB* and *Natural Comp Ena PhC* respectively. For example, if *Natural Comp Ena PhA* is set to “FALSE”, the unbalance current is not compensated. If *Natural Comp Ena PhA* is set to “TRUE”, the compensated unbalance current for phase A is calculated based on the equation.

$$\overline{I_{CompUnb\_A}} = \overline{I_{Unb\_A}} - \overline{I_{NatUnb\_A}}$$

(Equation 37)

|                  |  |
|------------------|--|
| $I_{CompUnb\_A}$ | Phase A-compensated unbalance current      |
| $I_{Urb\_A}$     | Phase A-measured unbalance current         |
| $I_{NatUnb\_A}$  | Phase A-recorded natural unbalance current |

The phasewise-compensated unbalance current amplitudes and angles

$I\_COM\_AMPL\_A$ ,  $I\_COM\_ANGL\_A$ ,  $I\_COM\_AMPL\_B$ ,  $I\_COM\_ANGL\_B$ ,  $I\_COM\_AMPL\_C$  and  $I\_COM\_ANGL\_C$  are available in the monitored data view.

The phase angles of the unbalance currents indicate the branch of a faulty element in a capacitor bank. For an internal fuse capacitor bank, the element failure branch location is determined based on the phase angle of the compensated unbalance current.

**Table 613: Detection of element failure location for internal fuse capacitor bank**

| Name of the phase angle | Phase angle of unbalance current | Element failure branch location <i>Figure 349</i> |
|-------------------------|----------------------------------|---|
| $I\_COM\_ANGL\_A$       | $\sim +180^\circ$                | Phase A - Branch 1 or Phase A - Branch 4          |
| $I\_COM\_ANGL\_A$       | $\sim 0^\circ$                   | Phase A - Branch 2 or Phase A - Branch 3          |
| $I\_COM\_ANGL\_B$       | $\sim +60^\circ$                 | Phase B - Branch 1 or Phase B - Branch 4          |
| $I\_COM\_ANGL\_B$       | $\sim -120^\circ$                | Phase B - Branch 2 or Phase B - Branch 3          |
| $I\_COM\_ANGL\_C$       | $\sim -60^\circ$                 | Phase C - Branch 1 or Phase C - Branch 4          |
| $I\_COM\_ANGL\_C$       | $\sim +120^\circ$                | Phase C - Branch 2 or Phase C - Branch 3          |

If external fuses are used, the direction of an unbalance current is opposite to that of the bank where internal fuses are in use.

**Table 614: Detection of element failure location for external fuse capacitor bank**

| Name of the phase angle | Phase angle of unbalance current | Element failure branch location <i>Figure 349</i> |
|-------------------------|----------------------------------|---|
| $I\_COM\_ANGL\_A$       | $\sim 0^\circ$                   | Phase A - Branch 1 or Phase A - Branch 4          |
| $I\_COM\_ANGL\_A$       | $\sim +180^\circ$                | Phase A - Branch 2 or Phase A - Branch 3          |
| $I\_COM\_ANGL\_B$       | $\sim -120^\circ$                | Phase B - Branch 1 or Phase B - Branch 4          |
| $I\_COM\_ANGL\_B$       | $\sim +60^\circ$                 | Phase B - Branch 2 or Phase B - Branch 3          |
| $I\_COM\_ANGL\_C$       | $\sim +120^\circ$                | Phase C - Branch 1 or Phase C - Branch 4          |
| $I\_COM\_ANGL\_C$       | $\sim -60^\circ$                 | Phase C - Branch 2 or Phase C - Branch 3          |



### Level detector 1

The phasewise-compensated unbalance currents  $I\_COM\_AMPL\_A$ ,  $I\_COM\_AMPL\_B$  and  $I\_COM\_AMPL\_C$  are compared to the set *Start value*. If the compensated unbalance current in one or more phases exceeds the set *Start value*, the Level detector 1 module sends the enabling signal to the Timer 1 module.

### Timer 1

Once activated, the Timer 1 module activates the `START` output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the `OPERATE` output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C* and *Curve parameter E*.

In a drop-off situation, that is, when a fault suddenly disappears before the operation delay is exceeded, the Timer 1 reset state is activated. The functionality of Timer 1 in the reset state depends on the combination of the *Operating curve type* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, an immediate reset occurs. The `START` output is deactivated when the reset timer has elapsed.

The setting *Time multiplier* is used for scaling the IDMT operation times.

The setting parameter *Minimum operate time* defines the minimum desired operation time for IDMT. The setting is applicable only when the IDMT curves are used.



The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting.

Timer 1 calculates the start duration value `START_DUR`, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

### Level detector 2

The phasewise-compensated unbalance currents  $I\_COM\_AMPL\_A$ ,  $I\_COM\_AMPL\_B$  and  $I\_COM\_AMPL\_C$  are compared to the set *Alarm start value*. If the compensated unbalance current in one or more phases exceeds the set *Alarm start value*, the Level detector 2 module sends the enabling signal to the Timer 2 module.

### Timer 2

Once activated, the timer activates the alarm timer. The timer characteristic is according to DT. When the alarm timer has reached the value set by *Alarm delay time*, the `ALARM` output is activated.

If the fault disappears before the alarm activates, the alarm timer is reset immediately.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting **Configuration > System > Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the “Freeze timers” mode, the operation timer is frozen to the prevailing value. In the “Block all” mode, the whole function is blocked and the timers are reset. In the “Block `OPERATE` output” mode, HCUBPTOC operates normally but the `OPERATE` output is not activated.

### 3.12.3.6

#### Application

Shunt capacitor banks (SCBs) are widely used in transmission and distribution networks to produce reactive power support. Located in relevant places such as in the vicinity of load centers, SCBs have beneficial effects on power system performance: increased power factor, reduced losses, improved system capacity and better voltage level at load points.

The capacitor bank terminology ‘Bank’, ‘Unit’ and ‘Element’ is shown in [Figure 351](#).

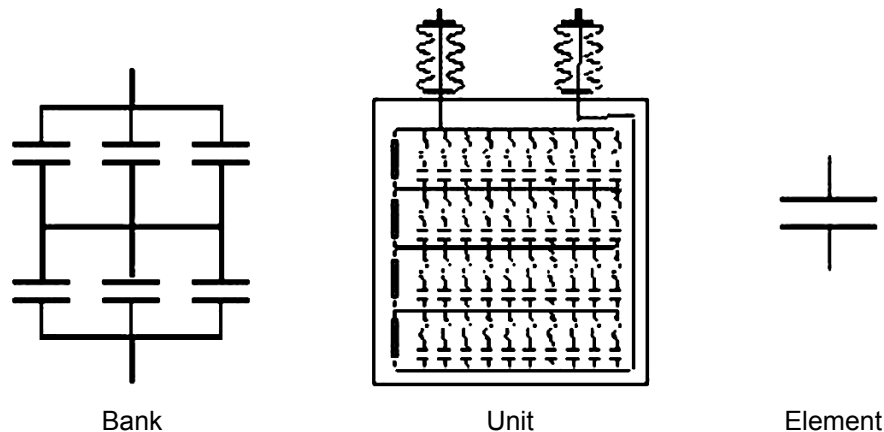


Figure 351: Bank, unit and element of a capacitor bank

HCUBPTOC is designed for the protection against internal faults in H-bridge-connected capacitor banks. This unbalance protection detects an asymmetry in the capacitor bank, caused by blown fuses or short-circuits across bushings, or between capacitor units and the racks in which they are mounted.

Normally, the capacitor units are designed to withstand 110% of the nominal voltage continuously. When an element inside a capacitor bank fails, the remaining healthy elements experience an increase in voltage across them. If the voltage exceeds 110% of the nominal voltage, it can lead to a failure of the healthy elements of the bank and in turn fail the entire capacitor bank. Since the capacitor unbalance current is directly proportional to element failures, unbalance protection is an effective way of detecting capacitor element failures. The current unbalance protection function is usually used along with the three-phase capacitor bank

overload protection function to increase the sensitivity of protection for capacitor banks.

Due to the two-stage (operation and alarm stage) unbalance protection and the natural unbalance compensation facility, the protection of capacitor banks with internal fuses can be implemented with a very high degree of sensitivity.

The unbalance protection function can be used for internally fused, externally fused and fuseless shunt capacitor banks. Since a fuseless capacitor bank lacks the individual capacitor unit fuses, current unbalance protection becomes even more critical for fuseless applications.

When an individual element fails, it creates current unbalance. With an increasing number of element failures, the unbalance current increases and HCUBPTOC gives an alarm. The alarm level is normally set to 50% of the maximum permitted level. The capacitor bank then should be taken out of service to replace the faulty units. If not, the capacitor bank is tripped when the maximum allowed unbalance current level is exceeded.

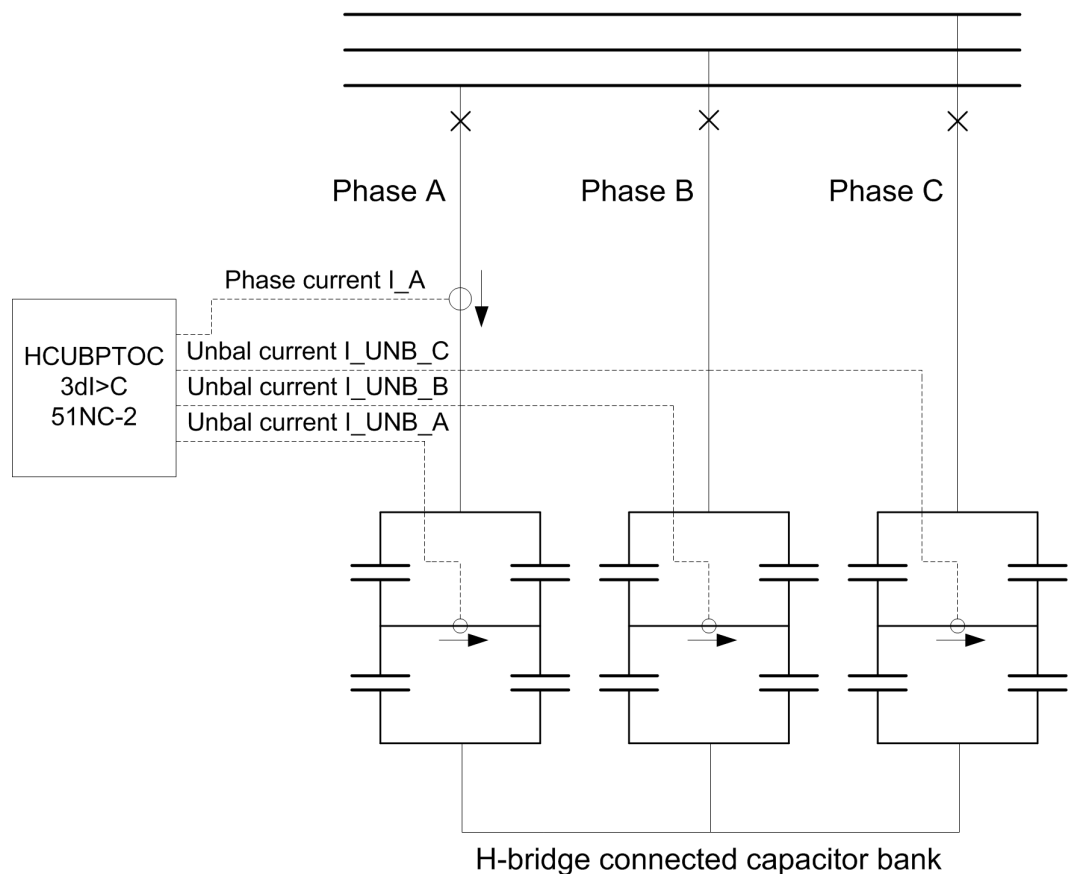


Figure 352: Application example of capacitor bank unbalance protection



The phase current analog input I\_A and at least one unbalance current must be connected to the protection relay for the HCUBPTOC function to start working.

#### Steps to measure natural unbalance current

1. The setting *Natural Comp Enable* must be set to "TRUE".
2. The capacitor bank must be energized.

3. The capacitor bank compensated unbalance current  $I_{COM\_AMPL}$  is observed from Monitored data.
4. The command *Record unbalance* must be activated by selecting the value “Record” which stores the unbalance reference for future unbalance calculations.
5. The compensated unbalance current ( $I_{COM\_AMPL}$ ) is re-checked to be approximately zero.



The natural unbalance recording should be made only during the steady-state condition and when all the capacitor bank elements are assumed to be in service.

### 3.12.3.7 Signals

**Table 615: HCUBPTOC Input signals**

| Name  | Type    | Default | Description                                   |
|-------|---------|---------|---|
| I3P1  | SIGNAL  | –       | Three-phase currents 1                        |
| I3P2  | SIGNAL  | –       | Three-phase currents 2                        |
| BLOCK | BOOLEAN | 0=False | Block signal for activating the blocking mode |

**Table 616: HCUBPTOC Output signals**

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |
| START   | BOOLEAN | Start       |
| ALARM   | BOOLEAN | Alarm       |

### 3.12.3.8 Settings

**Table 617: HCUBPTOC Group settings (Basic)**

| Parameter            | Values (Range)   | Unit | Step | Default          | Description                             |
|----------------------|--|------|------|------------------|---|
| Start value          | 0.01...1.00  | xIn  | 0.01 | 0.10             | Start value                             |
| Alarm start value    | 0.01...1.00  | xIn  | 0.01 | 0.05             | Alarm start value                       |
| Time multiplier      | 0.05...15.00   |      | 0.01 | 1.00             | Time multiplier in IEC/ANSI IDMT curves |
| Operating curve type | 1=ANSI Ext. inv.<br>2=ANSI Very inv.<br>3=ANSI Norm. inv.<br>4=ANSI Mod. inv.<br>5=ANSI Def. Time<br>6=L.T.E. inv.<br>7=L.T.V. inv.<br>8=L.T. inv.<br>9=IEC Norm. inv.<br>10=IEC Very inv. |      |      | 15=IEC Def. Time | Selection of time delay curve type      |

*Table continues on the next page*

| Parameter          | Values (Range)   | Unit | Step | Default | Description        |
|--------------------|--|------|------|---------|--------------------|
|                    | 11=IEC inv.<br>12=IEC Ext. inv.<br>13=IEC S.T. inv.<br>14=IEC L.T. inv.<br>15=IEC Def. Time<br>17=Programmable<br>18=RI type<br>19=RD type |      |      |         |                    |
| Operate delay time | 40...200000  | ms   | 10   | 5000    | Operate delay time |
| Alarm delay time   | 40...200000  | ms   | 10   | 200000  | Alarm delay time   |

**Table 618: HCUBPTOC Group settings (Advanced)**

| Parameter            | Values (Range)    | Unit | Step | Default | Description                               |
|----------------------|-------------------|------|------|---------|---|
| Natural Comp Ena PhA | 0=False<br>1=True |      |      | 0=False | Enable natural unbalance compensation PhA |
| Natural Comp Ena PhB | 0=False<br>1=True |      |      | 0=False | Enable natural unbalance compensation PhB |
| Natural Comp Ena PhC | 0=False<br>1=True |      |      | 0=False | Enable natural unbalance compensation PhC |

**Table 619: HCUBPTOC Non group settings (Basic)**

| Parameter         | Values (Range)          | Unit | Step | Default  | Description                                 |
|-------------------|-------------------------|------|------|----------|---|
| Operation         | 1=on<br>5=off           |      |      | 1=on     | Operation Off / On                          |
| Curve parameter A | 0.00860...120.0000<br>0 |      | 1    | 28.20000 | Parameter A for customer programmable curve |
| Curve parameter B | 0.00000...0.71200       |      | 1    | 0.12170  | Parameter B for customer programmable curve |
| Curve parameter C | 0.02...2.00             |      | 1    | 2.00     | Parameter C for customer programmable curve |
| Curve parameter E | 0.0...1.0               |      | 1    | 1.0      | Parameter E for customer programmable curve |

**Table 620: HCUBPTOC Non group settings (Advanced)**

| Parameter            | Values (Range) | Unit | Step | Default | Description                          |
|----------------------|----------------|------|------|---------|--------------------------------------|
| Reset delay time     | 0...60000      | ms   | 1    | 20      | Reset delay time                     |
| Minimum operate time | 20...60000     | ms   | 1    | 20      | Minimum operate time for IDMT curves |

### 3.12.3.9 Monitored data

**Table 621: HCUBPTOC Monitored data**

| Name         | Type    | Values (Range)   | Unit | Description  |
|--------------|---------|------------------|------|--|
| START_DUR    | FLOAT32 | 0.00...100.00    | %    | Ratio of start time / operate time                   |
| I_NAT_AMPL_A | FLOAT32 | 0.00...5.00      | xIn  | Recorded natural unbalance current amplitude phase A |
| I_NAT_ANGL_A | FLOAT32 | -179.00...179.00 | deg  | Recorded natural unbalance current angle phase A     |
| I_NAT_AMPL_B | FLOAT32 | 0.00...5.00      | xIn  | Recorded natural unbalance current amplitude phase B |
| I_NAT_ANGL_B | FLOAT32 | -179.00...179.00 | deg  | Recorded natural unbalance current angle phase B     |
| I_NAT_AMPL_C | FLOAT32 | 0.00...5.00      | xIn  | Recorded natural unbalance current amplitude phase C |
| I_NAT_ANGL_C | FLOAT32 | -179.00...179.00 | deg  | Recorded natural unbalance current angle phase C     |
| I_COM_AMPL_A | FLOAT32 | 0.00...5.00      | xIn  | Compensated unbalance current amplitude phase A      |
| I_COM_ANGL_A | FLOAT32 | -179.00...179.00 | deg  | Compensated unbalance current angle phase A          |
| I_COM_AMPL_B | FLOAT32 | 0.00...5.00      | xIn  | Compensated unbalance current amplitude phase B      |
| I_COM_ANGL_B | FLOAT32 | -179.00...179.00 | deg  | Compensated unbalance current angle phase B          |

*Table continues on the next page*

| Name         | Type    | Values (Range)   | Unit | Description                                     |
|--------------|---------|--|------|---|
| I_COM_AMPL_C | FLOAT32 | 0.00...5.00  | xIn  | Compensated unbalance current amplitude phase C |
| I_COM_ANGL_C | FLOAT32 | -179.00...179.00                                       | deg  | Compensated unbalance current angle phase C     |
| HCUBPTOC     | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status  |
| IL1-unb:1    | FLOAT32 | 0.00...5.00  | xIn  | Measured unbalance current amplitude phase A    |
| IL2-unb:1    | FLOAT32 | 0.00...5.00  | xIn  | Measured unbalance current amplitude phase B    |
| IL3-unb:1    | FLOAT32 | 0.00...5.00  | xIn  | Measured unbalance current amplitude phase C    |

### 3.12.3.10

### Technical data

Table 622: HCUBPTOC Technical data

| Characteristic                              | Value   |
|---|---|
| Operation accuracy                          | Depending on the frequency of the measured current:<br>$f_n \pm 2 \text{ Hz}$<br>1.5 % of the set value or $0.002 \times I_n$ |
| Start time <sup>1, 2</sup>                  | Typically 26 ms   |
| Reset time                                  | Typically 40 ms   |
| Reset ratio                                 | Typically 0.96  |
| Operate time accuracy in definite time mode | 1 % of the theoretical value or $\pm 20 \text{ ms}$   |
| Operate time accuracy in IDMT mode          | 5 % of the theoretical value or $\pm 20 \text{ ms}$   |
| Suppression of harmonics                    | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$   |

<sup>1</sup> Fundamental frequency current =  $1.0 \times I_n$ , current before fault =  $0.0 \times I_n$ , fault current =  $2.0 \times \text{Start value}$ , results based on statistical distribution of 1000 measurements

<sup>2</sup> Includes the delay of the signal output contact

### 3.12.4 Shunt capacitor bank switching resonance protection, current based, SRCPTOC (ANSI 55ITHD)

#### 3.12.4.1 Identification

| Function description   | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--|--------------------------|--------------------------|-------------------------------|
| Shunt capacitor bank switching resonance protection, current based | SRCPTOC                  | TD>                      | 55ITHD                        |

#### 3.12.4.2 Function block

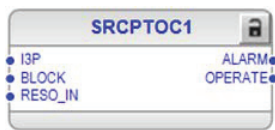


Figure 353: Function block symbol

#### 3.12.4.3 Functionality

The shunt capacitor bank switching resonance protection, current based, function SRCPTOC is used for detecting three-phase resonance caused by capacitor switching or topology changes in the network. The operating characteristic is a definite time (DT).

SRCPTOC contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

#### 3.12.4.4 Analog input configuration

SRCPTOC has one analog group input which must be properly configured.

Table 623: Analog inputs

| Input | Description          |
|-------|----------------------|
| I3P   | Three-phase currents |



See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.



### 3.12.4.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “On” and “Off”.

The operation of SRCPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

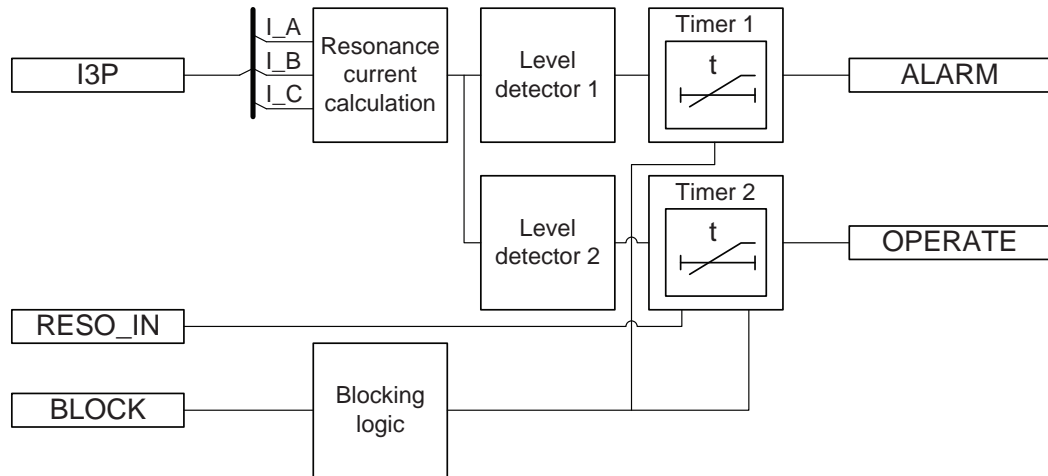


Figure 354: Functional module diagram

#### Resonance current calculation

This module calculates the resonance current per phase set as per setting *Tuning harmonic Num*. The resonance current for phase A is calculated with the equation.

$$I\_RESO\_A = \sqrt{I_{RMS\_A}^2 - I_{1\_A}^2 - I_{DC\_A}^2 - I_{K\_A}^2}$$

(Equation 38)

|              |   |
|--------------|---|
| $I_{RMS\_A}$ | RMS value of current in phase A (contains up to 11 <sup>th</sup> harmonic)                                |
| $I_{DC\_A}$  | DC-component in phase A current   |
| $I_{1\_A}$   | Fundamental component in phase A current  |
| $I_{K\_A}$   | K <sup>th</sup> harmonic component in phase A current, K is defined by setting <i>Tuning harmonic Num</i> |
| $I\_RESO\_A$ | Calculated resonance current for phase A  |

The resonance current is calculated through the filter implementation. The DC and fundamental components are removed by passing the total RMS current through the High pass filter. The K<sup>th</sup> harmonic component is removed by passing the High pass filter output through the K<sup>th</sup> harmonic Band stop filter. The magnitude response of the High pass filter and all the harmonic Band stop filters are shown in [Figure 355](#).

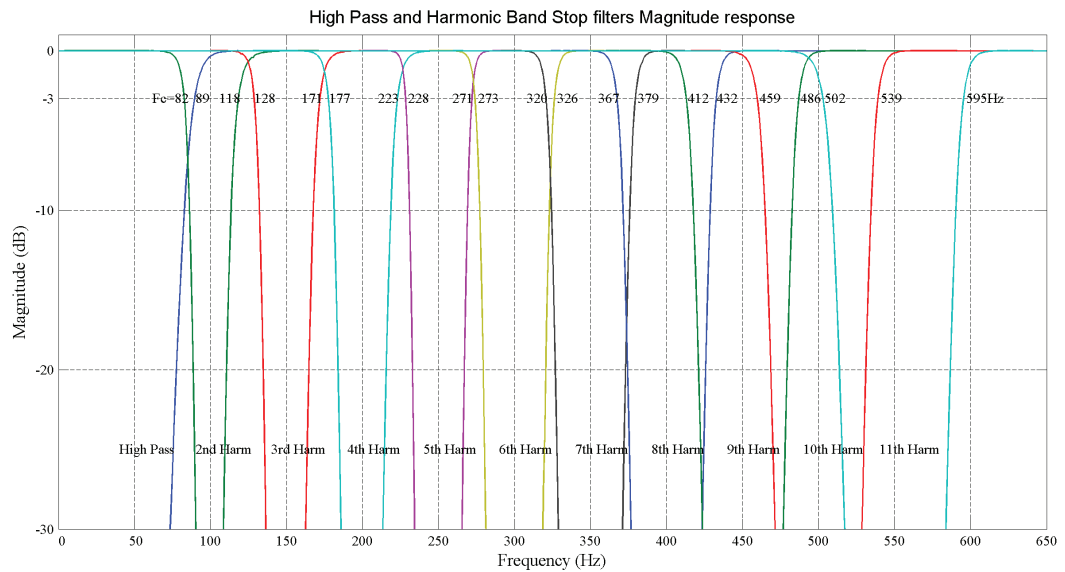


Figure 355: Magnitude response of High pass and all the harmonic Band stop filters

Similarly resonance current is calculated in the same way for phase B and phase C. Resonance currents  $I_{\_RESO\_A}$ ,  $I_{\_RESO\_B}$  and  $I_{\_RESO\_C}$  are available in the monitored data view.

The maximum of the three calculated resonance currents is further considered for calculation.

$$I_{\_RESONANCE} = \text{Max}(I_{\_RESO\_A}, I_{\_RESO\_B}, I_{\_RESO\_C})$$

(Equation 39)



If a capacitor bank is used only for reactive power compensation and there is no series reactor in a filter branch, the resonance protection is very important. In this case, the setting *Tuning harmonic Num* should be set to 1 because the capacitor branch is not tuned for a special frequency as in tuned filter applications. Even though *Tuning harmonic Num* is set to 1, the fundamental component is subtracted only once from  $I_{RMS}$ .

### Level detector 1

The maximum calculated resonance current is compared to the set *Alarm start value*. If the calculated  $I_{\_RESONANCE}$  exceeds the set *Alarm start value*, the module sends the enabling signal to the Timer 1 module.

### Level detector 2

The maximum calculated resonance current is compared to the set *Start value*. If the calculated  $I_{\_RESONANCE}$  exceeds the set *Start value*, this module sends the enabling signal to the Timer 2 module.

### Timer 1

Once activated, the timer activates the alarm timer. The timer characteristic is according to DT. When the alarm timer has reached the value set by *Alarm delay time*, the ALARM output is activated.

If the fault disappears before the alarm activates, the alarm timer is reset immediately.

### Timer 2

Once activated, the timer activates the operation timer. The timer characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the OPERATE output is activated.

If the fault disappears before the operate activates, the operation timer is reset immediately.

If the input RESO\_IN becomes active, the OPERATE output is activated immediately. If the resonance protection at a higher-order filter branch has already operated, the function in lower-order filter branches can be tripped immediately using this feature.

### Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting **Configuration > System > Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the “Freeze timers” mode, the operation timer is frozen to the prevailing value. In the “Block all” mode, the whole function is blocked and the timers are reset. In the “Block OPERATE output” mode, SRCPTOC operates normally but the OPERATE output is not activated.

#### 3.12.4.6

### Application

Switched shunt capacitor banks are widely used by utilities and customers in industrial distribution systems to provide voltage support and to improve the power factor of a load. Capacitor steps may be switched in and out of circuits routinely as the demand for capacitive VAR compensation of a load fluctuates. Normally, automatic power factor controllers are employed which automatically switch on or off the capacitors of the capacitor bank, depending upon the prevalent reactive power requirement in the system.

One potential problem for the application of automatic power factor controllers is that it may cause harmonic resonance under certain system conditions. Capacitor switching changes the parameters of the system, which may cause the resonance frequency of the circuit to be equal to one of the frequencies of the harmonic sources prevalent in the system. Harmonic resonance, when it occurs, may result in severe voltage and current distortions, which increases losses and causes overheating of other equipment in the circuit.

A traditional way of solving the problem is to conduct a detailed system study for each individual installation and use the results to properly size the capacitors and determine the right operating range of capacitors to avoid harmonic resonance with other system components. However, this method is not economical but more time-consuming.

The capacitor switching-resonance protection function can be used as a solution to the above mentioned problem. The basis for the harmonic resonance protection

is the detection of a current harmonic resonance condition caused by capacitor switching. A prolonged increase of the harmonic distortion level after a switching operation is a clear indication of such condition. When a resonant condition caused by capacitor switching occurs in a circuit, SRCPTOC detunes the circuit by taking the reverse action, that is, switching the capacitor bank off if switching it on causes resonance. If the resonance situation has been detected and SRCPTOC has switched off a capacitor bank, power factor controller should not try to switch on the capacitor bank until the switching resonance function reset.

The capacitor switching-resonance protection function can also be used to protect harmonic filters. In harmonic filter bank applications, the SRCPTOC function can be tuned to harmonic frequency for which the harmonic filter is designed to ensure that the function does not include the tuned harmonic frequency current into the calculation of the resonance current. If there is more than one harmonic filter bank involved, each SRCPTOC tunes to the harmonic frequency of its corresponding filter bank. The interlinking between the functions can be done in such a way that if resonance occurs in a higher harmonic frequency filter bank, all the lower harmonic frequency filter banks can be tripped immediately by activating the function input RESO\_IN.

The settings *Alarm start value* and *Start value* determine the portion of the total harmonic current (excluding the harmonic defined by the setting *Tuning harmonic Num*) in relation to the CT nominal value required for SRCPTOC to give alarm and operate respectively.

For power factor correction application

- *Tuning harmonic Num* must be set to 1.
- *Alarm start value* and *Start value* must be set according to the standard IEEE519-1992.

For harmonic filter application

- *Tuning harmonic Num* must be set to the filter design tuning frequency.
- *Alarm start value* and *Start value* must be set according to the standard IEEE519-1992.



Settings *Alarm start value* and *Start value* should be selected as such that in normal operation SRCPTOC should not operate.

### 3.12.4.7

## Signals

**Table 624: SRCPTOC Input signals**

| Name    | Type    | Default | Description   |
|---------|---------|---------|---|
| I3P     | SIGNAL  | –       | Three-phase currents                                |
| BLOCK   | BOOLEAN | 0=False | Block signal for activating the blocking mode       |
| RESO_IN | BOOLEAN | 0=False | Input signal from higher frequency resonance branch |

**Table 625: SRCPTOC Output signals**

| Name    | Type    | Description    |
|---------|---------|----------------|
| ALARM   | BOOLEAN | Alarm          |
| OPERATE | BOOLEAN | Operate signal |

### 3.12.4.8 Settings

**Table 626: SRCPTOC Group settings (Basic)**

| Parameter           | Values (Range) | Unit | Step | Default | Description  |
|---------------------|----------------|------|------|---------|--|
| Alarm start value   | 0.03...0.50    | xIn  | 0.01 | 0.03    | Alarm limit for filtered harmonic currents                                   |
| Start value         | 0.03...0.50    | xIn  | 0.01 | 0.03    | Tripping limit for filtered harmonic currents indicating resonance condition |
| Tuning harmonic Num | 1...11         |      | 1    | 11      | Tuning frequency harmonic number of the filter branch                        |
| Operate delay time  | 120...360000   | ms   | 1    | 200     | Operate delay time for resonance   |
| Alarm delay time    | 120...360000   | ms   | 1    | 200     | Alarm delay time for resonance alarm   |

**Table 627: SRCPTOC Non group settings (Basic)**

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

### 3.12.4.9 Monitored data

**Table 628: SRCPTOC Monitored data**

| Name     | Type    | Values (Range)   | Unit | Description                   |
|----------|---------|--|------|-------------------------------|
| I_RESO_A | FLOAT32 | 0.00...40.00   | xIn  | Resonance current for phase A |
| I_RESO_B | FLOAT32 | 0.00...40.00   | xIn  | Resonance current for phase B |
| I_RESO_C | FLOAT32 | 0.00...40.00   | xIn  | Resonance current for phase C |
| SRCPTOC  | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                        |

### 3.12.4.10 Technical data

Table 629: SRCPTOC Technical data

| Characteristic                              | Value  |
|---|--|
| Operation accuracy                          | Depending on the frequency of the measured current:<br>$f_n \pm 2 \text{ Hz}$  |
|   | Operate value accuracy:<br>$\pm 3 \%$ of the set value or $\pm 0.002 \times I_n$ (for 2nd order Harmonics)<br>$\pm 1.5 \%$ of the set value or $\pm 0.002 \times I_n$ (for 3rd order < Harmonics < 10th order)<br>$\pm 6 \%$ of the set value or $\pm 0.004 \times I_n$ (for Harmonics $\geq 10$ th order) |
| Reset time                                  | Typically 45 ms or maximum 50 ms   |
| Retardation time                            | Typically 0.96   |
| Retardation time                            | <35 ms   |
| Operate time accuracy in definite time mode | $\pm 1.0 \%$ of the set value or $\pm 20 \text{ ms}$   |
| Suppression of harmonics                    | -50 dB at $f = f_n$  |

## 4 Protection related functions

### 4.1 Three-phase inrush detector INRPHAR

#### 4.1.1 Identification

| Function description        | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|-----------------------------|--------------------------|--------------------------|-------------------------------|
| Three-phase inrush detector | INRPHAR                  | 3I2f>                    | 68                            |

#### 4.1.2 Function block

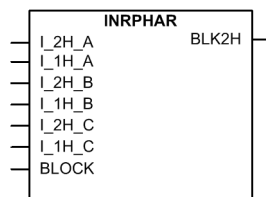


Figure 356: Function block

#### 4.1.3 Functionality

The three-phase inrush detector function INRPHAR is used to coordinate transformer inrush situations in distribution networks.

Transformer inrush detection is based on the following principle: the output signal `BLK2H` is activated once the numerically derived ratio of second harmonic current `I_2H` and the fundamental frequency current `I_1H` exceeds the set value.

The operate time characteristic for the function is of definite time (DT) type.

The function contains a blocking functionality. Blocking deactivates all outputs and resets timers.

#### 4.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of INRPHAR can be described using a module diagram. All the modules in the diagram are explained in the next sections.

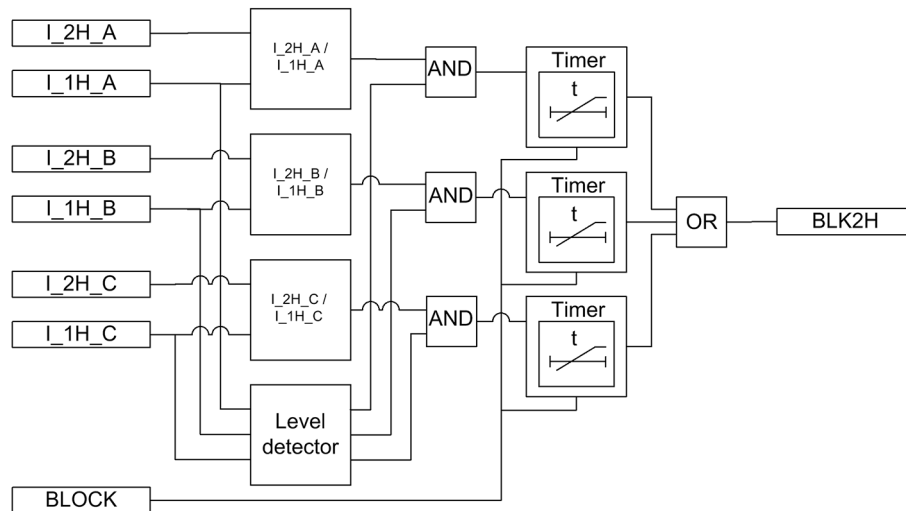


Figure 357: Functional module diagram

### I<sub>2H</sub>/I<sub>1H</sub>

This module calculates the ratio of the second harmonic (I<sub>2H</sub>) and fundamental frequency (I<sub>1H</sub>) phase currents. The calculated value is compared to the set *Start value*. If the calculated value exceeds the set *Start value*, the module output is activated.

### Level detector

The output of the phase specific level detector is activated when the fundamental frequency current I<sub>1H</sub> exceeds five percent of the nominal current.

### Timer

Once activated, the timer runs until the set *Operate delay time* value. The time characteristic is according to DT. When the operation timer has reached the *Operate delay time* value, the BLK2H output is activated. After the timer has elapsed and the inrush situation still exists, the BLK2H signal remains active until the I<sub>2H</sub>/I<sub>1H</sub> ratio drops below the value set for the ratio in all phases, that is, until the inrush situation is over. If the drop-off situation occurs within the operate time up counting, the reset timer is activated. If the drop-off time exceeds *Reset delay time*, the operate timer is reset.

The BLOCK input can be controlled with a binary input, a horizontal communication input or an internal signal of the relay program. The activation of the BLOCK input prevents the BLK2H output from being activated.



It is recommended to use the second harmonic and the waveform based inrush blocking from the TR2PTDF function if available.

## 4.1.5

### Application

Transformer protections require high stability to avoid tripping during magnetizing inrush conditions. A typical example of an inrush detector application is doubling the start value of an overcurrent protection during inrush detection.



The inrush detection function can be used to selectively block overcurrent and earth-fault function stages when the ratio of second harmonic component over the fundamental component exceeds the set value.

Other applications of this function include the detection of inrush in lines connected to a transformer.

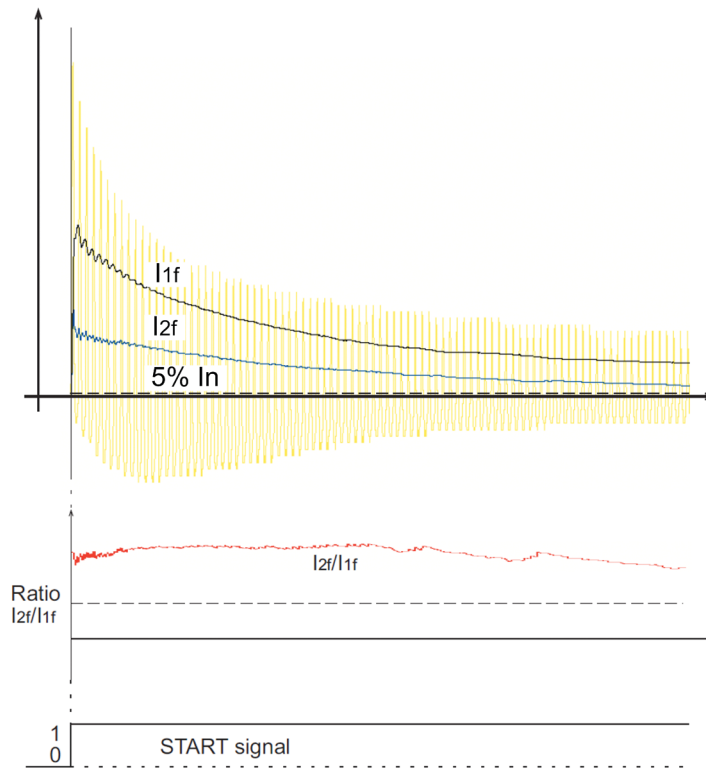


Figure 358: Inrush current in transformer



It is recommended to use the second harmonic and the waveform based inrush blocking from the transformer differential protection function TR2PTDF if available.

## 4.1.6 Signals

### 4.1.6.1 INRP HAR Input signals

Table 630: INRP HAR Input signals

| Name   | Type   | Default | Description                           |
|--------|--------|---------|---------------------------------------|
| I_2H_A | SIGNAL | 0       | Second harmonic phase A current       |
| I_1H_A | SIGNAL | 0       | Fundamental frequency phase A current |

Table continues on the next page

| Name   | Type    | Default | Description                           |
|--------|---------|---------|---------------------------------------|
| I_2H_B | SIGNAL  | 0       | Second harmonic phase B current       |
| I_1H_B | SIGNAL  | 0       | Fundamental frequency phase B current |
| I_2H_C | SIGNAL  | 0       | Second harmonic phase C current       |
| I_1H_C | SIGNAL  | 0       | Fundamental frequency phase C current |
| BLOCK  | BOOLEAN | 0=False | Block input status                    |

#### 4.1.6.2 INRPHAR Output signals

Table 631: INRPHAR Output signals

| Name  | Type    | Description                 |
|-------|---------|-----------------------------|
| BLK2H | BOOLEAN | Second harmonic based block |

### 4.1.7 Settings

#### 4.1.7.1 INRPHAR Settings

Table 632: INRPHAR Group settings (Basic)

| Parameter          | Values (Range) | Unit | Step | Default | Description   |
|--------------------|----------------|------|------|---------|---|
| Start value        | 5...100        | %    | 1    | 20      | Ratio of the 2. to the 1. harmonic leading to restraint |
| Operate delay time | 20...60000     | ms   | 1    | 20      | Operate delay time                                      |

Table 633: INRPHAR Non group settings (Basic)

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

**Table 634: INRP HAR Non group settings (Advanced)**

| Parameter        | Values (Range) | Unit | Step | Default | Description      |
|------------------|----------------|------|------|---------|------------------|
| Reset delay time | 0...60000      | ms   | 1    | 20      | Reset delay time |

## 4.1.8 Monitored data

### 4.1.8.1 INRP HAR Monitored data

**Table 635: INRP HAR Monitored data**

| Name     | Type | Values (Range)   | Unit | Description |
|----------|------|--|------|-------------|
| INRP HAR | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status      |

## 4.1.9 Technical data

**Table 636: INRP HAR Technical data**

| Characteristic        | Value  |
|-----------------------|--|
| Operation accuracy    | At the frequency $f = f_n$<br><br>Current measurement:<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$<br>Ratio $I_{2f}/I_{1f}$ measurement:<br>$\pm 5.0\%$ of the set value |
| Reset time            | +35 ms / -0 ms   |
| Reset ratio           | Typically 0.96   |
| Operate time accuracy | +35 ms / -0 ms   |

### 4.1.10 Technical revision history

Table 637: INRP HAR Technical revision history

| Technical revision | Change                |
|--------------------|-----------------------|
| B                  | Internal improvement. |
| C                  | Internal improvement. |

## 4.2 Circuit breaker failure protection CCBRBRF

### 4.2.1 Identification

| Function description               | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|------------------------------------|--------------------------|--------------------------|-------------------------------|
| Circuit breaker failure protection | CCBRBRF                  | 3I>/Io>BF                | 51BF/51NBF                    |

### 4.2.2 Function block

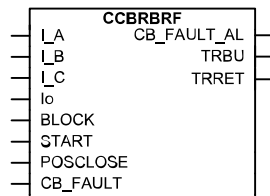


Figure 359: Function block

### 4.2.3 Functionality

The circuit breaker failure protection function CCBRBRF is activated by trip commands from the protection functions. The commands are either internal commands to the terminal or external commands through binary inputs. The start command is always a default for three-phase operation. CCBRBRF includes a three-phase conditional or unconditional re-trip function, and also a three-phase conditional back-up trip function.

CCBRBRF uses the same levels of current detection for both re-trip and back-up trip. The operating values of the current measuring elements can be set within a predefined setting range. The function has two independent timers for trip purposes: a re-trip timer for the repeated tripping of its own breaker and a back-up timer for the trip logic operation for upstream breakers. A minimum trip pulse length can be set independently for the trip output.

The function contains a blocking functionality. It is possible to block the function outputs, if desired.

## 4.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of CCBRRF can be described using a module diagram. All the modules in the diagram are explained in the next sections. Also further information on the retrip and backup trip logics is given in sub-module diagrams.

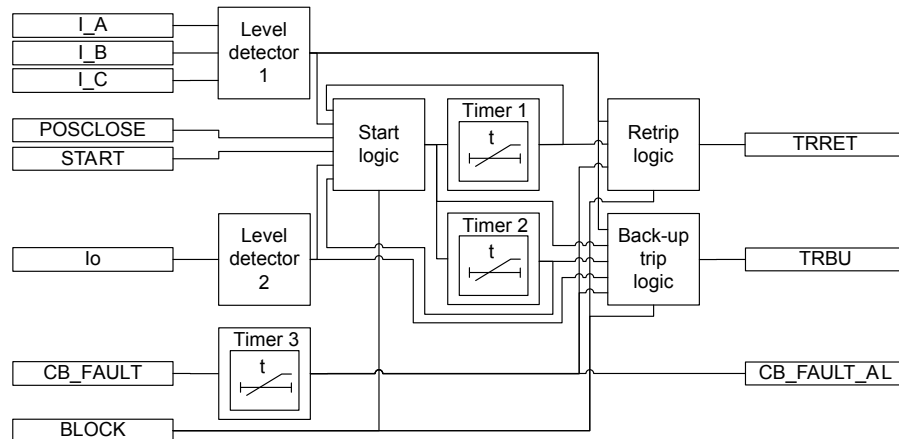


Figure 360: Functional module diagram

### Level detector 1

The measured phase currents are compared phase-wise to the set *Current value*. If the measured value exceeds the set *Current value*, the level detector reports the exceeding of the value to the start, retrip and backup trip logics. The parameter should be set low enough so that breaker failure situations with small fault current or high load current can be detected. The setting can be chosen in accordance with the most sensitive protection function to start the breaker failure protection.

### Level detector 2

The measured residual current is compared to the set *Current value Res*. If the measured value exceeds the set *Current value Res*, the level detector reports the exceeding of the value to the start and backup trip logics. In high-impedance earthed systems, the residual current at phase-to-earth faults is normally much smaller than the short circuit currents. To detect a breaker failure at single-phase earth faults in these systems, it is necessary to measure the residual current separately. In effectively earthed systems, also the setting of the earth-fault current protection can be chosen at a relatively low current level. The current setting should be chosen in accordance with the setting of the sensitive earth-fault protection.

### Start logic

The start logic is used to manage the starting of the timer 1 and timer 2. It also resets the function after the circuit breaker failure is handled. On the rising edge of the *START* input, the enabling signal is sent to the timer 1 and timer 2.

Function resetting is prevented during the next 150 ms. The 150 ms time elapse is provided to prevent malfunctioning due to oscillation in the starting signal.

In case the setting *Start latching mode* is set to "Level sensitive", the CCBRRF is reset immediately after the START signal is deactivated. The recommended setting value is "Rising edge".

The resetting of the function depends on the *CB failure mode* setting.

- If *CB failure mode* is set to "Current", the resetting logic further depends on the *CB failure trip mode* setting.
  - If *CB failure trip mode* is set to "1 out of 3", the resetting logic requires that the values of all the phase currents drop below the *Current value* setting.
  - If *CB failure trip mode* is set to "1 out of 4", the resetting logic requires that the values of the phase currents and the residual current drops below the *Current value* and *Current value Res* setting respectively.
  - If *CB failure trip mode* is set to "2 out of 4", the resetting logic requires that the values of all the phase currents drop below the *Current value* setting.
- If *CB failure mode* is set to the "Breaker status" mode, the resetting logic requires that the circuit breaker is in the open condition.
- If the *CB failure mode* setting is set to "Both", the resetting logic requires that the circuit breaker is in the open condition and the values of the phase currents and the residual current drops below the *Current value* and *Current value Res* setting respectively.

The activation of the BLOCK input resets the function.

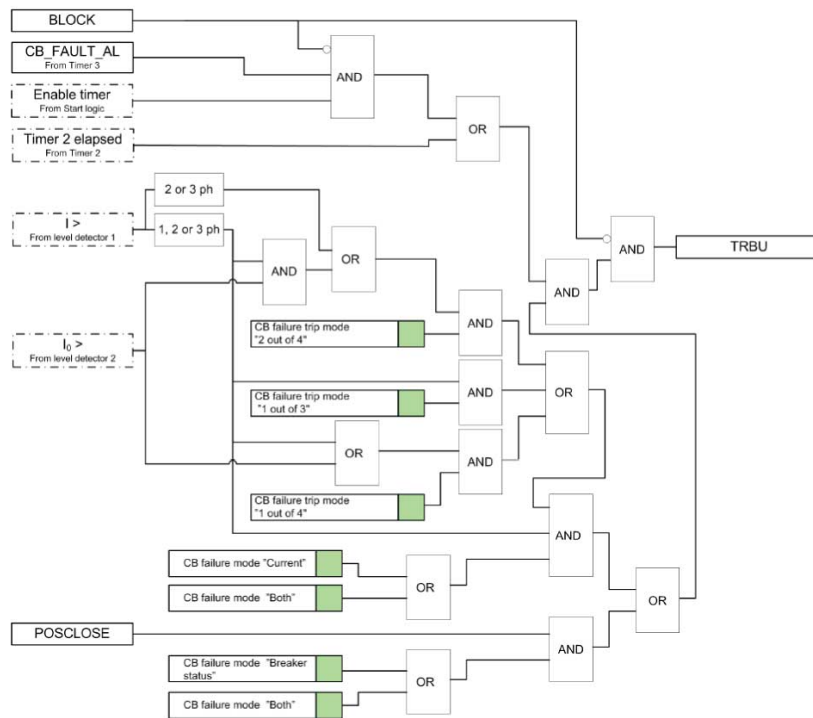


Figure 361: Start logic

### Timer 1

Once activated, the timer runs until the set *Retrip time* value has elapsed. The time characteristic is according to DT. When the operation timer has reached the value set with *Retrip time*, the retrip logic is activated. A typical setting is 0...50 ms.

**Timer 2**

Once activated, the timer runs until the set *CB failure delay* value has elapsed. The time characteristic is according to DT. When the operation timer has reached the set maximum time value *CB failure delay*, the backup trip logic is activated. The value of this setting is made as low as possible at the same time as any unwanted operation is avoided. A typical setting is 90 - 150 ms, which is also dependent on the retrip timer.

The minimum time delay for the CB failure delay can be estimated as:

$$CB_{failure\ delay} \geq Retriptime + t_{cbopen} + t_{BFP\_reset} + t_{margin}$$

|                  |   |
|------------------|---|
| $t_{cbopen}$     | maximum opening time for the circuit breaker  |
| $t_{BFP\_reset}$ | maximum time for the breaker failure protection to detect the correct breaker function (the current criteria reset) |
| $t_{margin}$     | safety margin   |

It is often required that the total fault clearance time is less than the given critical time. This time often depends on the ability to maintain transient stability in case of a fault close to a power plant.

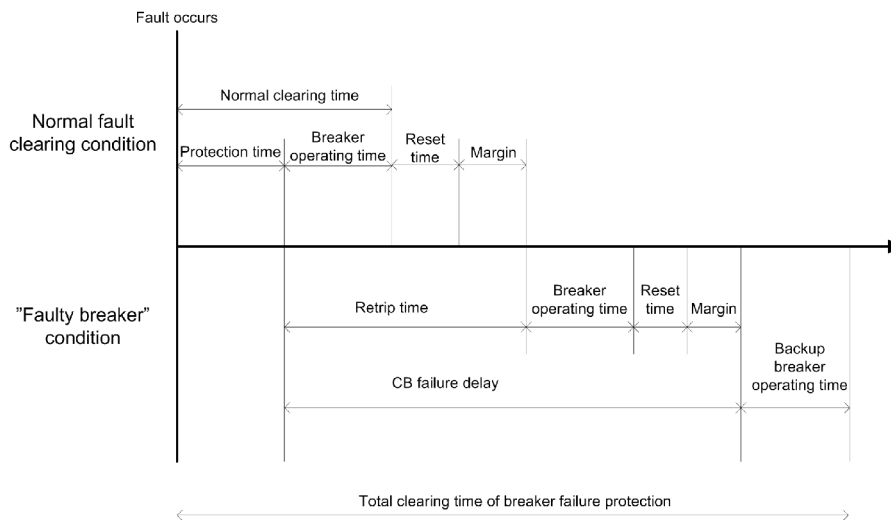


Figure 362: Timeline of the breaker failure protection

**Timer 3**

This module is activated by the *CB\_FAULT* signal. Once activated, the timer runs until the set *CB fault delay* value has elapsed. The time characteristic is according to DT. When the operation timer has reached the maximum time value *CB fault delay*, the *CB\_FAULT\_AL* output is activated. After the set time, an alarm is given so that the circuit breaker can be repaired. A typical value is 5 s.

### Retrip logic

The retrip logic provides the `TRRET` output, which can be used to give a retrip signal for the main circuit breaker. Timer 1 activates the retrip logic. The operation of the retrip logic depends on the *CB fail retrip mode* setting.

- The retrip logic is inactive if the *CB fail retrip mode* setting is set to "Off".
- If *CB fail retrip mode* is set to the "Current check" mode, the activation of the retrip output `TRRET` depends on the *CB failure mode* setting.
  - If *CB failure mode* is set to the "Current" mode, `TRRET` is activated when the value of any phase current exceeds the *Current value* setting. The `TRRET` output remains active for the time set with the *Trip pulse time* setting or until all phase current values drop below the *Current value* setting, whichever is longer.
  - If *CB failure mode* is set to the "Breaker status" mode, `TRRET` is activated if the circuit breaker is in the closed position. The `TRRET` output remains active for the time set with the *Trip pulse time* setting or the time the circuit breaker is in the closed position, whichever is longer.
  - If *CB failure mode* is set to "Both", `TRRET` is activated when either of the "Breaker status" or "Current" mode condition is satisfied.
- If *CB fail retrip mode* is set to the "Without check" mode, `TRRET` is activated once the timer 1 is activated without checking the current level. The `TRRET` output remains active for a fixed time set with the *Trip pulse time* setting.

The activation of the `BLOCK` input or the `CB_FAULT_AL` output deactivates the `TRRET` output.

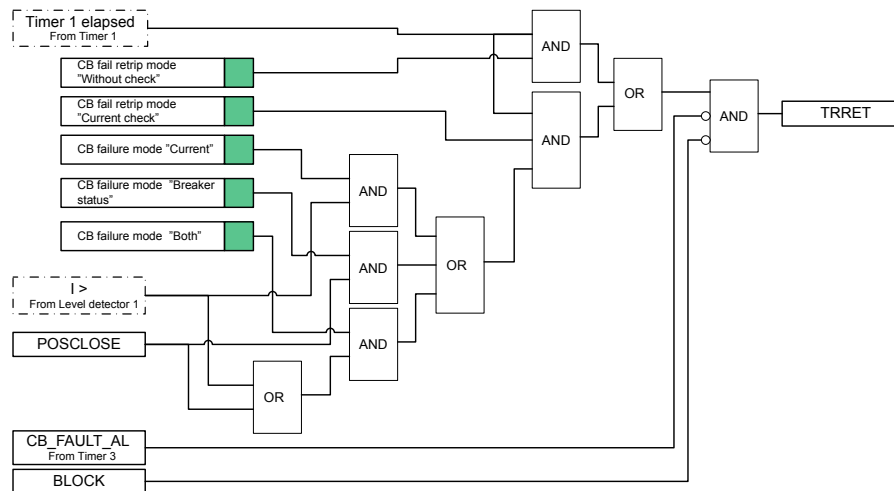


Figure 363: Retrip logic

### Backup trip logic

The backup trip logic provides the `TRBU` output which can be used to trip the upstream backup circuit breaker when the main circuit breaker fails to clear the fault. The backup trip logic is activated by the timer 2 module or timer-enabling signal from the start logic module (rising edge of the `START` input detected), and simultaneously `CB_FAULT_AL` is active. The operation of the backup logic depends on the *CB failure mode* setting.

- If the *CB failure mode* is set to "Current", the activation of `TRBU` depends on the *CB failure trip mode* setting.



- If *CB failure trip mode* is set to "1 out of 3", the failure detection is based on any of the phase currents exceeding the *Current value* setting. Once *TRBU* is activated, it remains active for the time set with the *Trip pulse time* setting or until the values of all the phase currents drop below the *Current value* setting, whichever takes longer.
- If *CB failure trip mode* is set to "1 out of 4", the failure detection is based on either a phase current or a residual current exceeding the *Current value* or *Current value Res* setting respectively. Once *TRBU* is activated, it remains active for the time set with the *Trip pulse time* setting or until the values of all the phase currents or residual currents drop below the *Current value* and *Current value Res* setting respectively, whichever takes longer.
- If *CB failure trip mode* is set to "2 out of 4", the failure detection requires that a phase current and a residual current both exceed the *Current value* and *Current value Res* setting respectively or two phase currents exceeding the *Current value*. Once *TRBU* is activated, it remains active for the time set with the *Trip pulse time* setting or until the values of all the phase currents drop below the *Current value*, whichever takes longer.



In most applications, "1 out of 3" is sufficient.

- If the *CB failure mode* is set to "Breaker status", the *TRBU* output is activated if the circuit breaker is in the closed position. Once activated, the *TRBU* output remains active for the time set with the *Trip pulse time* setting or the time the circuit breaker is in the closed position, whichever is longer.
- If the *CB failure mode* setting is set to "Both", *TRBU* is activated when the "Breaker status" or "Current" mode conditions are satisfied.

The activation of the *BLOCK* input deactivates the *TRBU* output.

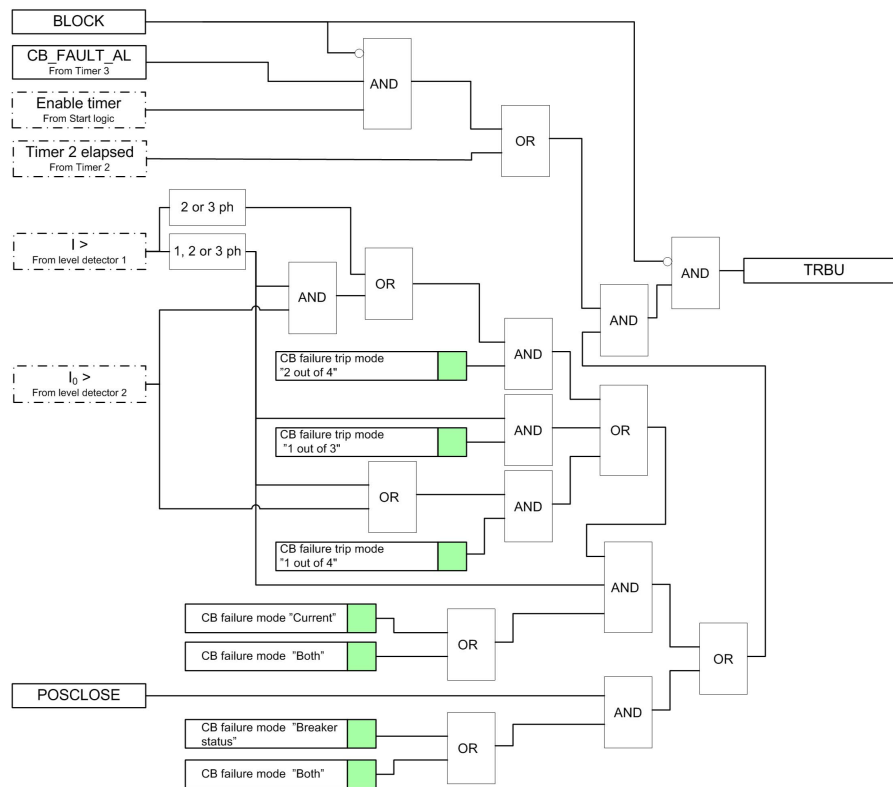


Figure 364: Backup trip logic

### 4.2.5 Application

The n-1 criterion is often used in the design of a fault clearance system. This means that the fault is cleared even if some component in the fault clearance system is faulty. A circuit breaker is a necessary component in the fault clearance system. For practical and economical reasons, it is not feasible to duplicate the circuit breaker for the protected component, but breaker failure protection is used instead.

The breaker failure function issues a backup trip command to up-stream circuit breakers in case the original circuit breaker fails to trip for the protected component. The detection of a failure to break the current through the breaker is made by measuring the current or by detecting the remaining trip signal (unconditional).

CCBRBRF can also retrip. This means that a second trip signal is sent to the protected circuit breaker. The retrip function is used to increase the operational reliability of the breaker. The function can also be used to avoid backup tripping of several breakers in case mistakes occur during IED maintenance and tests.

CCBRBRF is initiated by operating different protection functions or digital logics inside the IED. It is also possible to initiate the function externally through a binary input.

CCBRBRF can be blocked by using an internally assigned signal or an external signal from a binary input. This signal blocks the function of the breaker failure protection even when the timers have started or the timers are reset.

The retrip timer is initiated after the start input is set to true. When the pre-defined time setting is exceeded, CCBRBRF issues the retrip and sends a trip command, for example, to the circuit breaker's second trip coil. Both a retrip with current check and an unconditional retrip are available. When a retrip with current check is chosen, the retrip is performed only if there is a current flow through the circuit breaker.

The backup trip timer is also initiated at the same time as the retrip timer. If CCBRBRF detects a failure in tripping the fault within the set backup delay time, which is longer than the retrip time, it sends a backup trip signal to the chosen backup breakers. The circuit breakers are normally upstream breakers which feed fault current to a faulty feeder.

The backup trip always includes a current check criterion. This means that the criterion for a breaker failure is that there is a current flow through the circuit breaker after the set backup delay time.

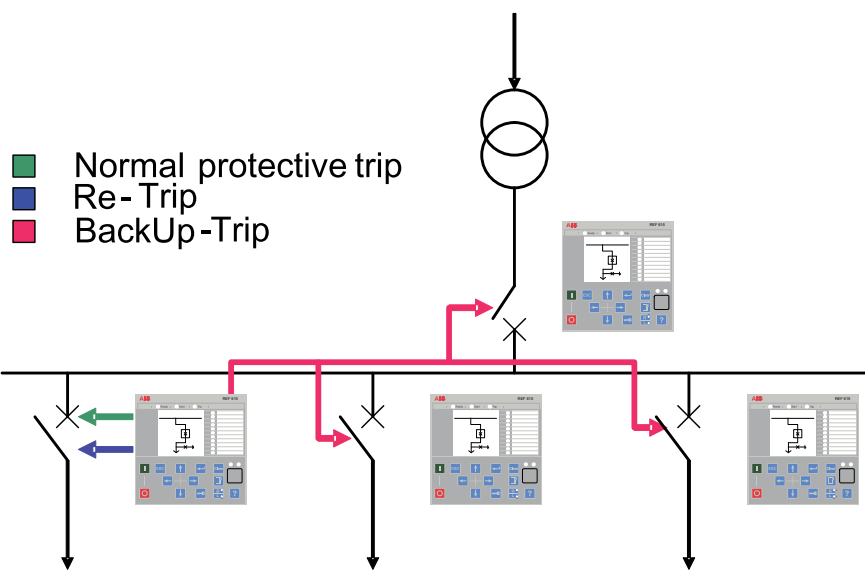


Figure 365: Typical breaker failure protection scheme in distribution substations

## 4.2.6 Signals

### 4.2.6.1 CCBRBRF Input signals

Table 638: CCBRBRF Input signals

| Name  | Type    | Default | Description          |
|-------|---------|---------|----------------------|
| I_A   | SIGNAL  | 0       | Phase A current      |
| I_B   | SIGNAL  | 0       | Phase B current      |
| I_C   | SIGNAL  | 0       | Phase C current      |
| Io    | SIGNAL  | 0       | Residual current     |
| BLOCK | BOOLEAN | 0=False | Block CBFP operation |

Table continues on the next page

| Name     | Type    | Default | Description                  |
|----------|---------|---------|------------------------------|
| START    | BOOLEAN | 0=False | CBFP start command           |
| POSCLOSE | BOOLEAN | 0=False | CB in closed position        |
| CB_FAULT | BOOLEAN | 0=False | CB faulty and unable to trip |

#### 4.2.6.2 CCBRBRF Output signals

Table 639: CCBRBRF Output signals

| Name        | Type    | Description              |
|-------------|---------|--------------------------|
| CB_FAULT_AL | BOOLEAN | Delayed CB failure alarm |
| TRBU        | BOOLEAN | Backup trip              |
| TRRET       | BOOLEAN | Retrip                   |

### 4.2.7 Settings

#### 4.2.7.1 CCBRBRF Settings

Table 640: CCBRBRF Non group settings (Basic)

| Parameter            | Values (Range)                               | Unit | Step | Default      | Description                    |
|----------------------|--|------|------|--------------|--------------------------------|
| Operation            | 1=on<br>5=off                                |      |      | 1=on         | Operation Off / On             |
| Current value        | 0.05...2.00                                  | xIn  | 0.05 | 0.30         | Operating phase current        |
| Current value Res    | 0.05...2.00                                  | xIn  | 0.05 | 0.30         | Operating residual current     |
| CB failure trip mode | 1=2 out of 4<br>2=1 out of 3<br>3=1 out of 4 |      |      | 2=1 out of 3 | Backup trip current check mode |
| CB failure mode      | 1=Current<br>2=Breaker status<br>3=Both      |      |      | 1=Current    | Operating mode of function     |
| CB fail retrip mode  | 1=Off<br>2=Without Check                     |      |      | 1=Off        | Operating mode of retrip logic |

*Table continues on the next page*

| Parameter        | Values (Range)  | Unit | Step | Default | Description                 |
|------------------|-----------------|------|------|---------|-----------------------------|
|                  | 3=Current check |      |      |         |                             |
| Retrip time      | 0..60000        | ms   | 10   | 120     | Delay timer for retrip      |
| CB failure delay | 0..60000        | ms   | 10   | 240     | Delay timer for backup trip |

Table 641: CCBRBRF Non group settings (Advanced)

| Parameter           | Values (Range)                     | Unit | Step | Default        | Description                                    |
|---------------------|------------------------------------|------|------|----------------|--|
| CB fault delay      | 0..60000                           | ms   | 10   | 5000           | Circuit breaker faulty delay                   |
| Measurement mode    | 2=DFT<br>3=Peak-to-Peak            |      |      | 3=Peak-to-Peak | Phase current measurement mode of function     |
| Trip pulse time     | 0..60000                           | ms   | 10   | 200            | Pulse length of retrip and backup trip outputs |
| Start latching mode | 1=Rising edge<br>2=Level sensitive |      |      | 1=Rising edge  | Start reset delayed or immediately             |

## 4.2.8 Monitored data

### 4.2.8.1 CCBRBRF Monitored data

Table 642: CCBRBRF Monitored data

| Name    | Type | Values (Range)   | Unit | Description |
|---------|------|--|------|-------------|
| CCBRBRF | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status      |

## 4.2.9 Technical data

Table 643: CCBRRF Technical data

| Characteristic        | Value  |
|-----------------------|--|
| Operation accuracy    | Depending on the frequency of the measured current: $f_n \pm 2$ Hz |
|                       | $\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$             |
| Operate time accuracy | $\pm 1.0\%$ of the set value or $\pm 20$ ms                        |
| Reset time            | Typically 40 ms  |
| Retardation time      | <20 ms   |

## 4.2.10 Technical revision history

Table 644: CCBRRF Technical revision history

| Technical revision | Change   |
|--------------------|--|
| B                  | Default trip pulse time changed to 150 ms  |
| C                  | Added new setting parameter <i>Start latching mode</i> .<br>Maximum value changed to $2.00 \times I_n$ for the <i>Current value</i> setting. |
| D                  | Internal improvement.  |
| E                  | Maximum value for <i>Current value</i> and <i>Current value Res</i> changed from " $1.00 \times I_n$ " to " $2.00 \times I_n$ ".             |

## 4.3 Master trip TRPPTRC

### 4.3.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|----------------------|--------------------------|--------------------------|-------------------------------|
| Master trip          | TRPPTRC                  | Master Trip              | 94/86                         |

### 4.3.2 Function block

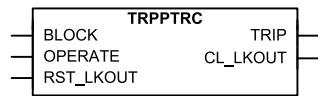


Figure 366: Function block

### 4.3.3 Functionality

The master trip function TRPPTRC is used as a trip command collector and handler after the protection functions. The features of this function influence the trip signal behavior of the circuit breaker. The minimum trip pulse length can be set when the non-latched mode is selected. It is also possible to select the latched or lockout mode for the trip signal.

### 4.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".



When the TRPPTRC function is disabled, all trip outputs intended to go through the function to the circuit breaker trip coil are blocked.

The operation of TRPPTRC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

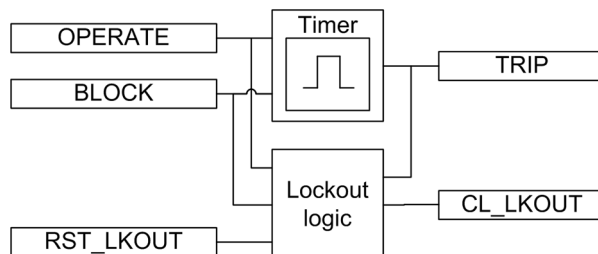


Figure 367: Functional module diagram

#### Timer

The duration of the TRIP output signal from TRPPTRC can be adjusted with the *Trip pulse time* setting when the "Non-latched" operation mode is used. The pulse length should be long enough to secure the opening of the breaker. For three-pole tripping, TRPPTRC has a single input OPERATE, through which all trip output signals are routed from the protection functions within the IED, or from external protection functions via one or more of the IED's binary inputs. The function has a single trip output TRIP for connecting the function to one or more of the IED's binary outputs, and also to other functions within the IED requiring this signal.

The BLOCK input blocks the TRIP output and resets the timer.

**Lockout logic**

TRPPTRC is provided with possibilities to activate a lockout. When activated, the lockout can be manually reset after checking the primary fault by activating the `RST_LKOUT` input or from the WHMI clear menu parameter. When using the "Latched" mode, the resetting of the `TRIP` output can be done similarly as when using the "Lockout" mode. It is also possible to reset the "Latched" mode remotely through a separate communication parameter.



The minimum pulse trip function is not active when using the "Lockout" or "Latched" modes but only when the "Non-latched" mode is selected.

The `CL_LKOUT` and `TRIP` outputs can be blocked with the `BLOCK` input.

**Table 645: Operation modes for the TRPPTRC trip output**

| Mode        | Operation  |
|-------------|--|
| Non-latched | The Trip pulse length parameter gives the minimum pulse length for TRIP                      |
| Latched     | TRIP is latched ; both local and remote clearing is possible.                                |
| Lockout     | TRIP is locked and can be cleared only locally via menu or the <code>RST_LKOUT</code> input. |

**4.3.5 Application**

All trip signals from different protection functions are routed through the trip logic. The most simplified application of the logic function is linking the trip signal and ensuring that the signal is long enough.

The tripping logic in the IED is intended to be used in the three-phase tripping for all fault types (3ph operating). To prevent the closing of a circuit breaker after a trip, TRPPTRC can block the CBXCBR closing.

TRPPTRC is intended to be connected to one trip coil of the corresponding circuit breaker. If tripping is needed for another trip coil or another circuit breaker which needs, for example, different trip pulse time, another trip logic function can be used. All instances of the PTRC function are identical, only the names of the functions, for example TRPPTRC1 and TRPPTRC2, are different. Therefore, even if all references are made only to TRPPTRC1, they also apply to all instances.

The inputs from the protection functions are connected to the `OPERATE` input. Usually, a logic block OR is required to combine the different function outputs to this input. The `TRIP` output is connected to the binary outputs on the IO board. This signal can also be used for other purposes within the IED, for example when starting the breaker failure protection.

TRPPTRC is used for simple three-phase tripping applications.



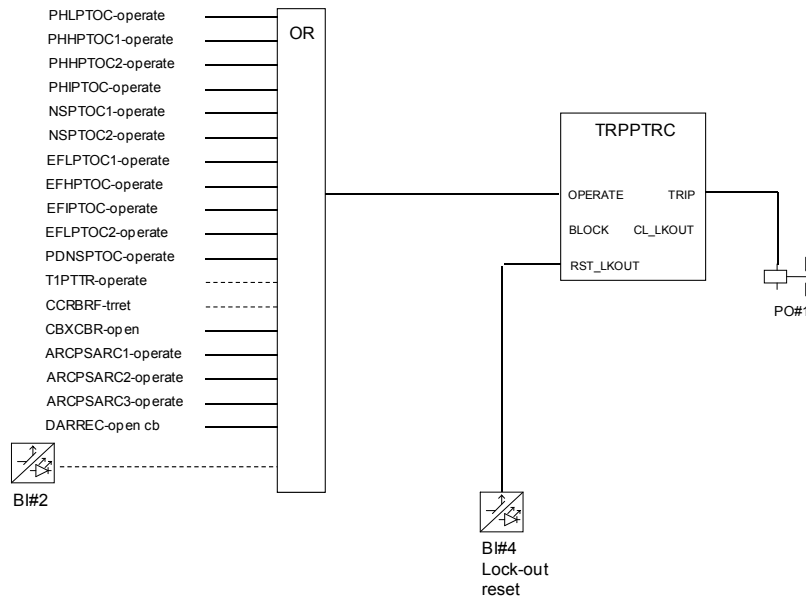


Figure 368: Typical TRPPTRC connection

### 4.3.6 Signals

#### 4.3.6.1 TRPPTRC Input signals

Table 646: TRPPTRC Input signals

| Name      | Type    | Default | Description  |
|-----------|---------|---------|--|
| BLOCK     | BOOLEAN | 0=False | Block of function  |
| OPERATE   | BOOLEAN | 0=False | Operate  |
| RST_LKOUT | BOOLEAN | 0=False | Input for resetting the circuit breaker lockout function |

#### 4.3.6.2 TRPPTRC Output signals

Table 647: TRPPTRC Output signals

| Name     | Type    | Description                                      |
|----------|---------|--|
| TRIP     | BOOLEAN | General trip output signal                       |
| CL_LKOUT | BOOLEAN | Circuit breaker lockout output (set until reset) |

## 4.3.7 Settings

### 4.3.7.1 TRPPTRC Settings

Table 648: TRPPTRC Non group settings (Basic)

| Parameter        | Values (Range)                          | Unit | Step | Default       | Description                               |
|------------------|---|------|------|---------------|---|
| Operation        | 1=on<br>5=off                           |      |      | 1=on          | Operation Off / On                        |
| Trip pulse time  | 20..60000                               | ms   | 1    | 250           | Minimum duration of trip output signal    |
| Trip output mode | 1=Non-latched<br>2=Latched<br>3=Lockout |      |      | 1=Non-latched | Select the operation mode for trip output |

## 4.3.8 Monitored data

### 4.3.8.1 TRPPTRC Monitored data

Table 649: TRPPTRC Monitored data

| Name    | Type | Values (Range)   | Unit | Description |
|---------|------|--|------|-------------|
| TRPPTRC | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status      |

## 4.3.9 Technical revision history

Table 650: TRPPTRC Technical revision history

| Technical revision | Change                |
|--------------------|-----------------------|
| B                  | -                     |
| C                  | -                     |
| D                  | Internal improvement. |

*Table continues on the next page*

| Technical revision | Change   |
|--------------------|--|
| E                  | Setting <i>Trip output mode</i> default setting is changed to "Latched". |
| F                  | Internal improvement.  |

## 4.4 Emergency start-up ESMGAPC

### 4.4.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|----------------------|--------------------------|--------------------------|-------------------------------|
| Emergency start-up   | ESMGAPC                  | ESTART                   | ESTART                        |

### 4.4.2 Function block

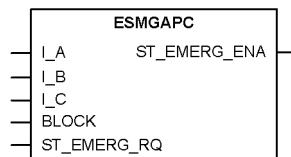


Figure 369: Function block

### 4.4.3 Functionality

An emergency condition can arise in cases where the motor needs to be started despite knowing that this can increase the temperature above limits or cause a thermal overload that can damage the motor. The emergency start-up function ESMGAPC allows motor start-ups during such emergency conditions. ESMGAPC is only to force the IED to allow the restarting of the motor. After the emergency start input is activated, the motor can be started normally. ESMGAPC itself does not actually restart the motor.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

### 4.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of ESMGAPC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

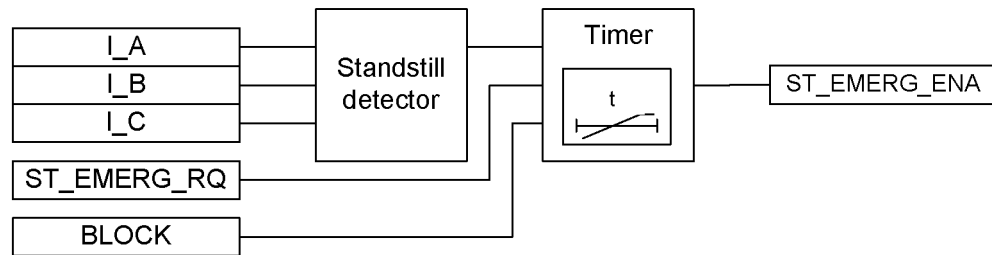


Figure 370: Functional module diagram

### Standstill detector

The module detects if the motor is in a standstill condition. The standstill condition can be detected based on the phase current values. If all three phase currents are below the set value of *Motor standstill A*, the motor is considered to be in a standstill condition.

### Timer

The timer is a fixed 10-minute timer that is activated when the `ST_EMERG_RQ` input is activated and motor standstill condition is fulfilled. Thus, the activation of the `ST_EMERG_RQ` input activates the `ST_EMERG_ENA` output, provided that the motor is in a standstill condition. The `ST_EMERG_ENA` output remains active for 10 minutes or as long as the `ST_EMERG_RQ` input is high, whichever takes longer.

The activation of the `BLOCK` input blocks and also resets the timer.

The function also provides the `ST_EMERG_ENA` output change date and time, `T_ST_EMERG`. The information is available in the monitored data view.

## 4.4.5 Application

If the motor needs to be started in an emergency condition at the risk of damaging the motor, all the external restart inhibits are ignored, allowing the motor to be restarted. Furthermore, if the calculated thermal level is higher than the restart inhibit level at an emergency start condition, the calculated thermal level is set slightly below the restart inhibit level. Also, if the register value of the cumulative start-up time counter exceeds the restart inhibit level, the value is set slightly below the restart disable value to allow at least one motor start-up.

The activation of the `ST_EMERG_RQ` digital input allows to perform emergency start. The IED is forced to a state which allows the restart of motor, and the operator can now restart the motor. A new emergency start cannot be made until the 10 minute time-out has passed or until the emergency start is released, whichever takes longer.

The last change of the emergency start output signal is recorded.

## 4.4.6 Signals

#### 4.4.6.1 ESMGAPC Input signals

Table 651: ESMGAPC Input signals

| Name        | Type    | Default | Description                                   |
|-------------|---------|---------|---|
| I_A         | SIGNAL  | 0       | Phase A current                               |
| I_B         | SIGNAL  | 0       | Phase B current                               |
| I_C         | SIGNAL  | 0       | Phase C current                               |
| BLOCK       | BOOLEAN | 0=False | Block signal for activating the blocking mode |
| ST_EMERG_RQ | BOOLEAN | 0=False | Emergency start input                         |

#### 4.4.6.2 ESMGAPC Output signals

Table 652: ESMGAPC Output signals

| Name         | Type    | Description     |
|--------------|---------|-----------------|
| ST_EMERG_ENA | BOOLEAN | Emergency start |

### 4.4.7 Settings

#### 4.4.7.1 ESMGAPC Settings

Table 653: ESMGAPC Group settings (Advanced)

| Parameter          | Values (Range) | Unit | Step | Default | Description   |
|--------------------|----------------|------|------|---------|---|
| Motor standstill A | 0.05...0.20    | xIn  | 0.01 | 0.12    | Current limit to check for motor standstill condition |

Table 654: ESMGAPC Non group settings (Basic)

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

#### 4.4.8 Monitored data

#### 4.4.8.1 ESMGAPC Monitored data

Table 655: ESMGAPC Monitored data

| Name       | Type      | Values (Range)   | Unit | Description                           |
|------------|-----------|--|------|---------------------------------------|
| T_ST_EMERG | Timestamp |  |      | Emergency start activation time-stamp |
| ESMGAPC    | Enum      | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                                |

#### 4.4.9 Technical data

Table 656: ESMGAPC Technical data

| Characteristic     | Value  |
|--------------------|--|
| Operation accuracy | At the frequency $f = f_n$                             |
|                    | $\pm 1.5\%$ of the set value or $\pm 0.002 \times U_n$ |

#### 4.4.10 Technical revision history

Table 657: ESMGAPC Technical revision history

| Technical revision | Change                |
|--------------------|-----------------------|
| B                  | Internal improvement. |
| C                  | Internal improvement. |

### 4.5 Fault locator SCEFRFLO

#### 4.5.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|----------------------|--------------------------|--------------------------|-------------------------------|
| Fault locator        | SCEFRFLO                 | FLOC                     | 21FL                          |

## 4.5.2 Function block

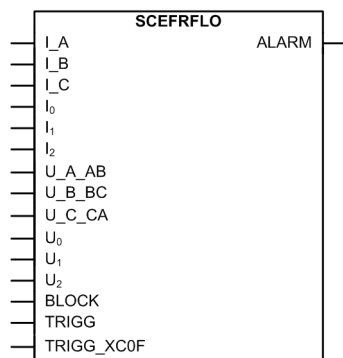


Figure 371: Function block

## 4.5.3 Functionality

The fault locator function SCEFRFLO provides impedance-based fault location. It is designed for radially operated distribution systems. It is applicable for locating short circuits in all kinds of distribution networks. Earth faults can be located in effectively earthed and in low-resistance or low-reactance earthed networks. Under certain limitations, SCEFRFLO can also be applied for an earth-fault location in unearthed distribution networks.

The fault distance calculation is based on locally measured fundamental frequency current and voltage phasors. The full operation of SCEFRFLO requires that all phase currents and phase-to-earth voltages are measured.

The fault distance estimate is obtained when SCEFRFLO is externally or internally triggered.

## 4.5.4 Operation principle

The fault distance calculation is done in two steps. First, the fault type is determined with the inbuilt Phase Selection Logic (PSL). Second, based on the selected impedance measuring element (fault loop) the fault distance from the measuring point to the fault location is calculated.

As a fundamental operation criterion, the phase current and voltage magnitudes must exceed the threshold values of  $2\% \times I_n$  and  $3\% \times U_n$ , respectively.

The function can be enabled or disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of SCEFRFLO can be described with a module diagram as shown in [Figure 372](#).

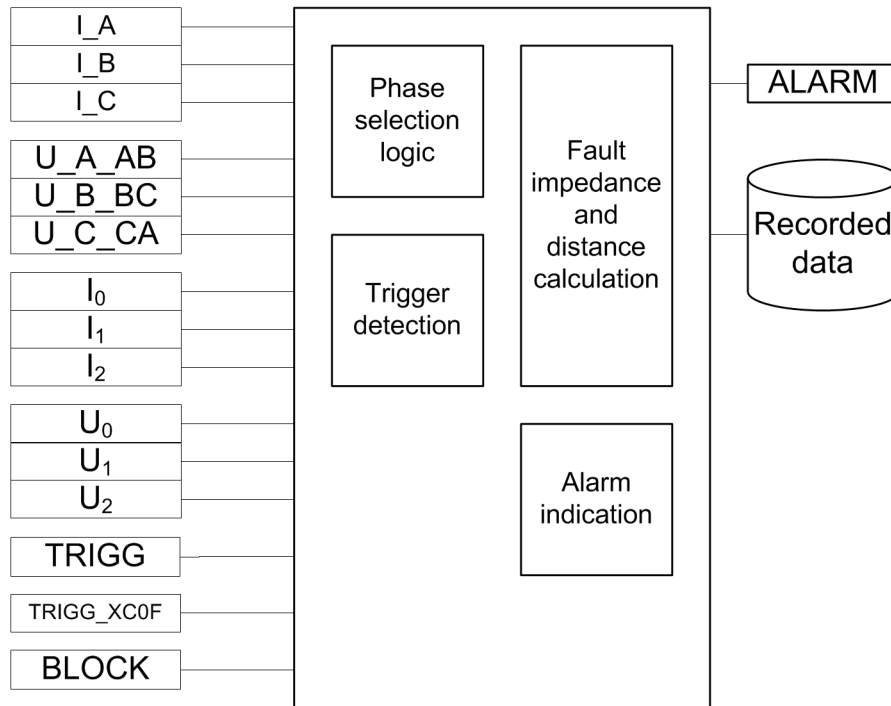


Figure 372: Functional module diagram

#### 4.5.4.1 Phase Selection Logic

Identification of the faulty phases is provided by the built-in Phase Selection Logic based on combined impedance and current criterion. Phase selection logic is virtually setting-free and has only one parameter, *Z Max phase load*, for discriminating a large symmetrical load from a three-phase fault. The setting *Z Max phase load* can be calculated using the equation.

$$Z \text{ Max phase load} = 0.8 \cdot \frac{U_{xy}^2}{S_{\max}}$$

|            |                                |
|------------|--------------------------------|
| $U_{xy}$   | Nominal phase-to-phase voltage |
| $S_{\max}$ | Maximum three-phase load       |

For example, if  $U_{xy} = 20 \text{ kV}$  and  $S_{\max} = 1 \text{ MVA}$ , then *Z Max phase load* = 320.0 Ω.

The identification of the faulty phases is compulsory for the correct operation of SCEFRFLO. This is because only one of the impedance-measuring elements (fault loops) provides the correct result for a specific fault type. A three-phase fault is an exception and theoretically it can be calculated with any of the fault loops. The fault loop used in the fault distance calculation is indicated in the recorded data Flt loop as specified in [Table 658](#).



**Table 658: Fault types and corresponding fault loops**

| Fault type | Description                      | Flt loop  |
|------------|----------------------------------|-----------|
| -          | No fault                         | No fault  |
| A-E        | Phase A-to-earth fault           | AG Fault  |
| B-E        | Phase B-to-earth fault           | BG Fault  |
| C-E        | Phase C-to-earth fault           | CG Fault  |
| A-B        | Phase A-to-B short circuit fault | AB Fault  |
| B-C        | Phase B-to-C short circuit fault | BC Fault  |
| C-A        | Phase C-to-A short circuit fault | AC Fault  |
| A-B-C-(E)  | Three-phase short circuit        | ABC Fault |

In case of two-phase-to-earth-faults (A-B-E, B-C-E or C-A-E), the selected fault loop depends on the location of the individual earth faults. When the faults are located at the same feeder, the corresponding phase-to-phase loop (either “AB Fault” or “BC Fault” or “CA Fault”) is used for calculation. When the faults are located at different feeders, the phase-to-earth loop (either “AG Fault” or “BG Fault” or “CG Fault”) corresponding to the faulty phase at the protected feeder is used for calculation.

#### 4.5.4.2

#### Fault impedance and distance calculation

As soon as a fault condition is recognized by the phase selection logic, the fault distance calculation is started with one of the seven impedance-measuring elements, that is, the fault loops. SCEFRFLO employs independent algorithms for each fault type to achieve optimal performance.

The inherent result from the fault distance calculation is the ohmic fault loop impedance value.

**Table 659: The calculated impedance values available in the recorded data**

| Impedance value      | Description   |
|----------------------|---|
| Flt phase reactance  | Estimated positive sequence reactance from the substation to the fault location in primary ohms.  |
| Flt point resistance | Fault resistance value in the fault spot in primary ohms. The composition of this term depends on the fault loop as described in the following subsections.   |
| Flt loop resistance  | The total fault loop resistance from the substation to the fault location in primary ohms. Fault point resistance is included in this value. The composition of this term is different for short-circuit and earth-fault loops as described in the following subsections. |
| Flt loop reactance   | The total fault loop reactance from the substation to the fault location in primary ohms. The composition of this term is different for short-circuit and earth-faults loops as described in the following subsections.   |

These impedance values can be utilized as such or they can be further processed in system level fault location applications, such as distribution management system (DMS).

#### **Fault loops “AG Fault” or “BG Fault” or “CG Fault”**

Fault loops “AG Fault”, “BG Fault” or “CG Fault” are used for single-phase-to-earth faults. When the individual earth faults are located at different feeders, they are also applied in the case of two-phase-to-earth fault. In this case, the phase-to-earth loop (either “AG Fault” or “BG Fault” or “CG Fault”) corresponding to the faulty phase at the protected feeder, is used for calculation. *Figure 373* shows the phase-to-earth fault loop model. The following impedances are measured and stored in the recorded data of SCEFRFLO.

$$\text{Flt point resistance} = R_{\text{fault}} \quad (\text{Equation 40})$$

$$\text{Flt loop resistance} = R_1 + R_N + R_{\text{fault}} \quad (\text{Equation 41})$$

$$\text{Flt loop reactance} = X_1 + X_N \quad (\text{Equation 42})$$

$$\text{Flt phase reactance} = X_1 \quad (\text{Equation 43})$$

|                    |   |
|--------------------|---|
| $R_1$              | Estimated positive-sequence resistance from the substation to the fault location                          |
| $X_1$              | Estimated positive-sequence reactance from the substation to the fault location                           |
| $R_0$              | Estimated zero-sequence resistance from the substation to the fault location                              |
| $X_0$              | Estimated zero-sequence reactance from the substation to the fault location                               |
| $R_N$              | Estimated the earth return path resistance (= $(R_0 - R_1)/3$ ) from the substation to the fault location |
| $X_N$              | Estimated is the earth return path reactance (= $(X_0 - X_1)/3$ ) from the substation to the fault        |
| $R_{\text{fault}}$ | Estimated fault resistance at the fault location  |

The recorded data Flt phase reactance provides the estimated positive-sequence reactance from the substation to the fault location.

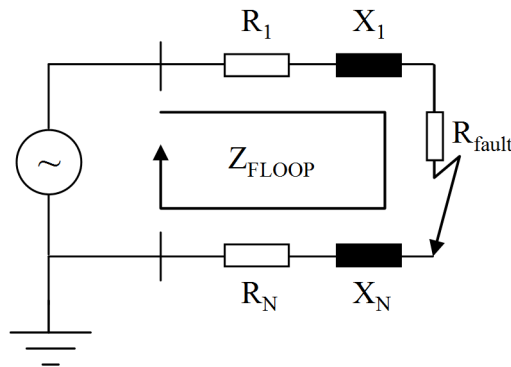


Figure 373: Fault loop impedance for phase-to-earth fault loops “AG Fault”, “BG Fault” or “CG Fault”

The earth-fault distance calculation algorithm is selected with setting *EF algorithm Sel.* Options for the selection are “Load compensation” and “Load modelling”. For the correct operation of both algorithms there should not be any zero-sequence current sources, for example, earthing transformers, in front of the IED location.

The “Load compensation” algorithm utilizes symmetrical components to compensate for the effect of load on the measured voltages and currents. In case of radial feeders, this algorithm should be selected with low-impedance/effectively earthed systems where the fault current is fed from one side only and there are no in-feeds along the protected line.

The “Load modelling” algorithm takes into account the effect of the load in the measured currents and voltages by considering it in the fault loop model. In case of radial feeders, this algorithm can be applied with low-impedance/effectively earthed systems where the fault current is fed from one side only. The “Load modelling” algorithm has been especially designed for unearthed systems.

The “Load modelling” algorithm requires the *Equivalent load Dis* setting, that is, an equivalent load distance, as an additional parameter. The derivation and meaning of this parameter is illustrated in [Figure 374](#), where the load is assumed to be evenly distributed along the feeder, resulting in the actual voltage drop curve as seen in the middle part of [Figure 374](#).

In case of evenly distributed load, *Equivalent load Dis*  $\sim 0.5$ . When the load is tapped at the end of the feeder, *Equivalent load Dis* = 1.0. If the load distribution is unknown, a default value of 0.5 can be used for *Equivalent load Dis*.

The maximum value of the voltage drop, denoted as  $U_{\text{drop}}(\text{real})$ , appears at the end of the feeder. The *Equivalent load Dis* parameter is the distance at which a single load tap corresponding to the total load of the feeder would result in a voltage drop equal to  $U_{\text{drop}}(\text{real})$ . The dashed curve shows the voltage drop profile in this case.

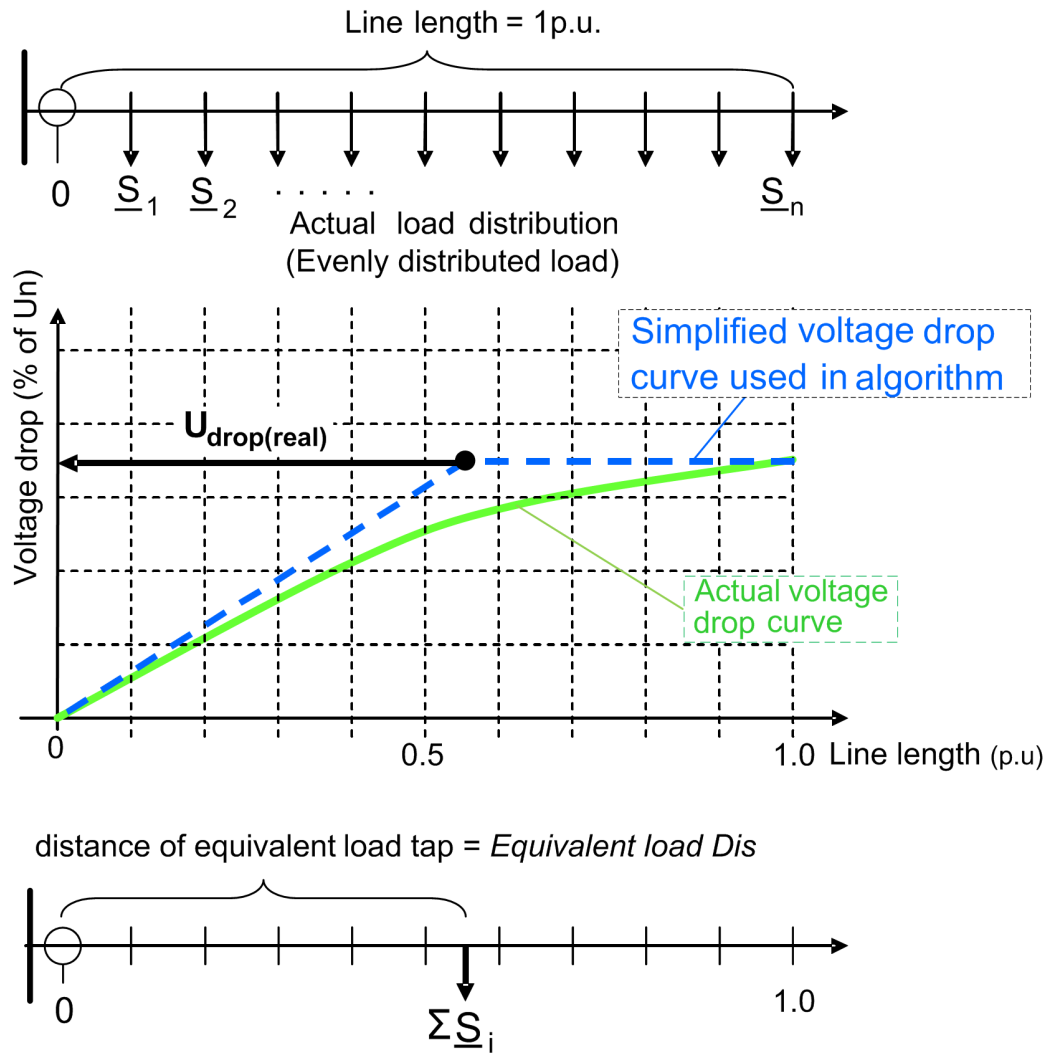


Figure 374: Description of the equivalent load distance

The exact value for *Equivalent load Dis* can be calculated based on the load flow and voltage drop calculations using data from DMS-system and the following equation.

$$\text{Equivalent load Dis} = \frac{U_{d(\text{real})}}{U_{d(\text{tap},d=1)}}$$

(Equation 44)

- $U_{d(\text{real})}$  The actual maximum voltage drop of the feeder
- $U_{d(\text{tap},d=1)}$  The fictional voltage drop, if the entire load would be tapped at the end ( $d=1$ ) of the feeder (not drawn in *Figure 374*). The calculation of this value requires data from the DMS system.

Alternatively, the setting *Equivalent load Dis* can be determined by conducting a single-phase earth-fault test ( $R_{\text{fault}} = 0 \Omega$ ) at that point of the feeder where the maximum actual voltage drop takes place. This point is typically located at the end

of the main line. As a result, the calculated value is stored in the recorded data Equivalent load Dis.

In addition, when the setting *EF algorithm Sel* is equal to “Load modelling”, the *EF algorithm Cur Sel* setting determines whether zero-sequence “Io based” or negative-sequence “I2 based” current based algorithm is used. The difference between “Io based” and “I2 based” methods is that “I2 based” does not require the *Ph capacitive React* and *Ph leakage Ris* settings. In case of “Io based”, these settings are needed to compensate for the influence of the line-charging capacitances of the protected feeder. This improves the accuracy of the fault location estimate when fault resistance is involved in the fault.

Under certain restrictions, the “Load modelling” algorithm can also be applied to unearthed networks. In this case the *EF algorithm Cur Sel* setting should be set to “Io based” and thus *Ph capacitive React* and *Ph leakage Ris* settings must be determined.

The prerequisite for the operation of SCEFRFLO in earth faults in unearthed networks is that the earth-fault current of the network corresponding to a solid fault exceeds the pre-fault load current; that is the [Equation 45](#) is valid.

$$Flt\ to\ Lod\ Cur\ ratio = \frac{|I_{ef(R_{fault}=0)}|}{|I_{Load}|} \geq 1$$

(Equation 45)

This ratio is estimated by SCEFRFLO and stored in the recorded data Flt to Lod Cur ratio together with the fault distance estimate.

In case of unearthed network, sufficient fault current magnitude resulting in Flt to Lod Cur ratio >1 can be achieved, for example, with proper switching operations in the background network, if possible, which increase the fault current. If the faulty feeder is re-energized after the switching operation, a new estimate for the fault distance can be obtained. Fault resistance decreases the fault location accuracy and the resistance should not be too high, the maximum is a few hundred ohms. Also low value of Flt to Lod Cur ratio causes inaccuracy and affects the quality of fault distance estimate. Considered inaccuracies affecting the calculated fault distance estimate are reported in the recorded result quality indicator value Flt Dist quality in [Table 660](#).

#### **Fault loops “AB Fault”, “BC Fault” or “CA Fault”**

Fault loops “AB Fault”, “BC Fault” or “CA Fault” are used for phase-to-phase short circuit faults as well as in the case of a two-phase-to-earth fault if the individual earth faults are located at the same feeder. [Figure 375](#) shows the phase-to-phase fault loop model. The following impedances are measured and stored in the recorded data of SCEFRFLO.

$$Flt\ point\ resistance = \frac{R_{fault}}{2}$$

(Equation 46)

$$\text{Flt loop resistance} = R_1 + \frac{R_{\text{fault}}}{2}$$

(Equation 47)

$$\text{Flt loop reactance} = \text{Flt phase reactance} = X_1$$

(Equation 48)

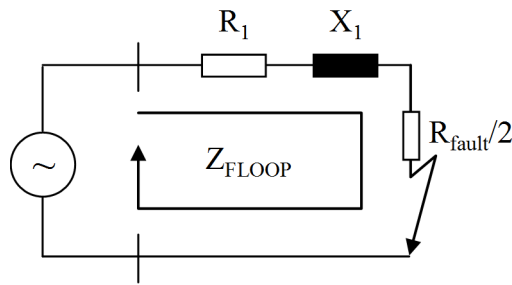


Figure 375: Fault loop impedance for phase-to-phase fault loops (either “AB Fault”, “BC Fault” or “CA Fault”)

The fault distance calculation algorithm for the phase-to-phase fault loops is defined by using settings *Load Com PP loops* and *Enable simple model*. Options for the selection are “Disabled” or “Enabled”.

Load compensation can be enabled or disabled with setting *Load Com PP loops*. The load compensation should be disabled only if the ratio between the fault current and load current is large or when the value of the fault distance estimate for the short circuit fault is required from each shot of an autoreclosing sequence.

The fault distance calculation is most accurate when calculated with the fault loop model. This model requires positive sequence impedances of the protected feeder to be given as settings. If these settings are not available, valid impedance values can be calculated also without the fault loop model with setting *Enable simple model* = “TRUE”. However, valid distance estimate, that is, the conversion of measured impedance (“electrical fault distance”) into a physical fault distance requires accurate positive sequence impedance settings.

#### Fault loop “ABC Fault”

Fault loop “ABC Fault” is used exclusively for the three-phase short circuit fault. [Figure 376](#) shows the three-phase fault loop model. The following impedances are measured and stored in the recorded data of SCEFRFLO.

$$\text{Flt point resistance} = R_{\text{fault}}$$

(Equation 49)

$$\text{Flt loop resistance} = R_1 + R_{\text{fault}}$$

(Equation 50)

$$Flt\ loop\ reactance = Flt\ phase\ reactance = X_1$$

(Equation 51)

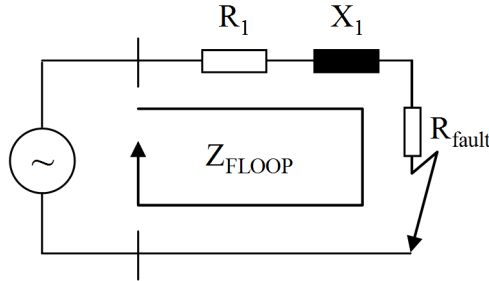


Figure 376: Fault loop impedance for a three-phase fault loop (“ABC Fault”)

The three-phase fault distance is calculated with a special measuring element using positive-sequence quantities. This is advantageous especially in case of non-transposed (asymmetric) lines, as the influence of line parameter asymmetry is reduced. If the line is non-transposed, all the phase-to-phase loops have different fault loop reactances. The use of positive-sequence quantities results in the average value of phase-to-phase loop reactances, that is, the most representative estimate in case of three-phase faults.

The fault distance calculation algorithm for the three-phase fault loop is defined by using settings *Load Com PP loops* and *Enable simple model*. Options for the selection are "Disabled" or "Enabled".

Load compensation can be enabled or disabled with setting *Load Com PP loops*. The load compensation should be disabled only if the ratio between the fault current and load current is large or when the value of the fault distance estimate for the short circuit fault is required from each shot of an autoreclosing sequence.

The fault distance calculation is most accurate when the calculation is made with the fault loop model. This model requires positive sequence impedances of the protected feeder to be given as settings. If these settings are not available, valid impedance values can be calculated also without the fault loop model with setting *Enable simple model* = "TRUE". However, valid distance estimate, that is, the conversion of measured impedance (“electrical fault distance”) into a physical fault distance requires accurate positive sequence impedance settings.

#### Estimation of fault resistance in different fault loops

The fault point resistance value provided by the impedance calculation is available in recorded data Flt point resistance and it depends on the applied fault loop as shown in [Figure 377](#). In case of earth faults, the estimated fault point resistance includes the total fault point resistance between the faulted phase and earth, for example, the arc and earthing resistances. In case of phase-to-phase faults, the estimated fault point resistance is half of the total fault point resistance between the phases. In case of a three-phase fault, the estimated fault point resistance equals the total fault point resistance as per phase value, for example, the arc resistance per phase.

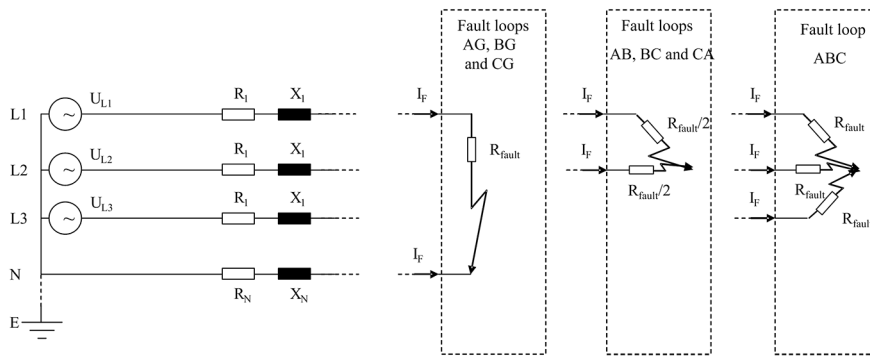


Figure 377: Definition of a physical fault point resistance in different fault loops

**Steady-state asymmetry and load compensation**

In reality, power systems are never perfectly symmetrical. The asymmetry produces steady-state quantities in the form of zero-sequence and negative- sequence voltages and currents. If not compensated, these are error sources for fault distance calculation especially in case of earth faults. All earth-fault distance calculation algorithms of SCEFRFLO utilize the delta-quantities which mitigate the effects of the steady-state asymmetry.

Load current is another error source for fault distance calculation. Its influence increases with higher fault resistance values. SCEFRFLO employs independent load compensation methods for each fault type to achieve optimal performance. The purpose of load compensation is to improve the accuracy of the fault distance calculation models by estimating the actual fault current in the fault location. Delta-quantities are used for this to mitigate the effect of load current on fault distance estimation. For earth faults, the load compensation is done automatically inside the fault distance calculation algorithm. For short circuit faults, load compensation is enabled with setting *Load Com PP loops*. The default value is “Enabled”. The parameter should be set to “Disabled” only if the ratio between the expected fault current and load current is large or when the fault distance estimate for short circuit fault is required for each shot of an autoreclosing sequence.

The delta-quantity describes the change in measured signal due to the fault.

$$\Delta X = X_{fault} + X_{pre-fault} \tag{Equation 52}$$

- $X_{fault}$  Corresponds to the signal value during fault
- $X_{pre-fault}$  Corresponds to the signal value during healthy state just before fault

**Result quality indicator**

The quality of the estimated fault distance is judged and reported in recorded data as the Flt Dist quality together with the fault distance estimate. The Flt Dist quality is a bit vector indicating detected sources of inaccuracy in the fault distance estimate. In case Flt Dist quality equals 1, the result is not affected by error sources. This results in good quality for fault distance estimate. If factors affecting negatively to fault distance estimation are detected, the Flt Dist quality is according to [Table 660](#). In this case estimated fault distance, Flt distance value is given in HMI in parenthesis.



**Table 660: Fault distance quality indicator Flt Dist quality**

| Value | Corresponding inaccuracy description   |
|-------|--|
| 2     | Estimation stability criterion has not been reached  |
| 4     | Fault point resistance exceeds 500 $\Omega$  |
| 8     | Fault point resistance exceeds $5 \times X_{loop}$   |
| 16    | Fault point resistance exceeds $20 \times X_{loop}$  |
| 32    | Flt to Lod Cur ratio is below 1.00   |
| 64    | Fault distance estimate outside tolerances (<-0.1 pu or >1.1 pu)                                   |
| 128   | Distance estimate calculation is not done due to too low magnitudes of I or U                      |
| 256   | Distance estimate calculation cannot be performed (for example avoiding internal division by zero) |

For example, if fault point resistance exceeds 500  $\Omega$  and Flt to Lod Cur ratio is below 1.0, Flt Dist quality is "36". As another example, if no error sources are found, but stability criterion is not met, the value of Flt Dist quality is "2".

### Impedance settings

The fault distance calculation in SCEFRFLO is based on the fault loop impedance modeling. The fault loop is parametrized with the impedance settings and these can be set at maximum for three line sections (A, B and C). Each section is enabled by entering a section length, which differs from zero to settings *Line Len section A*, *Line Len section B* or *Line Len section C* in the order section A-> section B-> section C.

The earth-fault loops require both positive-sequence and zero-sequence impedances, for example, *R1 line section A* and *X1 line section A*, *R0 line section A* and *X0 line section A*. For the short circuit loops, only positive-sequence impedances are needed. Even these can be omitted in the short circuit loops, if the setting *Enable simple model* equals "TRUE".

If the impedance settings are in use, it is important that the settings closely match the impedances of used conductor types. The impedance settings are given in primary ohms [ohm/pu] and the line section lengths in per unit [pu]. Thus, impedances can be either given in ohm/km and section length in km, or ohm/mile and section length in miles. The resulting Flt distance matches the units entered for the line section lengths.

### Positive-sequence impedance values

Fault location requires accurate setting values for line impedances. Positive-sequence impedances are required both for location of short circuits and earth faults. As data sheet impedance per unit values are generally valid only for a certain tower configuration, the values should be adjusted according to the actual installation configuration. This minimizes the fault location errors caused by inaccurate settings.

<sup>93</sup> Xloop is the total loop reactance according to settings

The positive-sequence reactance per unit and per phase can be calculated with a following approximation equation which applies to symmetrically transposed three-phase aluminium overhead lines without ground wires.

$$X_1 \approx \omega_n \cdot 10^{-4} \left( 2 \cdot \ln \frac{a_{en}}{r} + 0.5 \right) [\Omega / km]$$

(Equation 53)

- $\omega_n$   $2 \times \pi \times f_n$ , where  $f_n$  = fundamental frequency [Hz]
- $a_{en}$   $\sqrt[3]{(a_{12} \cdot a_{23} \cdot a_{31})}$   
the geometric average of phase distances [m]
- $a_{xy}$  distance [m] between phases x and y
- r radius [m] for single conductor

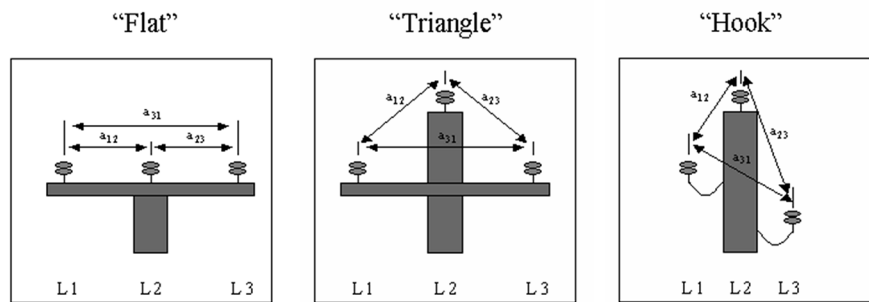


Figure 378: Typical distribution line tower configurations

Example values of positive-sequence impedances for typical medium voltage overhead-lines are given in the following tables.

**Table 661: Positive-sequence impedance values for typical 11 kV conductors, “Flat” tower configuration assumed**

| Name           | R1 [Ω/km] | X1 [Ω/km] |
|----------------|-----------|-----------|
| ACSR 50 SQ.mm  | 0.532     | 0.373     |
| ACSR 500 SQ.mm | 0.0725    | 0.270     |

**Table 662: Positive-sequence impedance values for typical 10/20 kV conductors, “Flat” tower configuration assumed**

| Name               | R1 [Ω/km] | X1 [Ω/km] |
|--------------------|-----------|-----------|
| Al/Fe 36/6 Sparrow | 0.915     | 0.383     |
| Al/Fe 54/9 Raven   | 0.578     | 0.368     |
| Al/Fe 85/14 Pigeon | 0.364     | 0.354     |
| Al/Fe 93/39 Imatra | 0.335     | 0.344     |
| Al/Fe 108/23 Vaasa | 0.287     | 0.344     |
| Al/Fe 305/39 Duck  | 0.103     | 0.314     |

**Table 663: Positive-sequence impedance values for typical 33 kV conductors, “Flat” tower configuration assumed**

| Name           | R1 [Ω/km] | X1 [Ω/km] |
|----------------|-----------|-----------|
| ACSR 50 sq.mm  | 0.529     | 0.444     |
| ACSR 100 sq.mm | 0.394     | 0.434     |
| ACSR 500 sq.mm | 0.0548    | 0.346     |

**Zero-sequence impedance values**

Location of earth faults requires both positive-sequence and zero-sequence impedances. For short circuit faults, zero-sequence impedances are not required.

The positive-sequence impedance per unit values for the lines are typically known or can easily be obtained from data sheets. The zero-sequence values are generally not as easy to obtain as they depend on the actual installation conditions and configurations. Sufficient accuracy can, however, be obtained with rather simple calculations using the following equations, which apply per phase for symmetrically transposed three-phase aluminium overhead lines without ground wires.

$$R_0 [50Hz] \approx R1 + 0.14804 [\Omega / km]$$

(Equation 54)

$$R_0 [60Hz] \approx R1 + 0.17765 [\Omega / km]$$

(Equation 55)

$$X_0 \approx 2 \cdot \omega_n \cdot 10^{-4} \left( 3 \cdot \ln \frac{W}{r_{en}} + 0.25 \right) [\Omega / km]$$

(Equation 56)

$R_1$  conductor AC resistance [Ω/km]

$$W = 658 \sqrt{\frac{\rho_{earth}}{f_n}}$$

the equivalent depth [m] of the earth return path

$\rho_{earth}$  earth resistivity [Ωm]

$$r_{en} = \sqrt[3]{r \cdot \sqrt[3]{a_{12}^2 \cdot a_{23}^2 \cdot a_{31}^2}}$$

the equivalent radius [m] for conductor bundle

$r$  radius [m] for single conductor

$a_{xy}$  distance [m] between phases x and y

**Ph leakage Ris and Ph capacitive React settings**

The *Ph leakage Ris* and *Ph capacitive React* settings are used for improving fault distance estimation accuracy for earth faults. They are critical for an accurate fault

location in unearthed networks. In other types of networks they are less critical. The *Ph leakage Ris* setting represents the leakage losses of the protected feeder in terms of resistance per phase. The *Ph capacitive React* setting represents the total phase-to-earth capacitive reactance of the protected feeder per phase. Based on experience, a proper estimate for *Ph leakage Ris* should be about  $20...40 \times Ph\ capacitive\ React$ .

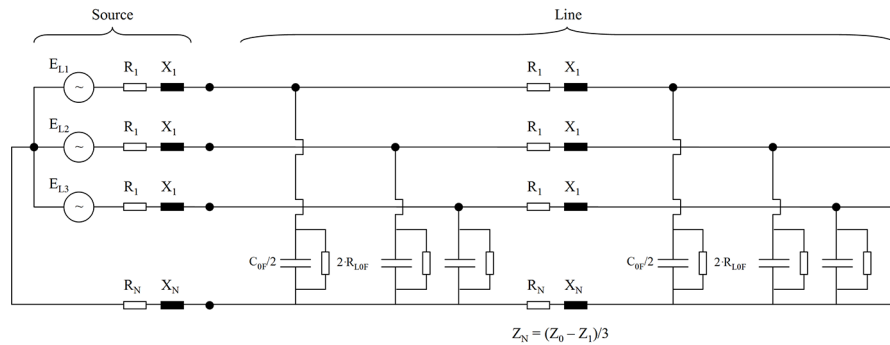


Figure 379: Equivalent diagram of the protected feeder.  $R_{LOF} = Ph\ leakage\ Ris$ .

The determination of the *Ph capacitive React* setting can be based either on network data or measurement.

If the total phase-to-earth capacitance (including all branches) per phase  $C_{0F}$  of the protected feeder is known, the setting value can be calculated.

$$Ph\ capacitive\ React = \frac{1}{(\omega_n \cdot C_{0F})}$$

(Equation 57)

In case of unearthed network, if the earth-fault current produced by the protected feeder  $I_{ef}$  is known, the setting value can be calculated.

$$Ph\ capacitive\ React = \frac{\sqrt{3} \cdot U_{xy}}{I_{ef}}$$

(Equation 58)

$U_{xy}$  Phase-to-earth voltage

SCEFRFLO can also determine the value for the *Ph capacitive React* setting by measurements. The calculation of *Ph capacitive React* is triggered by the binary signal connected to the TRIGG\_XC0F input when an earth-fault test is conducted outside the protected feeder during commissioning, for example, at the substation busbar. The *Calculation Trg mode* has to be “External”. After the activation of the TRIGG\_XC0F triggering input, the calculated value for setting *Ph capacitive React* is obtained from recorded data as parameter *XC0F Calc*. This value has to be manually entered for the *Ph capacitive React* setting. The calculated value matches the current switching state of the feeder and thus, if the switching state of the protected feeder changes, the value should be updated.

Figure 381 shows an example configuration, which enables the measurement of setting *Ph capacitive React*.

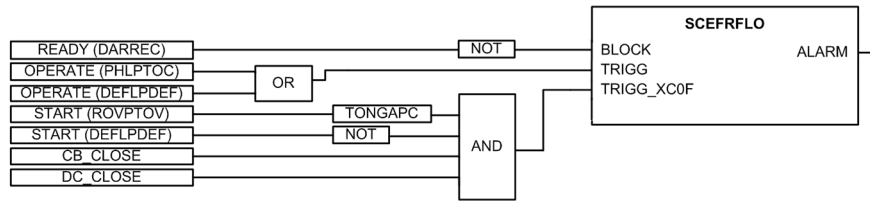


Figure 380: An example configuration, which enables the measurement of setting *Ph capacitive React*

If the earth fault is detected by the residual overvoltage function (START of ROVPTOV), but not seen by the forward-looking earth-fault protection function (START of DEFLPDEF), the fault is located outside the protected feeder. This is mandatory for valid measurement of setting *Ph capacitive React*. After a set delay (TONGAPC), the input TRIGG\_XCOF is activated and the parameter *XCOF Calc* in the recorded data is updated. The delay (TONGAPC) must be set longer than the start delay of the directional earth-fault function DEFLPDEF, but shorter than the minimum operating time of the directional earth-fault functions in any of the feeders. For example, if the start delay is 100 ms and the shortest operating time 300 ms, a value of 300 ms can be used. Circuit breaker and disconnecter status is used to verify that the entire feeder is measured.

### Modeling a non-homogeneous line

A typical distribution feeder is built with several different types of overhead lines and cables. This means that the feeder is electrically non-homogeneous. SCEFRFLO allows the modeling of the line impedance variation in IED with three line sections with independent impedance settings. This improves the accuracy of physical fault distance conversion done in the IED, especially in cases where the line impedance non-homogeneity is severe. Each section is enabled by entering a section length, which differs from zero, to settings *Line Len section A*, *Line Len section B* or *Line Len section C* in the order section A-> section B-> section C.

Impedance model with one line section is enabled by setting *Line Len section A* to differ from zero. In this case the impedance settings *R1 line section A*, *X1 line section A*, *R0 line section A* and *X0 line section A* are used for the fault distance calculation and for conversion from reactance to physical fault distance. This option should be used only in the case of a homogeneous line, that is, when the protected feeder consists of only one conductor type.

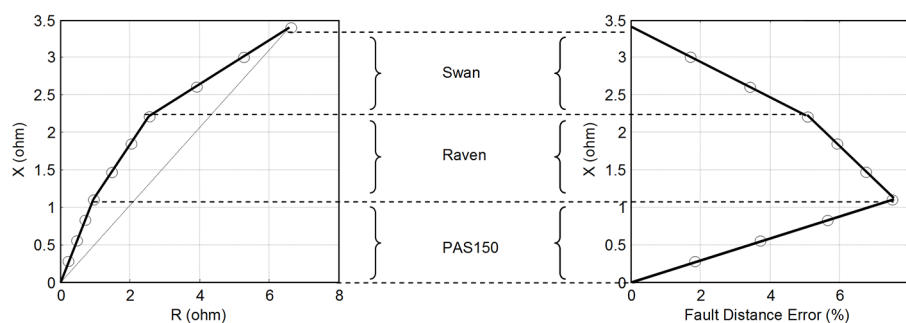
Impedance model with two line sections is enabled by setting both *Line Len section A* and *Line Len section B* to differ from zero. In this case the impedance settings *R1 line section A*, *X1 line section A*, *R0 line section A*, *X0 line section A*, *R1 line section B*, *X1 line section B*, *R0 line section B* and *X0 line section B* are used for the fault distance calculation and for conversion from reactance to physical fault distance. This option should be used in the case of a non-homogeneous line when the protected feeder consists of two types of conductors.

Impedance model with three line sections is enabled by setting *Line Len section A*, *Line Len section B* and *Line Len section C* all differ from zero. In this case the impedance settings *R1 line section A*, *X1 line section A*, *R0 line section A*, *X0 line section A*, *R1 line section B*, *X1 line section B*, *R0 line section B*, *X0 line section B*, *R1 line section C*, *X1 line section C*, *R0 line section C* and *X0 line section C* are used for the fault distance calculation and for conversion from reactance to physical fault distance. This option should be used in the case of a non-homogeneous line when the protected feeder consists of more than two types of conductors.

The effect of line impedance non-homogeneity in the conversion of fault loop reactance into physical fault distance is demonstrated in example shown in [Figure 381](#) with 10 kilometer long feeder with three line types. The total line impedance for the 10 km line is  $R1 = 6.602 \Omega$  ( $0.660 \Omega/\text{km}$ ) and  $X1 = 3.405 \Omega$  ( $0.341 \Omega/\text{km}$ ), consisting of the following sections and impedance values.

- 4 km of PAS 150 ( $R1 = 0.236 \Omega/\text{km}$ ,  $X1 = 0.276 \Omega/\text{km}$ )
- 3 km of Al/Fe 54/9 Raven ( $R1 = 0.536 \Omega/\text{km}$ ,  $X1 = 0.369 \Omega/\text{km}$ )
- 3 km of Al/Fe 21/4 Swan ( $R1 = 1.350 \Omega/\text{km}$ ,  $X1 = 0.398 \Omega/\text{km}$ )

The non-homogeneity of feeder impedance can be illustrated by drawing the protected feeder in RX-diagram (in the impedance plane), as shown in [Figure 381](#).



*Figure 381: Example impedance diagram of an electrically non-homogeneous feeder (left), and the resulting error in fault distance if the measured fault loop reactance is converted into physical fault distance by using only one line section parameters (right).*

In [Table 664](#) the feeder is modelled either with one or three line sections with parameters given in [Figure 381](#).

**Table 664: Impedance settings**

| Parameter          | Impedance model with one section | Impedance model with three sections |
|--------------------|----------------------------------|-------------------------------------|
| R1 line section A  | 0.660 $\Omega/\text{pu}$         | 0.236 $\Omega/\text{pu}$            |
| X1 line section A  | 0.341 $\Omega/\text{pu}$         | 0.276 $\Omega/\text{pu}$            |
| Line Len section A | 10000 pu                         | 4000 pu                             |
| R1 line section B  | N/A                              | 0.536 $\Omega/\text{pu}$            |
| X1 line section B  | N/A                              | 0.369 $\Omega/\text{pu}$            |
| Line Len section B | 0.000 pu                         | 3000 pu                             |
| R1 line section C  | N/A                              | 1.350 $\Omega/\text{pu}$            |
| X1 line section C  | N/A                              | 0.398 $\Omega/\text{pu}$            |
| Line Len section C | 0.000 pu                         | 3000 pu                             |

[Figure 382](#) illustrates the conversion error from measured fault loop reactance into physical fault distance. The fault location is varied from 1 km to 10 km in 1 km steps (marked with circles). An error of nearly eight per cent at maximum is created by the conversion procedure when modeling a non-homogenous line with only one section. By using impedance model with three line sections, there is no error in the conversion.

The previous example assumed a short circuit fault and thus, only positive-sequence impedance settings were used. The results, however, also apply for earth faults.

#### Taps or spurs in the feeder

If the protected feeder consists of taps or spurs, the measured fault impedance corresponds to several physical fault locations (For example, A or B in [Figure 382](#)). The actual fault location must be identified using additional information, for example, short circuit current indicators placed on tapping points.

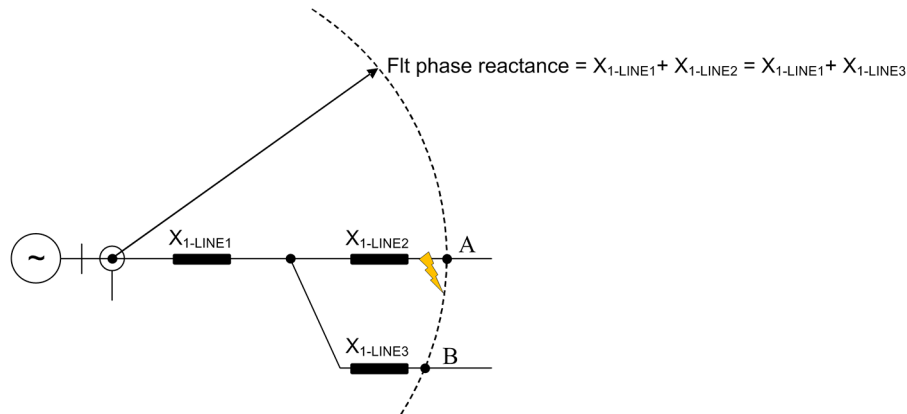


Figure 382: Fault on a distribution line with spurs

#### 4.5.4.3

#### Trigger detection

The fault distance estimate is obtained when SCEFRFLO is triggered. The triggering method is defined with setting *Calculation Trg mode*. The options for selection are: “External” or “Internal”, where the default value is “External”. The TRIGG\_OUT event indicates fault distance value recording moment. The fault distance estimate, Flt distance, together with the timestamp of actual triggering are saved in the recorded data of SCEFRFLO.

- In case of external triggering, an external trigger signal should be connected to the TRIGG input. The triggering signal is typically a trip signal from a protective function. At triggering moment the fault distance is stored into recorded data. It is important that triggering is timed suitably to provide sufficient distance estimation calculation time before tripping of the feeder circuit breaker.
- In case of internal triggering, the TRIGG input is not used for triggering. Instead, the trigger signal is created internally so that the estimation is started when phase selection logic detects a fault and the estimate is triggered when its value has stabilized sufficiently. This is judged by maximum variation in fault distance estimate and defined with setting *Distance estimate Va* (in the same unit as the fault distance estimate). When successive estimates during one fundamental cycle are within “final value  $\pm$  *Distance estimate Va*”, the fault distance estimate (mean of successive estimates) is recorded. In case stabilization criterion has not been fulfilled, the fault distance estimate is given just before the phase currents are interrupted. The phase selection logic is a non-directional function, and thus internal triggering should not be used when directionality is required.

Generally, SCEFRFLO requires a minimum of two fundamental cycles of measuring time after the fault occurrence. [Figure 383](#) illustrates typical behaviour of fault distance estimate of SCEFRFLO as a function of time.

- Immediately after the fault occurrence, the estimate is affected by initial fault transients in voltages and currents.
- Approximately one fundamental cycle after the fault occurrence, the fault distance estimate starts to approach the final value.
- Approximately two fundamental cycles after the fault occurrence, the stability criterion for fault distance estimate is fulfilled and the TRIGG\_OUT event is sent. The recorded data values are stored at this moment.

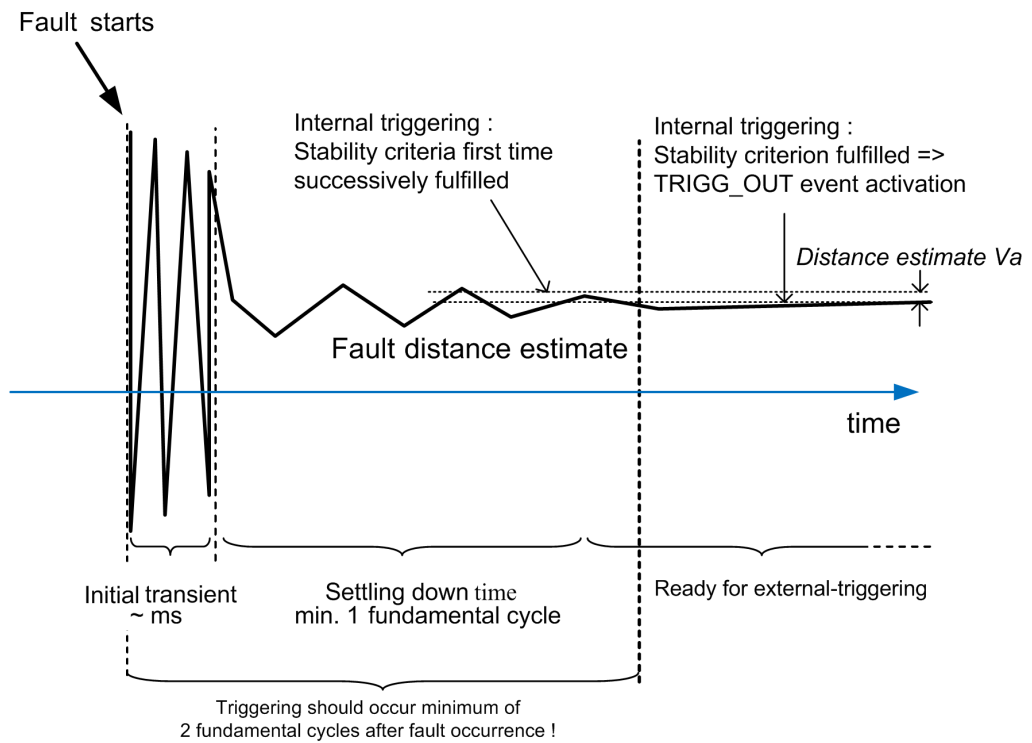


Figure 383: The behavior of fault distance estimate in time

#### 4.5.4.4 Alarm indication

SCEFRFLO contains an alarm output for the calculated fault distance. If the calculated fault distance `FLT_DISTANCE` is between the settings *Low alarm Dis limit* and *High alarm Dis limit*, the `ALARM` output is activated.

The `ALARM` output can be utilized, for example, in regions with waterways or other places where knowledge of certain fault locations is of high importance.



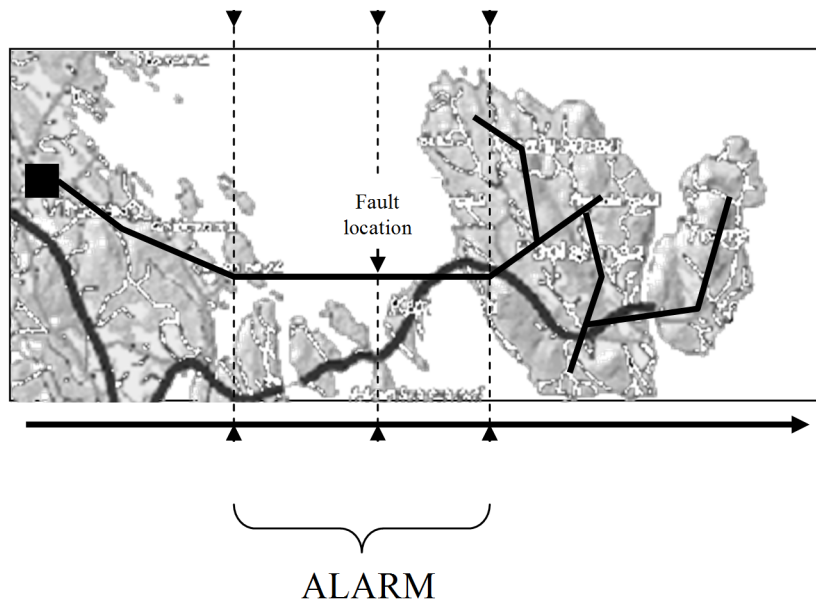


Figure 384: An example of the ALARM output use

#### 4.5.4.5 Recorded data

All the information required for a later fault analysis is recorded to SCEFRFLO recorded data. In the IED, recorded data is found in **Monitoring > Recorded data > Other protection > SCEFRFLO**.

SCEFRFLO has also monitored data values which are used for the read-out of continuous calculation values. The cross reference table shows which of the recorded data values are available as continuous monitoring values during a fault.

Table 665: Cross reference table for recorded and monitored data values

| Recorded data        | Monitored data |
|----------------------|----------------|
| Flt loop             | FAULT_LOOP     |
| Flt distance         | FLT_DISTANCE   |
| Flt Dist quality     | FLT_DIST_Q     |
| Flt loop resistance  | RFLOOP         |
| Flt loop reactance   | XFLOOP         |
| Flt phase reactance  | XFPHASE        |
| Flt point resistance | RF             |
| Flt to Lod Cur ratio | IFLT_PER_ILD   |
| Equivalent load Dis  | S_CALC         |
| XCOF Calc            | XCOF_CALC      |

#### 4.5.4.6 Measurement modes

The full operation of SCEFRFLO requires that all three phase-to-earth voltages are measured. The voltages can be measured with conventional voltage transformers or voltage dividers connected between the phase and earth ( *VT connection* is set to

“Wye”). Another alternative is to measure phase-to-phase voltages ( *VT connection* is set to “Delta”) and residual voltage ( $U_0$ ). Both alternatives are covered by setting the configuration parameter *Phase voltage Meas* to “Accurate”.

When the *Phase voltage Meas* setting is set to “Ph-to-ph without  $U_0$ ” and only phase-to-phase voltages are available (but not  $U_0$ ), only short-circuit measuring loops (fault loops “AB Fault”, “BC Fault” or “CA Fault” or “ABC Fault”) can be measured accurately. In this case, the earth-fault loops (fault loops either “AG Fault”, “BG Fault” or “CG Fault”) cannot provide correct fault distance estimates and the triggering of the function in case of earth fault is automatically disabled.

### 4.5.5 Application

The main objective of the feeder terminals is a fast, selective and reliable operation in faults inside the protected feeder. In addition, information on the distance to the fault point is very important for those involved in operation and maintenance. Reliable information on the fault location greatly decreases the downtime of the protected feeders and increases the total availability of a power system.

SCEFRFLO provides impedance-based fault location. It is designed for radially operated distribution systems and is applicable for locating short circuits in all kinds of distribution networks. Earth faults can be located in effectively earthed and low resistance/low-reactance earthed networks. Under certain limitations, SCEFRFLO can also be applied for earth-fault location in unearthed distribution networks.

#### Configuration example

A typical configuration example for SCEFRFLO triggering is illustrated in [Figure 380](#) where external triggering is applied, that is, *Calculation Trg mode* is set to “External”. The *OPERATE* signal from non-directional overcurrent function PHLPTOC is used to provide an indication of a short circuit fault. The *OPERATE* signal from the directional earth-fault function DEFLPDEF is used to provide an indication of an earth fault at the protected feeder.

#### SCEFRFLO with the autoreclosing function

When SCEFRFLO is used with the autoreclosing sequence, the distance estimate from the first trip is typically the most accurate one. The fault distance estimates from successive trips are possible but accuracy can be decreased due to inaccurate load compensation. During the dead time of an autoreclosing sequence, the load condition of the feeder is uncertain.

The triggering of SCEFRFLO can also be inhibited during the autoreclosing sequence. This is achieved by connecting the inverted *READY* signal from the autoreclosing function DARREC, which indicates that the autoreclosing sequence is in progress, to the *BLOCK* input of SCEFRFLO. Blocking of the SCEFRFLO triggering is suggested during the autoreclosing sequence when the load compensation or steady-state asymmetry elimination is based on the delta quantities. This applies to the short circuit faults when *Load Com PP loops* is set to “Enabled” or, for earth faults, when *EF algorithm Sel* is set to “Load compensation” or “Load modelling”.

## 4.5.6 Signals

### 4.5.6.1 SCEFRFLO Input signals

Table 666: SCEFRFLO Input signals

| Name           | Type    | Default | Description   |
|----------------|---------|---------|---|
| I_A            | SIGNAL  | 0       | Phase A current                                       |
| I_B            | SIGNAL  | 0       | Phase B current                                       |
| I_C            | SIGNAL  | 0       | Phase C current                                       |
| I <sub>0</sub> | SIGNAL  | 0       | Residual current                                      |
| I <sub>1</sub> | SIGNAL  | 0       | Positive sequence current                             |
| I <sub>2</sub> | SIGNAL  | 0       | Negative sequence current                             |
| U_A_AB         | SIGNAL  | 0       | Phase to earth voltage A or phase to phase voltage AB |
| U_B_BC         | SIGNAL  | 0       | Phase to earth voltage B or phase to phase voltage BC |
| U_C_CA         | SIGNAL  | 0       | Phase to earth voltage C or phase to phase voltage CA |
| U <sub>0</sub> | SIGNAL  | 0       | Residual voltage                                      |
| U <sub>1</sub> | SIGNAL  | 0       | Positive phase sequence voltage                       |
| U <sub>2</sub> | SIGNAL  | 0       | Negative phase sequence voltage                       |
| BLOCK          | BOOLEAN | 0=False | Block signal for activating the blocking mode         |
| TRIGG          | BOOLEAN | 0=False | Distance calculation triggering signal                |
| TRIGG_XCOF     | BOOLEAN | 0=False | XCOF calculation triggering signal                    |

### 4.5.6.2 SCEFRFLO Output signals

Table 667: SCEFRFLO Output signals

| Name  | Type    | Description                 |
|-------|---------|-----------------------------|
| ALARM | BOOLEAN | Fault location alarm signal |

## 4.5.7 Settings

### 4.5.7.1 SCEFRFLO Settings

**Table 668: SCEFRFLO Group settings (Basic)**

| Parameter           | Values (Range)   | Unit     | Step  | Default | Description  |
|---------------------|------------------|----------|-------|---------|--|
| Z Max phase load    | 1.0...10000.0    | ohm      | 0.1   | 80.0    | Impedance per phase of max. load, overcurr./ under-imp., PSL |
| Ph leakage Ris      | 20...1000000     | ohm      | 1     | 210000  | Line PhE leakage resistance in primary ohms                  |
| Ph capacitive React | 10...1000000     | ohm      | 1     | 7000    | Line PhE capacitive reactance in primary ohms                |
| R1 line section A   | 0.000...1000.000 | ohm / pu | 0.001 | 1.000   | Positive sequence line resistance, line section A            |
| X1 line section A   | 0.000...1000.000 | ohm / pu | 0.001 | 1.000   | Positive sequence line reactance, line section A             |
| R0 line section A   | 0.000...1000.000 | ohm / pu | 0.001 | 4.000   | Zero sequence line resistance, line section A                |
| X0 line section A   | 0.000...1000.000 | ohm / pu | 0.001 | 4.000   | Zero sequence line reactance, line section A                 |
| Line Len section A  | 0.000...1000.000 | pu       | 0.001 | 0.000   | Line length, section A                                       |

**Table 669: SCEFRFLO Group settings (Advanced)**

| Parameter            | Values (Range) | Unit | Step  | Default | Description               |
|----------------------|----------------|------|-------|---------|---------------------------|
| High alarm Dis limit | 0.000...1.000  | pu   | 0.001 | 0.000   | High alarm limit for cal- |

*Table continues on the next page*

| Parameter           | Values (Range)   | Unit     | Step  | Default | Description   |
|---------------------|------------------|----------|-------|---------|---|
|                     |                  |          |       |         | culated distance  |
| Low alarm Dis limit | 0.000...1.000    | pu       | 0.001 | 0.000   | Low alarm limit for calculated distance                             |
| Equivalent load Dis | 0.00...1.00      |          | 0.01  | 0.50    | Equivalent load distance when EF algorithm equals to load modelling |
| R1 line section B   | 0.000...1000.000 | ohm / pu | 0.001 | 1.000   | Positive sequence line resistance, line section B                   |
| X1 line section B   | 0.000...1000.000 | ohm / pu | 0.001 | 1.000   | Positive sequence line reactance, line section B                    |
| R0 line section B   | 0.000...1000.000 | ohm / pu | 0.001 | 4.000   | Zero sequence line resistance, line section B                       |
| X0 line section B   | 0.000...1000.000 | ohm / pu | 0.001 | 4.000   | Zero sequence line reactance, line section B                        |
| Line Len section B  | 0.000...1000.000 | pu       | 0.001 | 0.000   | Line length, section B  |
| R1 line section C   | 0.000...1000.000 | ohm / pu | 0.001 | 1.000   | Positive sequence line resistance, line section C                   |
| X1 line section C   | 0.000...1000.000 | ohm / pu | 0.001 | 1.000   | Positive sequence line reactance, line section C                    |
| R0 line section C   | 0.000...1000.000 | ohm / pu | 0.001 | 4.000   | Zero sequence line resistance, line section C                       |
| X0 line section C   | 0.000...1000.000 | ohm / pu | 0.001 | 4.000   | Zero sequence line reactance, line section C                        |
| Line Len section C  | 0.000...1000.000 | pu       | 0.001 | 0.000   | Line length, section C  |

**Table 670: SCEFRFLO Non group settings (Basic)**

| Parameter            | Values (Range)                      | Unit | Step | Default    | Description                           |
|----------------------|-------------------------------------|------|------|------------|---------------------------------------|
| Operation            | 1=on<br>5=off                       |      |      | 1=on       | Operation Off / On                    |
| Phase voltage Meas   | 1=Accurate<br>2=Ph-to-ph without Uo |      |      | 1=Accurate | Phase voltage measurement principle   |
| Calculation Trg mode | 1=Internal<br>2=External            |      |      | 2=External | Trigger mode for distance calculation |

**Table 671: SCEFRFLO Non group settings (Advanced)**

| Parameter            | Values (Range)                          | Unit | Step  | Default             | Description   |
|----------------------|---|------|-------|---------------------|---|
| EF algorithm Sel     | 1=Load compensation<br>2=Load modelling |      |       | 1=Load compensation | Selection for PhE-loop calculation algorithm            |
| EF algorithm Cur Sel | 1=Io based<br>2=I2 based                |      |       | 1=Io based          | Selection for earth-fault current model                 |
| Load Com PP loops    | 0=Disabled<br>1=Enabled                 |      |       | 1=Enabled           | Enable load compensation for PP/3P-loops                |
| Enable simple model  | 0=Disabled<br>1=Enabled                 |      |       | 0=Disabled          | Enable calc. without impedance settings for PP/3P-loops |
| Distance estimate Va | 0.001...0.300                           |      | 0.001 | 0.015               | Allowed variation of short circuit distance estimate    |

#### 4.5.8 Monitored data

### 4.5.8.1 SCEFRFLO Monitored data

**Table 672: SCEFRFLO Monitored data**

| Name         | Type    | Values (Range)   | Unit | Description                                       |
|--------------|---------|--|------|---|
| RF           | FLOAT32 | 0.0...1000000.0  | ohm  | Fault point resistance in primary ohms            |
| FAULT_LOOP   | Enum    | 1=AG Fault<br>2=BG Fault<br>3=CG Fault<br>4=AB Fault<br>5=BC Fault<br>6=CA Fault<br>7=ABC Fault<br>-5=No fault |      | Fault impedance loop                              |
| FLT_DISTANCE | FLOAT32 | 0.00...3000.00   | pu   | Fault distance in units selected by the user      |
| FLT_DIST_Q   | INT32   | 0...511  |      | Fault distance quality                            |
| RFLOOP       | FLOAT32 | 0.0...1000000.0  | ohm  | Fault loop resistance in primary ohms             |
| XFLOOP       | FLOAT32 | 0.0...1000000.0  | ohm  | Fault loop reactance in primary ohms              |
| XFPHASE      | FLOAT32 | 0.0...1000000.0  | ohm  | Positive sequence fault reactance in primary ohms |
| IFLT_PER_ILD | FLOAT32 | 0.00...60000.00  |      | Fault to load current ratio                       |
| S_CALC       | FLOAT32 | 0.00...1.00  |      | Estimated equivalent load distance                |
| XCOF_CALC    | FLOAT32 | 0.0...1000000.0  | ohm  | Estimated PhE capacitive reactance of line        |
| SCEFRFLO     | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off   |      | Status  |

*Table continues on the next page*

| Name                 | Type      | Values (Range)   | Unit | Description                                    |
|----------------------|-----------|--|------|--|
| Triggering time      | Timestamp |  |      | Estimate triggering time                       |
| Flt loop             | Enum      | 1=AG Fault<br>2=BG Fault<br>3=CG Fault<br>4=AB Fault<br>5=BC Fault<br>6=CA Fault<br>7=ABC Fault<br>-5=No fault |      | Fault loop                                     |
| Flt distance         | FLOAT32   | 0.00...3000.00   | pu   | Fault distance                                 |
| Flt Dist quality     | INT32     | 0...511  |      | Fault distance quality                         |
| Flt loop resistance  | FLOAT32   | 0.0...1000000.0  | ohm  | Fault loop resistance                          |
| Flt loop reactance   | FLOAT32   | 0.0...1000000.0  | ohm  | Fault loop reactance                           |
| Flt phase reactance  | FLOAT32   | 0.0...1000000.0  | ohm  | Fault phase reactance                          |
| Flt point resistance | FLOAT32   | 0.0...1000000.0  | ohm  | Fault resistance                               |
| Flt to Lod Cur ratio | FLOAT32   | 0.00...60000.00  |      | Fault to load current ratio                    |
| Equivalent load Dis  | FLOAT32   | 0.00...1.00  |      | Estimated equivalent load distance             |
| XC0F Calc            | FLOAT32   | 0.0...1000000.0  | ohm  | Estimated PhE capacitive reactance of the line |
| Pre fault time       | Timestamp |  |      | Pre-fault time                                 |
| A Pre Flt Phs A Magn | FLOAT32   | 0.00...40.00   | xIn  | Pre-fault current phase A, magnitude           |
| A Pre Flt Phs A Angl | FLOAT32   | -180.00...180.00   | deg  | Pre-fault current phase A, angle               |
| A Pre Flt Phs B Magn | FLOAT32   | 0.00...40.00   | xIn  | Pre-fault current phase B, magnitude           |
| A Pre Flt Phs B Angl | FLOAT32   | -180.00...180.00   | deg  | Pre-fault current phase B, angle               |
| A Pre Flt Phs C Magn | FLOAT32   | 0.00...40.00   | xIn  | Pre-fault current phase C, magnitude           |

*Table continues on the next page*



| Name                 | Type    | Values (Range)   | Unit | Description                          |
|----------------------|---------|------------------|------|--------------------------------------|
| A Pre Flt Phs C Angl | FLOAT32 | -180.00...180.00 | deg  | Pre-fault current phase C, angle     |
| V Pre Flt Phs A Magn | FLOAT32 | 0.00...40.00     | xIn  | Pre-fault voltage phase A, magnitude |
| V Pre Flt Phs A Angl | FLOAT32 | -180.00...180.00 | deg  | Pre-fault voltage phase A, angle     |
| V Pre Flt Phs B Magn | FLOAT32 | 0.00...40.00     | xIn  | Pre-fault voltage phase B, magnitude |
| V Pre Flt Phs B Angl | FLOAT32 | -180.00...180.00 | deg  | Pre-fault voltage phase B, angle     |
| V Pre Flt Phs C Magn | FLOAT32 | 0.00...40.00     | xIn  | Pre-fault voltage phase C, magnitude |
| V Pre Flt Phs C Angl | FLOAT32 | -180.00...180.00 | deg  | Pre-fault voltage phase C, angle     |
| A Flt Phs A Magn     | FLOAT32 | 0.00...40.00     | xIn  | Fault current phase A, magnitude     |
| A Flt Phs A angle    | FLOAT32 | -180.00...180.00 | deg  | Fault current phase A, angle         |
| A Flt Phs B Magn     | FLOAT32 | 0.00...40.00     | xIn  | Fault current phase B, magnitude     |
| A Flt Phs B angle    | FLOAT32 | -180.00...180.00 | deg  | Fault current phase B, angle         |
| A Flt Phs C Magn     | FLOAT32 | 0.00...40.00     | xIn  | Fault current phase C, magnitude     |
| A Flt Phs C angle    | FLOAT32 | -180.00...180.00 | deg  | Fault current phase C, angle         |
| V Flt Phs A Magn     | FLOAT32 | 0.00...40.00     | xIn  | Fault voltage phase A, magnitude     |
| V Flt Phs A angle    | FLOAT32 | -180.00...180.00 | deg  | Fault voltage phase A, angle         |
| V Flt Phs B Magn     | FLOAT32 | 0.00...40.00     | xIn  | Fault voltage phase B, magnitude     |
| V Flt Phs B angle    | FLOAT32 | -180.00...180.00 | deg  | Fault voltage phase B, angle         |
| V Flt Phs C Magn     | FLOAT32 | 0.00...40.00     | xIn  | Fault voltage phase C, magnitude     |
| V Flt Phs C angle    | FLOAT32 | -180.00...180.00 | deg  | Fault voltage phase C, angle         |

### 4.5.9 Technical data

Table 673: SCEFRFLO Technical data

| Characteristic       | Value  |
|----------------------|--|
| Measurement accuracy | At the frequency $f = f_n$                         |
|                      | Impedance:<br>$\pm 2.5\%$ or $\pm 0.25 \Omega$     |
|                      | Distance:<br>$\pm 2.5\%$ or $\pm 0.16$ km/0.1 mile |
|                      | XCOF_CALC:<br>$\pm 2.5\%$ or $\pm 50 \Omega$       |
|                      | IFLT_PER_ILD:<br>$\pm 5\%$ or $\pm 0.05$           |

### 4.5.10 Technical revision history

Table 674: SCEFRFLO Technical revision history

| Technical revision | Change                |
|--------------------|-----------------------|
| B                  | Internal improvement. |

## 4.6 Switch onto fault CBPSOF

### 4.6.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|----------------------|--------------------------|--------------------------|-------------------------------|
| Switch onto fault    | CBPSOF                   | SOTF                     | SOTF                          |

### 4.6.2 Function block

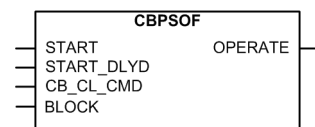


Figure 385: Function block

### 4.6.3 Functionality

The switch onto fault function CBPSOF provides an instantaneous trip or a time delayed trip when closing the breaker while a fault exists.

CBPSOF is activated when the `CB_CL_CMD` circuit breaker closing command is set high. CBPSOF has `START` and `START_DLYD` inputs for immediate or delayed start operation respectively.

The function contains a blocking functionality. It is possible to block function outputs and the reset timers, if desired.

### 4.6.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of switch onto fault function can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

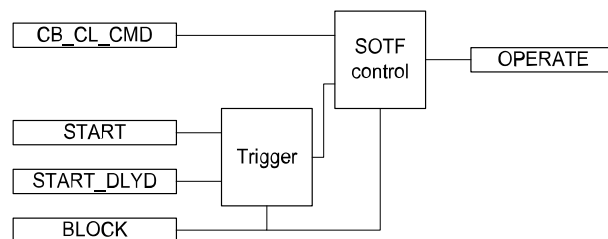


Figure 386: Functional module diagram

#### Trigger

This module is used for detecting possible fault immediately after closing the circuit breaker. An external protection function for example, PHxPTOC or EFxPTOC is used for fault indication. The `START` and `START_DLYD` inputs are available for feeding the detected fault.

- `START` input is used when it is required to enable SOTF control immediately after protection function indicates a fault.
- `START_DLYD` input is used when time delayed SOTF control enabling is needed. In this case, the delay can be set with a *Operate delay time* setting.

#### SOTF control

The SOTF control is activated when `CB_CL_CMD` circuit breaker closing command input is activated. The module is kept active until the set *SOTF reset time* is exceeded after the `CB_CL_CMD` is deactivated. The `OPERATE` output is activated when a fault indication signal is received from the Trigger module while the SOTF control is still active.

## 4.6.5 Application

The `CB_CL_CMD` input activates CBPSOF. In the standard configuration, the breaker close command should be connected to this input. The *SOTF reset time* setting parameter is used for keeping CBRSOFF active for a certain time after the CB close command is executed.

The overcurrent high and instantaneous signals, for example, the `PHIPTOC START` signal is connected to the function `START` input. When the SOTF control module is active and the `START` input is activated, the function operates instantaneously without any delays.

The overcurrent low stage signals, for example, `PHLPTOC START` signal is connected to the function `START_DLYD` input. The setting parameter *Operate delay time* is used to delay the operation in case of inrush situation.

## 4.6.6 Signals

### 4.6.6.1 CBPSOF Input signals

Table 675: CBPSOF Input signals

| Name       | Type    | Default | Description  |
|------------|---------|---------|--|
| START      | BOOLEAN | 0=False | Start from function to be accelerated by SOTF            |
| START_DLYD | BOOLEAN | 0=False | Start from function to be accelerated with delay by SOTF |
| CB_CL_CMD  | BOOLEAN | 0=False | External enabling of SOTF by CB close command            |
| BLOCK      | BOOLEAN | 0=False | Block of function  |

### 4.6.6.2 CBPSOF Output signals

Table 676: CBPSOF Output signals

| Name    | Type    | Description |
|---------|---------|-------------|
| OPERATE | BOOLEAN | Operate     |

## 4.6.7 Settings

### 4.6.7.1 CBPSOF Settings

**Table 677: CBPSOF Group settings (Basic)**

| Parameter          | Values (Range) | Unit | Step | Default | Description                |
|--------------------|----------------|------|------|---------|----------------------------|
| Operate delay time | 0...60000      | ms   | 1    | 0       | Time delay for start input |

**Table 678: CBPSOF Group settings (Advanced)**

| Parameter       | Values (Range) | Unit | Step | Default | Description                                |
|-----------------|----------------|------|------|---------|--|
| SOTF reset time | 0...60000      | ms   | 1    | 1000    | SOTF detection period after initialization |

**Table 679: CBPSOF Non group settings (Basic)**

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

## 4.6.8 Monitored data

### 4.6.8.1 CBPSOF Monitored data

**Table 680: CBPSOF Monitored data**

| Name   | Type | Values (Range)   | Unit | Description |
|--------|------|--|------|-------------|
| CBPSOF | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status      |

## 4.6.9 Technical data

**Table 681: CBPSOF Technical data**

| Characteristic        | Value                            |
|-----------------------|----------------------------------|
| Operate time accuracy | ±1.0% of the set value or ±20 ms |

## 4.7 Load blinder LBRDOB

### 4.7.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE identification |
|----------------------|--------------------------|--------------------------|--------------------------|
| Load blinder         | LBRDOB                   | LB                       | 21LB                     |

### 4.7.2 Function block



Figure 387: Function block

### 4.7.3 Functionality

Load blinder, or Load encroachment, function LBRDOB is used to block the directional overcurrent protection aiming at avoiding incorrect trip in case of heavy loading condition in network whose power factor close to 1.00.

Operation principle is based on calculated positive sequence impedance. Function provides blocking signal if positive sequence impedance is in load blinder forward or reverse area.

### 4.7.4 Operation principle

The *Operation* setting is used to enable or disable the function. When selected "On" the function is enabled and respectively "Off" means function is disabled.

The operation of Load blinder LBRDOB can be described by using a module diagram (see [Figure 388](#)). All the modules in the diagram are explained in the next sections.

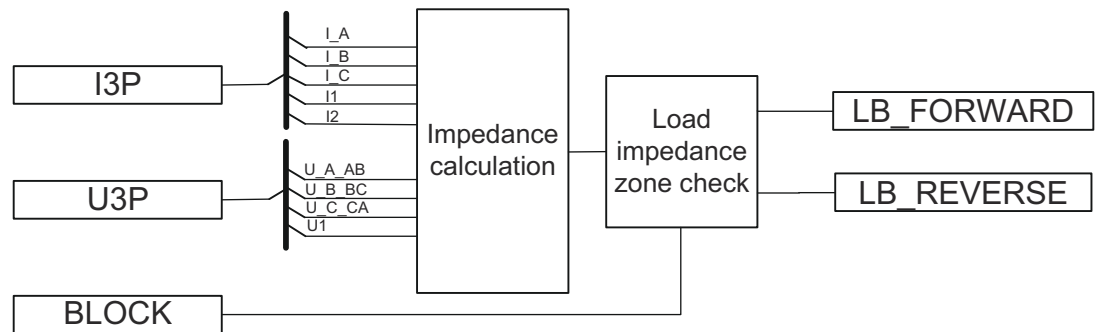


Figure 388: Functional module diagram

### Impedance calculation

The impedance calculation is enabled if the negative sequence current stays below the *Max Ng Seq current* setting and the positive sequence voltage stays above the *Min Ps Seq voltage* setting.

The positive sequence impedance phasor  $\bar{Z}_1$  is calculated according to:

$$\bar{Z}_1 = \frac{\bar{U}_1}{\bar{I}_1}$$

(Equation 59)

where  $\bar{U}_1$  is positive sequence voltage phasor and  $\bar{I}_1$  is positive sequence current phasor.

The calculated positive sequence impedance amplitude  $Z1\_AMPL$  (primary ohms) and angle  $Z1\_ANGLE$  (degrees) are available in monitored data view.

The calculated impedance is converted to primary ohms as the operating characteristics are defined with settings in primary ohms.

### Load impedance zone check

The forward and reverse load blinder sectors are defined separately. The load blinder forward area, or load-out region, or load exporting is limited with the *Max impedance angle* and *Min impedance angle*. Similarly, these two setting parameters are also as limitations for the load blinder reverse area, or load-in region, or load importing. the *Resistive reach Fw* is maximum resistive load on forward load blinder area. *Resistive reach Rv* is maximum resistive load on reverse load blinder area. Characteristics are shown [Figure 389](#).

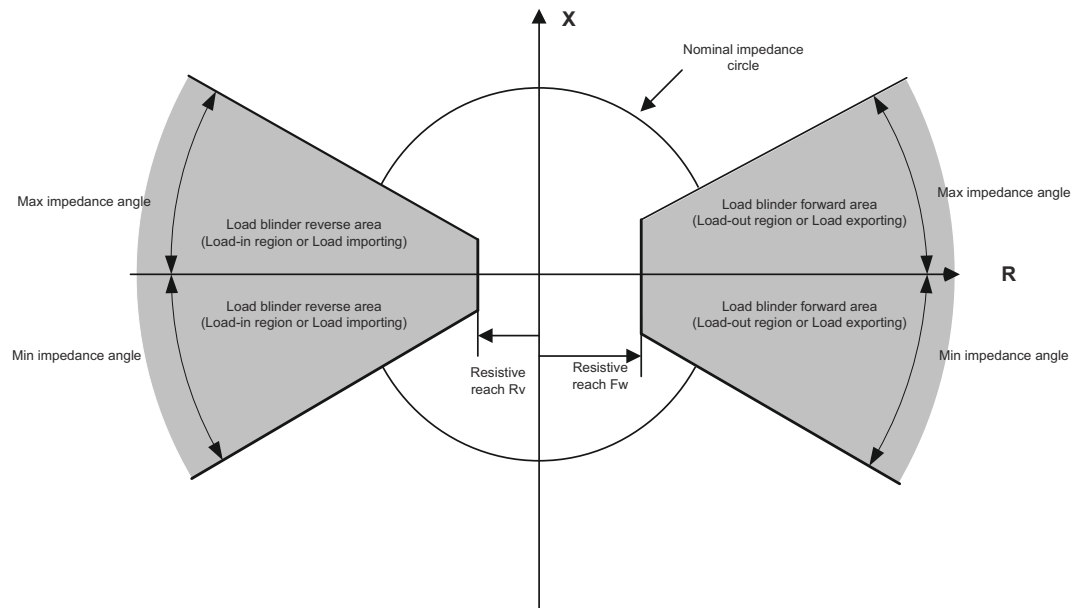


Figure 389: Operating sectors for load blinder

The blinder directional operation can be selected with the *Directional mode* setting. The alternatives are "Non-directional", "Forward" and "Reverse" operation.

Forward operation is allowed if *Directional mode* is set to "Forward". If the resistive part value of positive sequence impedance is higher than *Resistive reach Fw* and the angle of positive sequence impedance stays in the range limited with the *Max impedance angle* and *Min impedance angle* on forward area, the function output `LB_FORWARD` is activated.

Reverse operation is allowed if *Directional mode* is set to "Reverse". If the resistive part value of positive sequence impedance exceeds the limitation of *Resistive reach Rv* and the angle of positive sequence impedance stays in the range limited with the *Max impedance angle* and *Min impedance angle* on reverse area, the function output `LB_REVERSE` is activated.

In case *Directional mode* is set to "Non-directional", operation is allowed both directions according to conditions described above.

Activation of the `BLOCK` input deactivates the function outputs.

## 4.7.5 Application

Load blinder or load encroachment, function `LBRDOB` is used to block the directional overcurrent protection aiming at avoiding incorrect trip in case of heavy loading condition in network. In general, the active power increases to the level leading to a high power factor, the network turns into heavy load status, and there exists risk of incorrect trip for the directional overcurrent protection because of high level of load current.

The suitability of *Resistive reach Fw* and *Resistive reach Rv* settings will influence the activation of load blinder function. If *Resistive reach Fw* and *Resistive reach Rv* are set beyond the network minimal resistive load, the function will be not activated in the case that the load impedance approaches the network minimal impedance load. Hence, the absolute values of *Resistive reach Fw* and *Resistive reach Rv* should be set less than that of the minimal resistive load.



The blinder in forward direction, *Resistive reach Fw*, can be calculated according to

$$\text{Resistive reach } Fw = K \cdot \frac{U_{\text{expmin}}^2}{P_{\text{expmax}}}$$

(Equation 60)

where:

- $P_{\text{expmax}}$  is the maximum exporting active power
- $U_{\text{expmin}}$  is minimum phase-to-phase voltage when the exporting active power occurs
- $K$  is a security factor to ensure that the setting of *Resistive reach Fw* less than minimal resistive load, with a recommended value 0.8.

The resistive boundary *Resistive reach Rv* can be obtained in the same way as *Resistive reach Fw*, but replace the maximum exporting active power  $P_{\text{expmax}}$  and the corresponding voltage  $U_{\text{expmin}}$  with the maximum importing active power  $P_{\text{impmax}}$  and the corresponding voltage  $U_{\text{impmin}}$ .

The *Max impedance angle* and *Min impedance angle* are symmetric in forward and reverse direction, these values are recommended to set the maximum possible load angle when load active power arrives at top. A value bigger than 20° must be used.

## 4.7.6 Signals

### 4.7.6.1 LBRDOB Input signals

Table 682: LBRDOB Input signals

| Name  | Type            | Default | Description            |
|-------|-----------------|---------|------------------------|
| I3P   | GROUP<br>SIGNAL | 0.0     | Three phase currents   |
| U3P   | GROUP<br>SIGNAL | 0.0     | Three phase voltages   |
| BLOCK | BOOLEAN         | FALSE   | Block overall function |

### 4.7.6.2 LBRDOB Output signals

Table 683: LBRDOB Output signals

| Name       | Type    | Description                       |
|------------|---------|-----------------------------------|
| LB_FORWARD | BOOLEAN | Forward direction of load blinder |
| LB_REVERSE | BOOLEAN | Reverse direction of load blinder |

## 4.7.7 Settings

### 4.7.7.1 LBRDOB Settings

Table 684: LBRDOB Group settings (basic)

| Parameter          | Values (Range) | Unit | Step | Default | Description   |
|--------------------|----------------|------|------|---------|---|
| Resistive reach Fw | 1.00...6000.00 | Ohm  | 0.01 | 150     | Maximum resistive load on forward load blinder area |
| Resistive reach Rv | 1.00...6000.00 | Ohm  | 0.01 | 150     | Maximum resistive load on reverse load blinder area |

*Table continues on the next page*

| Parameter           | Values (Range)                                 | Unit | Step | Default     | Description                       |
|---------------------|--|------|------|-------------|-----------------------------------|
| Max impedance angle | 5...85   | Deg  | 1    | 25          | Maximum load blinder sector angle |
| Min impedance angle | -85...-5                                       | Deg  | 1    | -25         | Minimum load blinder sector angle |
| Directional mode    | 1= Non-directional<br>2= Forward<br>3= Reverse |      |      | 2 = Forward | Directional mode                  |

**Table 685: LBRDOB Non-group settings (Basic)**

| Parameter | Values (Range)    | Unit | Default | Description        |
|-----------|-------------------|------|---------|--------------------|
| Operation | 1 = on<br>5 = off | -    | 1 = on  | Operation Off / On |

**Table 686: LBRDOB Non-group settings (Advanced)**

| Parameter          | Values (Range) | Unit | Step | Default | Description   |
|--------------------|----------------|------|------|---------|---|
| Max Ng Seq current | 0.01...10.00   | xIn  | 0.01 | 0.2     | Negative sequence current limit for disabling impedance calculation |
| Min Ps Seq voltage | 0.1...1.00     | xUn  | 0.1  | 0.1     | Positive sequence voltage limit for enabling impedance calculation  |

## 4.7.8 Monitored data

#### 4.7.8.1 LBRDOB Monitored data

Table 687: LBRDOB Monitored data

| Name     | Type    | Values (Range) | Unit | Description                             |
|----------|---------|----------------|------|---|
| Z1_AMPL  | FLOAT32 |                |      | Positive sequence impedance amplitude   |
| Z1_ANGLE | FLOAT32 |                |      | Positive sequence impedance phase angle |

#### 4.7.9 Technical data

Table 688: LBRDOB Technical Data

| Characteristic                 | Value   |
|--------------------------------|---|
| Operation accuracy             | Depending on the frequency of the current measured: $f_n$<br>Current:<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times I_n$<br>Voltage:<br>$\pm 1.5\%$ of the set value or $\pm 0.002 \times U_n$<br>Impedance accuracy:<br>$\pm 3\%$ of the set value<br>(In range load angle < 75 deg)<br>$\pm 4.5\%$ of the set value<br>(In range 75 deg < load angle < 83 deg)<br>$\pm 8\%$ of the set value<br>(In range load angle > 83 deg)<br>Phase angle: $\pm 2^\circ$ |
| Reset ratio                    | Typically 0.96  |
| Operation time <sup>1, 2</sup> | Typically 30 ms   |
| Reset time                     | Typically 25 ms   |

<sup>1</sup>  $f_n = 50\text{Hz}$ , results based on statistical distribution of 1000 measurements

<sup>2</sup> Includes the delay of the signal output contact

## 4.8 Anomaly detector ANOGAPC

### 4.8.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE identification |
|----------------------|--------------------------|--------------------------|--------------------------|
| Anomaly detector     | ANOGAPC                  | ANOGAPC                  | ANOGAPC                  |

### 4.8.2 Function block

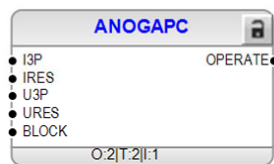


Figure 390: Function block

### 4.8.3 Functionality

The anomaly detector function ANOGAPC aims to identify atypical events, which would potentially be indicative of future performance degradation or fault occurrence. The algorithm uses raw sampled current and voltage measurements as inputs and can be configured to trigger a disturbance recording when it notices exceptional situations that can be potentially interesting.

Analysis of the disturbance recordings is not a part of this function. The disturbance recordings can be used by other applications for further offline analysis possibly in combination with data from other sources also (e.g., weather data). The analysis results can provide information on evolving faults, and information for longer term predictive maintenance activities.



The function should not be used for protection.

### 4.8.4 Operation principle

The *Operation* setting is used to enable or disable the function. When selected "On" the function is enabled and respectively "Off" means function is disabled.

#### 4.8.4.1 Analog channel configuration

ANOGAPC has four analog group inputs which must be properly configured.

**Table 689: Analog inputs**

| Input              | Description          |
|--------------------|----------------------|
| I3P <sup>94</sup>  | Three-phase currents |
| IRES <sup>94</sup> | Residual current     |
| U3P <sup>94</sup>  | Three-phase voltages |
| URES <sup>94</sup> | Residual voltage     |

At least one analog channel must always be connected. Improper analog channel configuration causes a validation error.

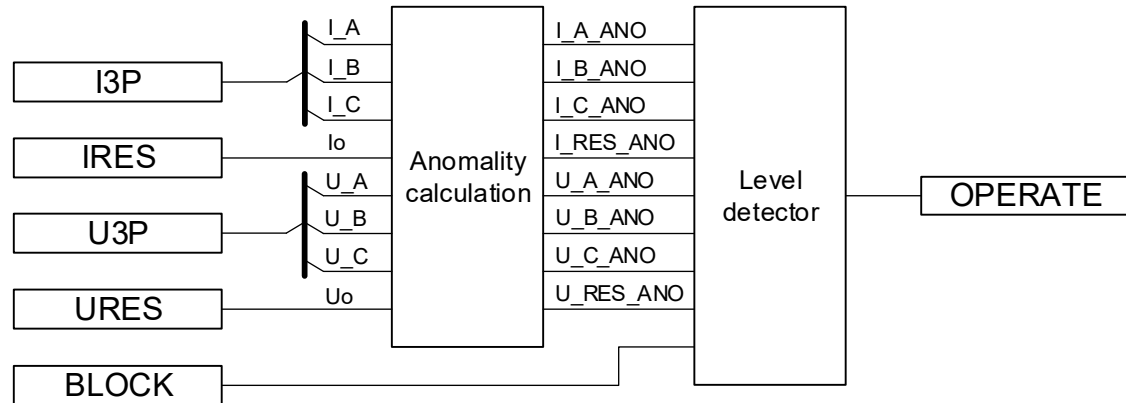


Figure 391: Functional module diagram

#### 4.8.4.2 Anomaly calculation

This module continuously calculates an anomaly indicator separately for each connected channel, which is used to identify events or anomalies on the measured channel. The algorithm compares the measured signal with a reconstructed signal according to:

$$anomaly\ indicator = \sqrt{\sum_i^n (x_i - \tilde{x}_i)^2}$$

(Equation 61)

where:

- $x$  one cycle of the input signal
- $\tilde{x}$  one cycle of the reconstructed signal

<sup>94</sup> Can be connected to GRPOFF if channel is not in use.

The total window size length for the anomaly detector algorithm is determined by the parameter *Detection window* size multiplied by the fundamental cycle time.

E.g., for a 50 Hz nominal frequency signal the fundamental cycle time is 20 ms.

#### 4.8.4.3 Level detector

This module compares the calculated anomaly indicator value against the measurement channel specific setting value as explained in table.

**Table 690: Channel table**

| Calculated anomaly indicator value | Setting value       | Operate signal in monitored data |
|------------------------------------|---------------------|----------------------------------|
| I_A_ANO                            | Anomaly level A     | OPR_I_A                          |
| I_B_ANO                            | Anomaly level A     | OPR_I_B                          |
| I_C_ANO                            | Anomaly level A     | OPR_I_C                          |
| I_RES_ANO                          | Anomaly level Res A | OPR_I_RES                        |
| U_A_ANO                            | Anomaly level PhV   | OPR_U_A                          |
| U_B_ANO                            | Anomaly level PhV   | OPR_U_B                          |
| U_C_ANO                            | Anomaly level PhV   | OPR_U_C                          |
| U_RES_ANO                          | Anomaly level Res V | OPR_U_RES                        |

If the anomaly indicator exceeds the set operate level of the latest to mean anomaly ratio, the common `OPERATE` output is activated. The specific channel and phase wise operates can be seen from the monitored data view.

When `OPERATE` output is activated, it is kept active until the set detection window size time has elapsed. The `OPERATE` output can be used as rising edge triggering for the disturbance recorder.

Activation of `BLOCK` input disables the Level detector, and forces common `OPERATE` output and measurement channel specific operate signals in monitored data into `FALSE` state.

#### 4.8.5 Application

ANOGAPC is intended to detect abnormal behavior in distribution network by monitoring the measured currents and voltages. The intention is that ANOGAPC would trig the disturbance recorder before the real fault is even detected by any other protection function. After ANOGAPC has indicated the anomalous events in the measured data, these recorded occurrences can be used to create more refined analysis of the electrical network equipment status. The refined analysis might mean for example artificial intelligence algorithms predicting future fault conditions.

## 4.8.6 Signals

### 4.8.6.1 ANOGAPC Input signals

Table 691: ANOGAPC Input signals

| Name  | Type   | Default | Description                                   |
|-------|--------|---------|---|
| I3P   | Signal | 0       | Three phase current                           |
| IRES  | Signal | 0       | Residual current                              |
| U3P   | Signal | 0       | Three phase voltage                           |
| URES  | Signal | 0       | Residual voltage                              |
| BLOCK | BOOL   | FALSE   | Block signal for activating the blocking mode |

### 4.8.6.2 ANOGAPC Output signals

Table 692: ANOGAPC Output signals

| Name    | Type | Description |
|---------|------|-------------|
| OPERATE | BOOL | Operate     |

## 4.8.7 Settings

### 4.8.7.1 ANOGAPC Settings

Table 693: ANOGAPC Non-group settings (Basic)

| Name                  | Values (Range)    | Unit | Default | Description   |
|-----------------------|-------------------|------|---------|---|
| Operation             | 1 = on<br>5 = off | -    | 1 = on  | Operation Off / On  |
| Detection window size | 1 ... 10000       | -    | 50      | Sliding window size in fundamental cycles for anomaly detection |
| Anomaly level PhV     | 101 ... 10000     | -    | 200     | Operate level of the latest to mean anomaly ratio for PhV       |

*Table continues on the next page*



| Name                | Values (Range) | Unit | Default | Description   |
|---------------------|----------------|------|---------|---|
| Anomaly level Res V | 101 ... 10000  | -    | 200     | Operate level of the latest to mean anomaly ratio for Res V |
| Anomaly level A     | 101 ... 10000  | -    | 200     | Operate level of the latest to mean anomaly ratio for A     |
| Anomaly level Res A | 101 ... 10000  | -    | 200     | Operate level of the latest to mean anomaly ratio for Res A |

## 4.8.8 Monitored data

### 4.8.8.1 ANOGAPC Monitored data

Table 694: ANOGAPC Monitored data

| IEC name  | Type | Description                 |
|-----------|------|-----------------------------|
| OPR_I_A   | BOOL | Anomaly in current phase 1  |
| OPR_I_B   | BOOL | Anomaly in current phase 2  |
| OPR_I_C   | BOOL | Anomaly in current phase 3  |
| OPR_I_RES | BOOL | Anomaly in current residual |
| OPR_U_A   | BOOL | Anomaly in voltage phase 1  |
| OPR_U_B   | BOOL | Anomaly in voltage phase 2  |
| OPR_U_C   | BOOL | Anomaly in voltage phase 3  |
| OPR_U_RES | BOOL | Anomaly in voltage residual |

## 5 Supervision functions

### 5.1 Runtime counter for machines and devices MDSOPT

#### 5.1.1 Identification

| Function description                     | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--|--------------------------|--------------------------|-------------------------------|
| Runtime counter for machines and devices | MDSOPT                   | OPTS                     | OPTM                          |

#### 5.1.2 Function block

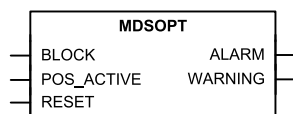


Figure 392: Function block

#### 5.1.3 Functionality

The runtime counter for machines and devices function MDSOPT calculates and presents the accumulated operation time of a machine or device as the output. The unit of time for accumulation is hour. The function generates a warning and an alarm when the accumulated operation time exceeds the set limits. It utilizes a binary input to indicate the active operation condition.

The accumulated operation time is one of the parameters for scheduling a service on the equipment like motors. It indicates the use of the machine and hence the mechanical wear and tear. Generally, the equipment manufacturers provide a maintenance schedule based on the number of hours of service.

#### 5.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of MDSOPT can be described using a module diagram. All the modules in the diagram are explained in the next sections.

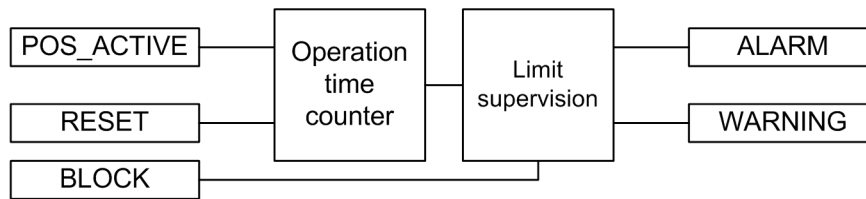


Figure 393: Functional module diagram

### Operation time counter

This module counts the operation time. When `POS_ACTIVE` is active, the count is continuously added to the time duration until it is deactivated. At any time the `OPR_TIME` output is the total duration for which `POS_ACTIVE` is active. The unit of time duration count for `OPR_TIME` is hour. The value is available through the Monitored data view.

The `OPR_TIME` output is a continuously increasing value and it is stored in a non-volatile memory. When `POS_ACTIVE` is active, the `OPR_TIME` count starts increasing from the previous value. The count of `OPR_TIME` saturates at the final value of 299999, that is, no further increment is possible. The activation of `RESET` can reset the count to the *Initial value* setting.

### Limit Supervision

This module compares the motor run-time count to the set values of *Warning value* and *Alarm value* to generate the `WARNING` and `ALARM` outputs respectively when the counts exceed the levels.

The activation of the `WARNING` and `ALARM` outputs depends on the *Operating time mode* setting. Both `WARNING` and `ALARM` occur immediately after the conditions are met if *Operating time mode* is set to "Immediate". If *Operating time mode* is set to "Timed Warn", `WARNING` is activated within the next 24 hours at the time of the day set using the *Operating time hour* setting. If *Operating time mode* is set to "Timed Warn Alm", the `WARNING` and `ALARM` outputs are activated at the time of day set using *Operating time hour*.



The *Operating time hour* setting is used to set the hour of day in Coordinated Universal Time (UTC). The setting has to be adjusted according to the local time and local daylight-saving time.

The function contains a blocking functionality. Activation of the `BLOCK` input blocks both `WARNING` and `ALARM`.

## 5.1.5 Application

The machine operating time since commissioning indicates the use of the machine. For example, the mechanical wear and lubrication requirement for the shaft bearing of the motors depend on the use hours.

If some motor is used for long duration runs, it might require frequent servicing, while for a motor that is not used regularly the maintenance and service are scheduled less frequently. The accumulated operating time of a motor together with the appropriate settings for warning can be utilized to trigger the condition based maintenance of the motor.

The operating time counter combined with the subsequent reset of the operating-time count can be used to monitor the motor's run time for a single run.

Both the long term accumulated operating time and the short term single run duration provide valuable information about the condition of the machine and device. The information can be co-related to other process data to provide diagnoses for the process where the machine or device is applied.

## 5.1.6 Signals

### 5.1.6.1 MDSOPT Input signals

Table 695: MDSOPT Input signals

| Name       | Type    | Default | Description  |
|------------|---------|---------|--|
| BLOCK      | BOOLEAN | 0=False | Block input status                                     |
| POS_ACTIVE | BOOLEAN | 0=False | When active indicates the equipment is running         |
| RESET      | BOOLEAN | 0=False | Resets the accumulated operation time to initial value |

### 5.1.6.2 MDSOPT Output signals

Table 696: MDSOPT Output signals

| Name    | Type    | Description  |
|---------|---------|--|
| ALARM   | BOOLEAN | Alarm accumulated operation time exceeds Alarm value     |
| WARNING | BOOLEAN | Warning accumulated operation time exceeds Warning value |

## 5.1.7 Settings

### 5.1.7.1 MDSOPT Settings

Table 697: MDSOPT Non group settings (Basic)

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on           |      |      | 1=on    | Operation Off / On |

*Table continues on the next page*

| Parameter     | Values (Range) | Unit | Step | Default | Description                                  |
|---------------|----------------|------|------|---------|--|
|               | 5=off          |      |      |         |  |
| Warning value | 0...299999     | h    | 1    | 8000    | Warning value for operation time supervision |
| Alarm value   | 0...299999     | h    | 1    | 10000   | Alarm value for operation time supervision   |

Table 698: MDSOPT Non group settings (Advanced)

| Parameter           | Values (Range)                                  | Unit | Step | Default     | Description                                   |
|---------------------|---|------|------|-------------|---|
| Initial value       | 0...299999                                      | h    | 1    | 0           | Initial value for operation time supervision  |
| Operating time hour | 0...23  | h    | 1    | 0           | Time of day when alarm and warning will occur |
| Operating time mode | 1=Immediate<br>2=Timed Warn<br>3=Timed Warn Alm |      |      | 1=Immediate | Operating time mode for warning and alarm     |

## 5.1.8 Monitored data

### 5.1.8.1 MDSOPT Monitored data

Table 699: MDSOPT Monitored data

| Name     | Type  | Values (Range)   | Unit | Description                   |
|----------|-------|--|------|-------------------------------|
| MDSOPT   | Enum  | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                        |
| OPR_TIME | INT32 | 0...299999   | h    | Total operation time in hours |

## 5.1.9 Technical data

Table 700: MDSOPT Technical data

| Description                                      | Value |
|--|-------|
| Motor runtime measurement accuracy <sup>95</sup> | ±0.5% |

## 5.1.10 Technical revision history

Table 701: MDSOPT Technical revision history

| Technical revision | Change                |
|--------------------|-----------------------|
| B                  | Internal improvement. |
| C                  | Internal improvement. |
| D                  | Internal improvement. |

## 5.2 Fuse failure supervision SEQSPVC (ANSI VCM, 60)

### 5.2.1 Identification

| Function description     | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--------------------------|--------------------------|--------------------------|-------------------------------|
| Fuse failure supervision | SEQSPVC                  | FUSEF                    | VCM, 60                       |

### 5.2.2 Function block

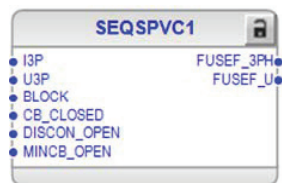


Figure 394: Function block

### 5.2.3 Functionality

The fuse failure supervision function SEQSPVC is used to block the voltagemasuring functions when failure occurs in the secondary circuits between

<sup>95</sup> Of the reading, for a stand-alone relay, without time synchronization

the voltage transformer (or combi sensor or voltage sensor) and merging unit to avoid misoperations of the voltage protection functions.

SEQSPVC has two algorithms, a negative sequence-based algorithm and a delta current and delta voltage algorithm.

A criterion based on the delta current and the delta voltage measurements can be activated to detect three-phase fuse failures which usually are more associated with the voltage transformer switching during station operations.

## 5.2.4 Analog channel configuration

SEQSPVC has two analog group inputs which all must be properly configured.

**Table 702: Analog inputs**

| Input | Description          |
|-------|----------------------|
| I3P   | Three-phase currents |
| U3P   | Three-phase voltages |



See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

**Table 703: Special conditions**

| Condition                          | Description  |
|------------------------------------|--|
| U3P connected to real measurements | The function can work with any two voltage channels connected but it is recommended to connect all three voltage channels. |

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

## 5.2.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of SEQSPVC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

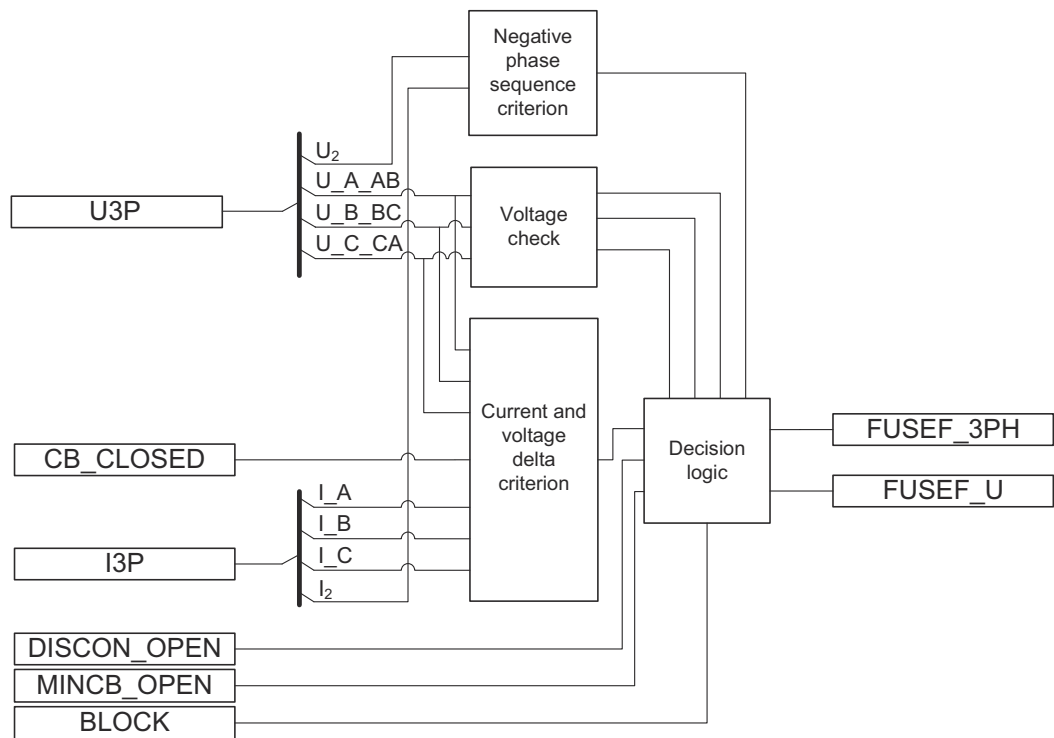


Figure 395: Functional module diagram

### Negative phase-sequence criterion

A fuse failure based on the negative-sequence criterion is detected if the measured negative-sequence voltage exceeds the set *Neg Seq voltage Lev* value and the measured negative-sequence current is below the set *Neg Seq current Lev* value. The detected fuse failure is reported to the decision logic module.

### Voltage check

The phase voltage magnitude is checked when deciding whether the fuse failure is a three, two or a single-phase fault.

The module makes a phase-specific comparison between each voltage input and the *Seal in voltage* setting. If the input voltage is lower than the setting, the corresponding phase is reported to the decision logic module.

### Current and voltage delta criterion

The delta function can be activated by setting the *Change rate enable* parameter to "True". Once the function is activated, it operates in parallel with the negative sequence-based algorithm. The current and voltage are continuously measured in all three phases to calculate:

- Change of voltage  $dU/dt$
- Change of current  $dI/dt$

The calculated delta quantities are compared to the respective set values of the *Current change rate* and *Voltage change rate* settings.

The delta current and delta voltage algorithms detect a fuse failure if there is a sufficient negative change in the voltage amplitude without a sufficient change in



the current amplitude in each phase separately. This is performed when the circuit breaker is closed. Information about the circuit breaker position is connected to the `CB_CLOSED` input.

There are two conditions for activating the current and voltage delta function.

- The magnitude of  $dU/dt$  exceeds the corresponding value of the *Voltage change rate* setting and magnitude of  $dI/dt$  is below the value of the *Current change rate* setting in any phase at the same time due to the closure of the circuit breaker (`CB_CLOSED = TRUE`).
- The magnitude of  $dU/dt$  exceeds the value of the *Voltage change rate* setting and the magnitude of  $dI/dt$  is below the *Current change rate* setting in any phase at the same time and the magnitude of the phase current in the same phase exceeds the *Min Op current delta* setting.

The first condition requires the delta criterion to be fulfilled in any phase at the same time as the circuit breaker is closed. Opening the circuit breaker at one end and energizing the line from the other end onto a fault could lead to an improper operation of SEQSPVC with an open breaker. If this is considered to be an important disadvantage, the `CB_CLOSED` input is to be connected to `FALSE`. In this way only the second criterion can activate the delta function.

The second condition requires the delta criterion to be fulfilled in one phase together with a high current for the same phase. The measured phase current is used to reduce the risk of a false fuse failure detection. If the current on the protected line is low, a voltage drop in the system (not caused by the fuse failure) is not followed by a current change and a false fuse failure can occur. To prevent this, the minimum phase current criterion is checked.

The fuse failure detection is active until the voltages return above the *Min Op voltage delta* setting. If a voltage in a phase is below the *Min Op voltage delta* setting, a new fuse failure detection for that phase is not possible until the voltage returns above the setting value.

### Decision logic



If voltages are Wye-connected, it is recommended to scale the default values of voltage-based settings with  $1/\sqrt{3}$  because the default setting values apply for Delta-connected settings.

The fuse failure detection outputs `FUSEF_U` and `FUSEF_3PH` are controlled according to the detection criteria or external signals.

**Table 704: Fuse failure output control**

| Fuse failure detection criterion | Conditions and function response  |
|----------------------------------|---|
| Negative-sequence criterion      | If a fuse failure is detected based on the negative sequence criterion, the <code>FUSEF_U</code> output is activated.   |
|                                  | If the fuse failure detection is active for more than five seconds and at the same time all the phase voltage values are below the set value of the <i>Seal in voltage</i> setting with <i>Enable seal in</i> turned to "True", the function activates the <code>FUSE_3PH</code> output signal. |

*Table continues on the next page*

| Fuse failure detection criterion             | Conditions and function response  |
|--|---|
|  | <p>The FUSEF_U output signal is also activated if all the phase voltages are above the <i>Seal in voltage</i> setting for more than 60 seconds and at the same time the negative sequence voltage is above <i>Neg Seq voltage Lev</i> for more than 5 seconds, all the phase currents are below the <i>Current dead Lin Val</i> setting and the circuit breaker is closed, that is, CB_CLOSED is TRUE.</p>  |
| Current and voltage delta function criterion | <p>If the current and voltage delta criterion detects a fuse failure condition, but all the voltages are not below the <i>Seal in voltage</i> setting, only the FUSEF_U output is activated.</p> <p>If the fuse failure detection is active for more than five seconds and at the same time all the phase voltage values are below the set value of the <i>Seal in voltage</i> setting with <i>Enable seal in</i> turned to "True", the function activates the FUSE_3PH output signal.</p>  |
| External fuse failure detection              | <p>The MINCB_OPEN input signal is supposed to be connected through a protection relay binary input to the N.C. auxiliary contact of the miniature circuit breaker protecting the VT secondary circuit. The MINCB_OPEN signal sets the FUSEF_U output signal to block all the voltage-related functions when MCB is in the open state.</p> <p>The DISCON_OPEN input signal is supposed to be connected through a protection relay binary input to the N.C. auxiliary contact of the line disconnecter. The DISCON_OPEN signal sets the FUSEF_U output signal to block the voltage-related functions when the line disconnecter is in the open state.</p> |



It is recommended to always set *Enable seal in* to "True". This secures that the blocked protection functions remain blocked until normal voltage conditions are restored if the fuse failure has been active for 5 seconds, that is, the fuse failure outputs are deactivated when the normal voltage conditions are restored.

The activation of the BLOCK input deactivates both FUSEF\_U and FUSEF\_3PH outputs.

### 5.2.6 Application

Some protection functions operate on the basis of the measured voltage value in the protection relay point. These functions can fail if there is a fault in the measuring circuits between the voltage transformer (or combi sensor or voltage sensor) and protection relay.

A fault in the voltage-measuring circuit is called a fuse failure. This term is misleading since a blown fuse is just one of the many possible reasons for a broken circuit. Since incorrectly measured voltage can result in a faulty operation of some of the protection functions, it is important to detect the fuse failures. A fast fuse failure detection is one of the means to block voltage-based functions before they operate.

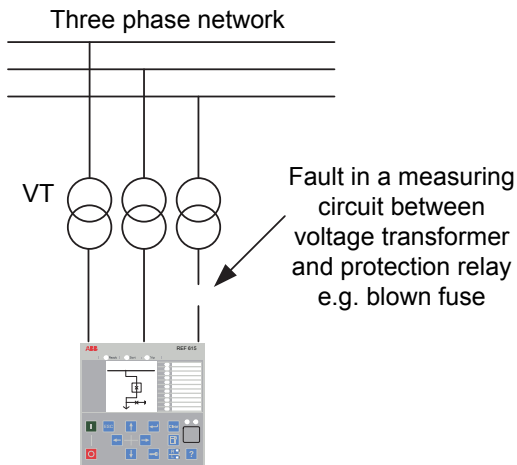


Figure 396: Fault in a circuit from the voltage transformer to the protection relay

A fuse failure occurs due to blown fuses, broken wires or intended substation operations. The negative sequence component-based function can be used to detect different types of single-phase or two-phase fuse failures. However, at least one of the three circuits from the voltage transformers must be intact. The supporting delta-based function can also detect a fuse failure due to three-phase interruptions.

In the negative sequence component-based part of the function, a fuse failure is detected by comparing the calculated value of the negative sequence component voltage to the negative sequence component current. The sequence entities are calculated from the measured current and voltage data for all three phases. The purpose of this function is to block voltage-dependent functions when a fuse failure is detected. Since the voltage dependence differs between these functions, SEQSPVC has two outputs for this purpose.

## 5.2.7 Signals

Table 705: SEQSPVC Input signals

| Name        | Type    | Default | Description  |
|-------------|---------|---------|--|
| I3P         | SIGNAL  | –       | Three-phase currents                                     |
| U3P         | SIGNAL  | –       | Three-phase voltages                                     |
| BLOCK       | BOOLEAN | 0=False | Block of function  |
| CB_CLOSED   | BOOLEAN | 0=False | Active when circuit breaker is closed                    |
| DISCON_OPEN | BOOLEAN | 0=False | Active when line disconnector is open                    |
| MINCB_OPEN  | BOOLEAN | 0=False | Active when external MCB opens protected voltage circuit |

**Table 706: SEQSPVC Output signals**

| Name      | Type    | Description                   |
|-----------|---------|-------------------------------|
| FUSEF_3PH | BOOLEAN | Three-phase start of function |
| FUSEF_U   | BOOLEAN | General start of function     |

## 5.2.8 Settings

**Table 707: SEQSPVC Non group settings (Basic)**

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On |

**Table 708: SEQSPVC Non group settings (Advanced)**

| Parameter            | Values (Range)    | Unit | Step | Default | Description  |
|----------------------|-------------------|------|------|---------|--|
| Neg Seq current Lev  | 0.03...0.20       | xIn  | 0.01 | 0.03    | Operate level of neg seq undercurrent element                |
| Neg Seq voltage Lev  | 0.03...0.20       | xUn  | 0.01 | 0.10    | Operate level of neg seq overvoltage element                 |
| Current change rate  | 0.01...0.50       | xIn  | 0.01 | 0.15    | Operate level of change in phase current                     |
| Voltage change rate  | 0.25...0.90       | xUn  | 0.01 | 0.40    | Operate level of change in phase voltage                     |
| Change rate enable   | 0=False<br>1=True |      |      | 0=False | Enabling operation of change based function                  |
| Min Op voltage delta | 0.01...1.00       | xUn  | 0.01 | 0.50    | Minimum operate level of phase voltage for delta calculation |
| Min Op current delta | 0.01...1.00       | xIn  | 0.01 | 0.10    | Minimum operate level of phase current for delta calculation |
| Seal in voltage      | 0.01...1.00       | xUn  | 0.01 | 0.50    | Operate level of seal-in phase voltage                       |
| Enable seal in       | 0=False<br>1=True |      |      | 0=False | Enabling seal in functionality                               |
| Current dead Lin Val | 0.05...1.00       | xIn  | 0.01 | 0.05    | Operate level for open phase current detection               |

## 5.2.9 Monitored data

**Table 709: SEQSPVC Monitored data**

| Name    | Type | Values (Range) | Unit | Description |
|---------|------|----------------|------|-------------|
| SEQSPVC | Enum | 1=on           |      | Status      |

| Name | Type | Values (Range)                                 | Unit | Description |
|------|------|--|------|-------------|
|      |      | 2=blocked<br>3=test<br>4=test/blocked<br>5=off |      |             |

## 5.2.10 Technical data

Table 710: SEQSPVC Technical data

| Characteristic |                | Value  |        |
|----------------|----------------|--|--------|
| Operate time   | NPS function   | $U_{\text{Fault}} = 1.1 \times \text{set } \textit{Neg Seq voltage Lev}$ | <33 ms |
|                |                | $U_{\text{Fault}} = 5.0 \times \text{set } \textit{Neg Seq voltage Lev}$ | <18 ms |
|                | Delta function | $\Delta U = 1.1 \times \text{set } \textit{Voltage change rate}$         | <30 ms |
|                |                | $\Delta U = 2.0 \times \text{set } \textit{Voltage change rate}$         | <24 ms |

<sup>1</sup> Includes the delay of the signal output contact,  $f_n = 50$  Hz, fault voltage with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements.

## 6 Condition monitoring functions

### 6.1 Circuit breaker condition monitoring SSCBR

#### 6.1.1 Identification

| Function description                 | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--------------------------------------|--------------------------|--------------------------|-------------------------------|
| Circuit-breaker condition monitoring | SSCBR                    | CBCM                     | CBCM                          |

#### 6.1.2 Function block

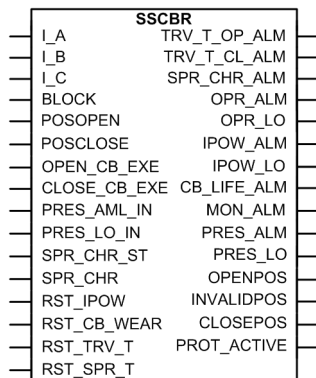


Figure 397: Function block

#### 6.1.3 Functionality

The circuit-breaker condition monitoring function SSCBR is used to monitor different parameters of the circuit breaker. The breaker requires maintenance when the number of operations has reached a predefined value. The energy is calculated from the measured input currents as a sum of  $I^2t$  values. Alarms are generated when the calculated values exceed the threshold settings.

The function contains a blocking functionality. It is possible to block the function outputs, if desired.

### 6.1.4 Operation principle

The circuit breaker condition monitoring function includes different metering and monitoring sub-functions. The functions can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “On” and “Off”. The operation counters are cleared when *Operation* is set to “Off”.

The operation of SSCBR can be described with a module diagram. All the modules in the diagram are explained in the next sections.

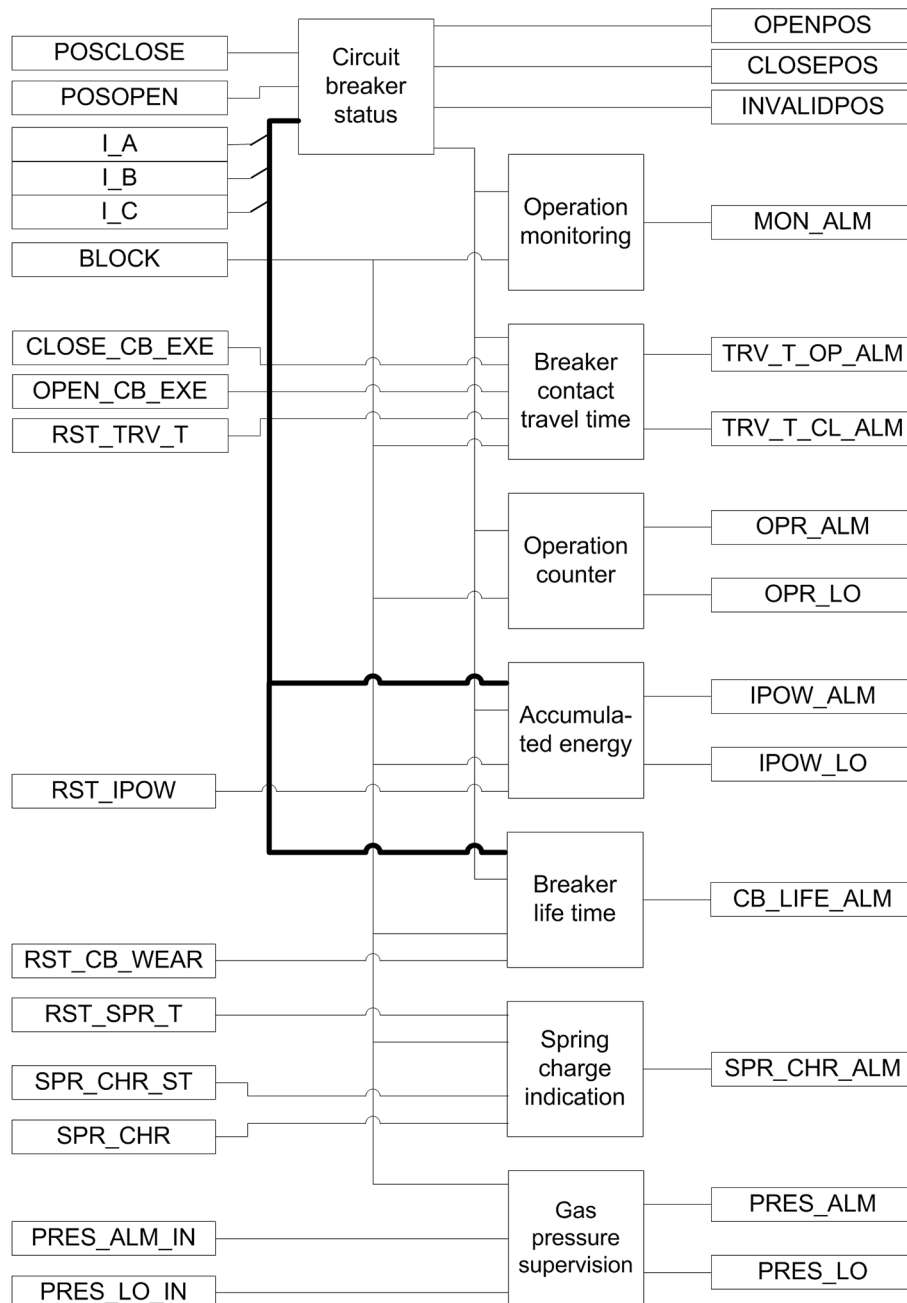


Figure 398: Functional module diagram

### 6.1.4.1 Circuit breaker status

The Circuit breaker status sub-function monitors the position of the circuit breaker, that is, whether the breaker is in open, closed or invalid position. The operation of the breaker status monitoring can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

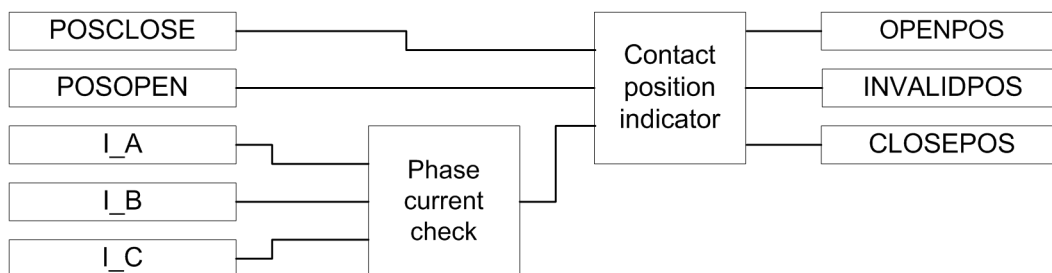


Figure 399: Functional module diagram for monitoring circuit breaker status

#### Phase current check

This module compares the three phase currents to the setting *Acc stop current*. If the current in a phase exceeds the set level, information about the phase is reported to the contact position indicator module.

#### Contact position indicator

The OPENPOS output is activated when the auxiliary input contact POSCLOSE is FALSE, the POSOPEN input is TRUE and all the phase currents are below the setting *Acc stop current*.

The CLOSEPOS output is activated when the auxiliary POSOPEN input is FALSE and the POSCLOSE input is TRUE.

The INVALIDPOS output is activated when both the auxiliary contacts have the same value, that is, both are in the same logical level, or if the auxiliary input contact POSCLOSE is FALSE and the POSOPEN input is TRUE and any of the phase currents exceed the setting *Acc stop current*.

The status of the breaker is indicated by the binary outputs OPENPOS, INVALIDPOS and CLOSEPOS for open, invalid and closed position respectively.

### 6.1.4.2 Circuit breaker operation monitoring

The purpose of the circuit breaker operation monitoring subfunction is to indicate if the circuit breaker has not been operated for a long time.

The operation of the circuit breaker operation monitoring can be described with a module diagram. All the modules in the diagram are explained in the next sections.



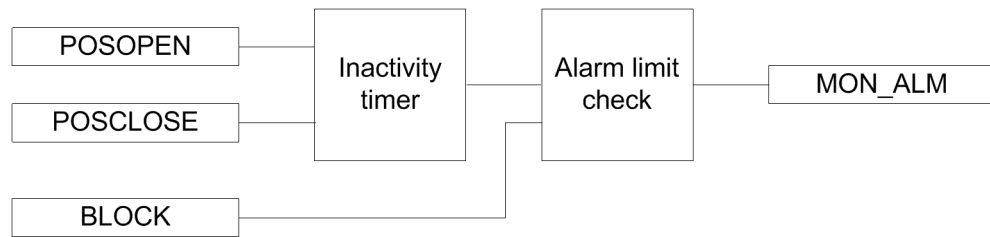


Figure 400: Functional module diagram for calculating inactive days and alarm for circuit breaker operation monitoring

### Inactivity timer

The module calculates the number of days the circuit breaker has remained inactive, that is, has stayed in the same open or closed state. The calculation is done by monitoring the states of the POSOPEN and POSCLOSE auxiliary contacts.

The inactive days `INA_DAYS` is available in the monitored data view. It is also possible to set the initial inactive days with the *Ini inactive days* parameter.

### Alarm limit check

When the inactive days exceed the limit value defined with the *Inactive Alm days* setting, the `MON_ALM` alarm is initiated. The time in hours at which this alarm is activated can be set with the *Inactive Alm hours* parameter as coordinates of UTC. The alarm signal `MON_ALM` can be blocked by activating the binary input `BLOCK`.

## 6.1.4.3

### Breaker contact travel time

The Breaker contact travel time module calculates the breaker contact travel time for the closing and opening operation. The operation of the breaker contact travel time measurement can be described with a module diagram. All the modules in the diagram are explained in the next sections.

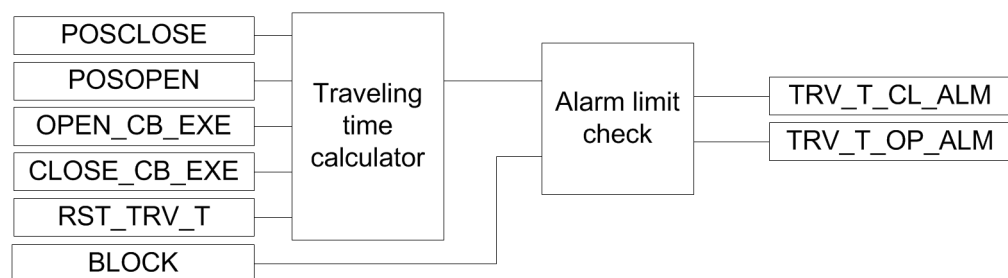


Figure 401: Functional module diagram for breaker contact travel time

### Traveling time calculator

The travel time can be calculated using two different methods based on the setting *Travel time Clc mode*.

When the setting *Travel time Clc mode* is “From Pos to Pos”, the contact travel time of the breaker is calculated from the time between auxiliary contacts' state change. The opening travel time is measured between the opening of the POSCLOSE auxiliary contact and the closing of the POSOPEN auxiliary contact. The travel time is also

measured between the opening of the POSOPEN auxiliary contact and the closing of the POSCLOSE auxiliary contact.

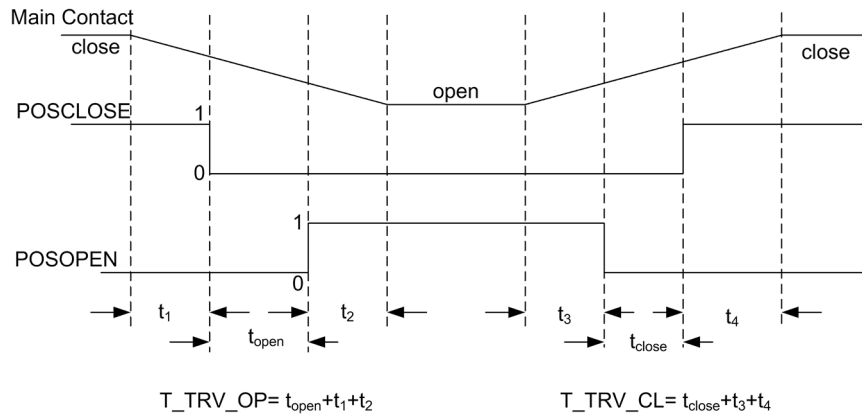


Figure 402: Travel time calculation when Travel time Clc mode is “From Pos to Pos”

There is a time difference  $t_1$  between the start of the main contact opening and the opening of the POSCLOSE auxiliary contact. Similarly, there is a time gap  $t_2$  between the time when the POSOPEN auxiliary contact opens and the main contact is completely open. To incorporate the time  $t_1 + t_2$ , a correction factor needs to be added with  $t_{open}$  to get the actual opening time. This factor is added with the *Opening time Cor* ( $= t_1 + t_2$ ) setting. The closing time is calculated by adding the value set with the *Closing time Cor* ( $t_3 + t_4$ ) setting to the measured closing time.

When the setting *Travel time Clc mode* is “From Cmd to Pos”, the contact travel time of the breaker is calculated from the time between the circuit breaker opening or closing command and the auxiliary contacts’ state change. The opening travel time is measured between the rising edge of the OPEN\_CB\_EXE command and the POSOPEN auxiliary contact. The closing travel time is measured between the rising edge of the CLOSE\_CB\_EXE command and the POSCLOSE auxiliary contact.

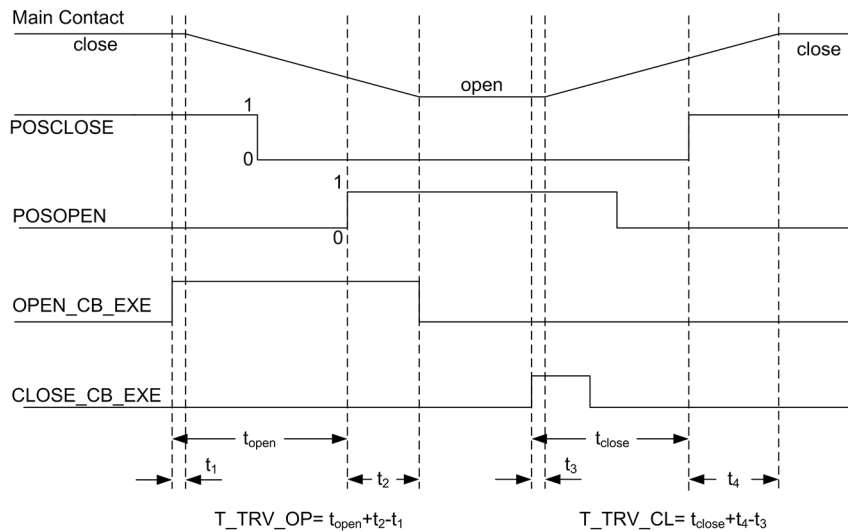


Figure 403: Travel time calculation when Travel time Clc mode is “From Cmd to Pos”

There is a time difference  $t_1$  between the start of the main contact opening and the OPEN\_CB\_EXE command. Similarly, there is a time gap  $t_2$  between the time

when the `POSOPEN` auxiliary contact opens and the main contact is completely open. Therefore, to incorporate the times  $t_1$  and  $t_2$ , a correction factor needs to be added with  $t_{open}$  to get the actual opening time. This factor is added with the *Opening time Cor* ( $= t_2 - t_1$ ) setting. The closing time is calculated by adding the value set with the *Closing time Cor* ( $t_4 - t_3$ ) setting to the measured closing time.

The last measured opening travel time `T_TRV_OP` and the closing travel time `T_TRV_CL` are available in the monitored data view on the WHMI or through tools via communications.

#### Alarm limit check

When the measured opening travel time is longer than the value set with the *Open alarm time* setting, the `TRV_T_OP_ALM` output is activated. Respectively, when the measured closing travel time is longer than the value set with the *Close alarm time* setting, the `TRV_T_CL_ALM` output is activated.

It is also possible to block the `TRV_T_CL_ALM` and `TRV_T_OP_ALM` alarm signals by activating the `BLOCK` input.

### 6.1.4.4 Operation counter

The operation counter subfunction calculates the number of breaker operation cycles. The opening and closing operations are both included in one operation cycle. The operation counter value is updated after each opening operation.

The operation of the subfunction can be described with a module diagram. All the modules in the diagram are explained in the next sections.

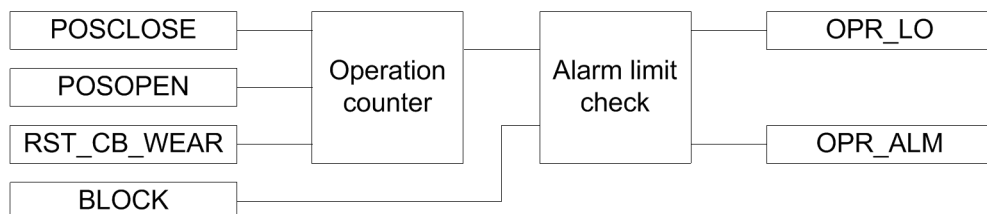


Figure 404: Functional module diagram for counting circuit breaker operations

#### Operation counter

The operation counter counts the number of operations based on the state change of the binary auxiliary contacts inputs `POSCLOSE` and `POSOPEN`.

The number of operations `NO_OPR` is available in the monitored data view on the WHMI or through tools via communications. The old circuit breaker operation counter value can be taken into use by writing the value to the *Counter initial Val* parameter and by setting the parameter *CB wear values* in the clear menu from WHMI.

#### Alarm limit check

The `OPR_ALM` operation alarm is generated when the number of operations exceeds the value set with the *Alarm Op number* threshold setting. However, if the number of operations increases further and exceeds the limit value set with the *Lockout Op number* setting, the `OPR_LO` output is activated.

The binary outputs `OPR_LO` and `OPR_ALM` are deactivated when the `BLOCK` input is activated.

### 6.1.4.5 Accumulation of Iyt

Accumulation of the Iyt module calculates the accumulated energy.

The operation of the module can be described with a module diagram. All the modules in the diagram are explained in the next sections.

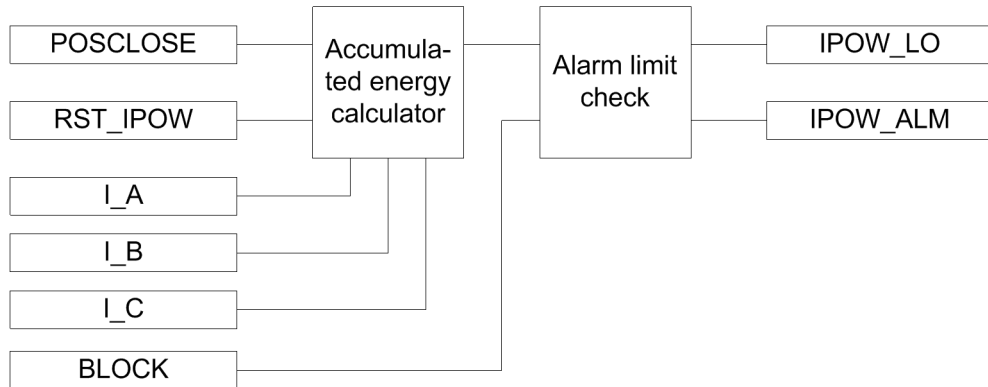


Figure 405: Functional module diagram for calculating accumulative energy and alarm

#### Accumulated energy calculator

This module calculates the accumulated energy  $I^y t$  [(kA)<sup>y</sup>s]. The factor  $y$  is set with the *Current exponent* setting.

The calculation is initiated with the `POSCLOSE` input opening events. It ends when the RMS current becomes lower than the *Acc stop current* setting value.

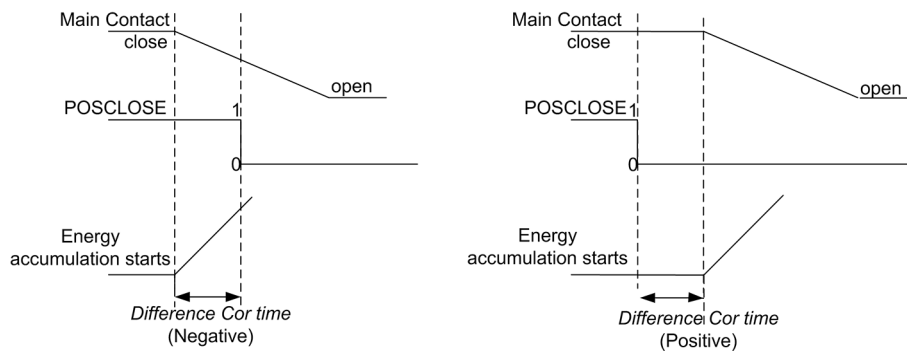


Figure 406: Significance of the Difference Cor time setting

The *Difference Cor time* setting is used instead of the auxiliary contact to accumulate the energy from the time the main contact opens. If the setting is positive, the calculation of energy starts after the auxiliary contact has opened and when the delay is equal to the value set with the *Difference Cor time* setting. When the setting is negative, the calculation starts in advance by the correction time before the auxiliary contact opens.

The accumulated energy outputs  $I_{POW\_A}$  ( $_B$ ,  $_C$ ) are available in the monitored data view on the WHMI or through tools via communications. The values can be reset by setting the parameter *CB accum. currents power* setting to true in the clear menu from WHMI.

#### Alarm limit check

The  $I_{POW\_ALM}$  alarm is activated when the accumulated energy exceeds the value set with the *Alm Acc currents Pwr* threshold setting. However, when the energy exceeds the limit value set with the *LO Acc currents Pwr* threshold setting, the  $I_{POW\_LO}$  output is activated.

The  $I_{POW\_ALM}$  and  $I_{POW\_LO}$  outputs can be blocked by activating the binary input BLOCK.

### 6.1.4.6 Remaining life of circuit breaker

Every time the breaker operates, the life of the circuit breaker reduces due to wearing. The wearing in the breaker depends on the tripping current, and the remaining life of the breaker is estimated from the circuit breaker trip curve provided by the manufacturer. The remaining life is decremented at least with one when the circuit breaker is opened.

The operation of the remaining life of the circuit breaker subfunction can be described with a module diagram. All the modules in the diagram are explained in the next sections.

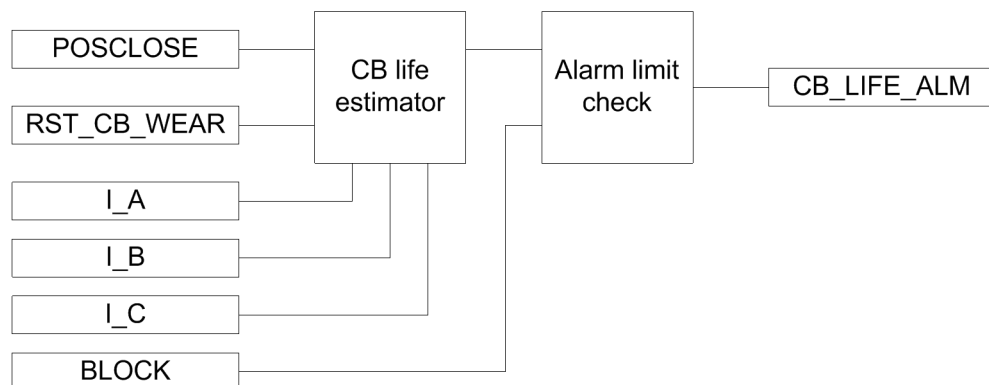


Figure 407: Functional module diagram for estimating the life of the circuit breaker

#### Circuit breaker life estimator

The circuit breaker life estimator module calculates the remaining life of the circuit breaker. If the tripping current is less than the rated operating current set with the *Rated Op current* setting, the remaining operation of the breaker reduces by one operation. If the tripping current is more than the rated fault current set with the *Rated fault current* setting, the possible operations are zero. The remaining life of the tripping current in between these two values is calculated based on the trip curve given by the manufacturer. The *Op number rated* and *Op number fault* parameters set the number of operations the breaker can perform at the rated current and at the rated fault current, respectively.

The remaining life is calculated separately for all three phases and it is available as a monitored data value `CB_LIFE_A` (`_B`, `_C`). The values can be cleared by setting the parameter *CB wear values* in the clear menu from WHMI.



Clearing *CB wear values* also resets the operation counter.

#### Alarm limit check

When the remaining life of any phase drops below the *Life alarm level* threshold setting, the corresponding circuit breaker life alarm `CB_LIFE_ALM` is activated.

It is possible to deactivate the `CB_LIFE_ALM` alarm signal by activating the binary input `BLOCK`. The old circuit breaker operation counter value can be taken into use by writing the value to the *Initial CB Rmn life* parameter and resetting the value via the clear menu from WHMI.

### 6.1.4.7 Circuit breaker spring-charged indication

The circuit breaker spring-charged indication subfunction calculates the spring charging time.

The operation of the subfunction can be described with a module diagram. All the modules in the diagram are explained in the next sections.

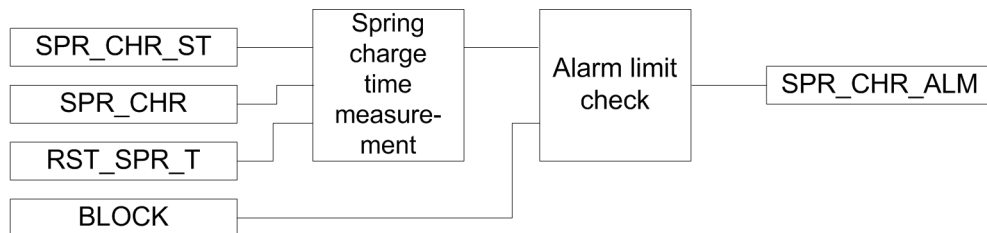


Figure 408: Functional module diagram for circuit breaker spring-charged indication and alarm

#### Spring charge time measurement

Two binary inputs, `SPR_CHR_ST` and `SPR_CHR`, indicate spring charging started and spring charged, respectively. The spring-charging time is calculated from the difference of these two signal timings.

The spring charging time `T_SPR_CHR` is available in the monitored data view on the WHMI or through tools via communications.

#### Alarm limit check

If the time taken by the spring to charge is more than the value set with the *Spring charge time* setting, the subfunction generates the `SPR_CHR_ALM` alarm.

It is possible to block the `SPR_CHR_ALM` alarm signal by activating the `BLOCK` binary input.

### 6.1.4.8 Gas pressure supervision

The gas pressure supervision subfunction monitors the gas pressure inside the arc chamber.

The operation of the subfunction can be described with a module diagram. All the modules in the diagram are explained in the next sections.

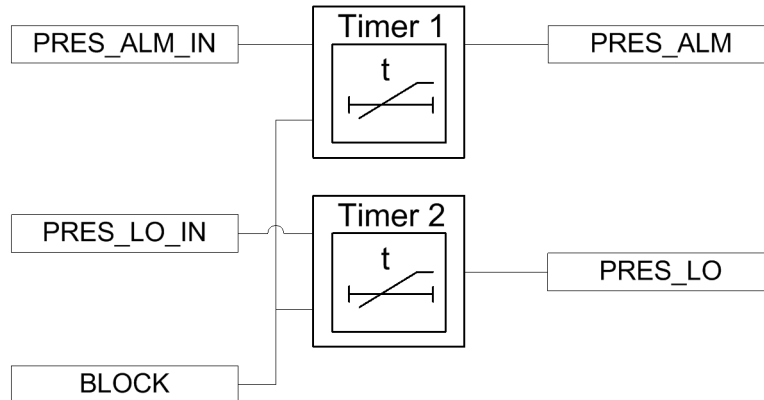


Figure 409: Functional module diagram for circuit breaker gas pressure alarm

The gas pressure is monitored through the binary input signals `PRES_LO_IN` and `PRES_ALM_IN`.

#### Timer 1

When the `PRES_ALM_IN` binary input is activated, the `PRES_ALM` alarm is activated after a time delay set with the *Pressure alarm time* setting. The `PRES_ALM` alarm can be blocked by activating the `BLOCK` input.

#### Timer 2

If the pressure drops further to a very low level, the `PRES_LO_IN` binary input becomes high, activating the lockout alarm `PRES_LO` after a time delay set with the *Pres lockout time* setting. The `PRES_LO` alarm can be blocked by activating the `BLOCK` input.

### 6.1.5 Application

SSCBR includes different metering and monitoring subfunctions.

#### Circuit breaker status

Circuit breaker status monitors the position of the circuit breaker, that is, whether the breaker is in an open, closed or intermediate position.

#### Circuit breaker operation monitoring

The purpose of the circuit breaker operation monitoring is to indicate that the circuit breaker has not been operated for a long time. The function calculates the number of days the circuit breaker has remained inactive, that is, has stayed in the same open or closed state. There is also the possibility to set an initial inactive day.

**Breaker contact travel time**

High traveling times indicate the need for the maintenance of the circuit breaker mechanism. Therefore, detecting excessive traveling time is needed. During the opening cycle operation, the main contact starts opening. The auxiliary contact A opens, the auxiliary contact B closes and the main contact reaches its opening position. During the closing cycle, the first main contact starts closing. The auxiliary contact B opens, the auxiliary contact A closes and the main contact reaches its closed position. The travel times are calculated based on the state changes of the auxiliary contacts and the adding correction factor to consider the time difference of the main contact's and the auxiliary contact's position change.

**Operation counter**

Routine maintenance of the breaker, such as lubricating breaker mechanism, is generally based on a number of operations. A suitable threshold setting to raise an alarm when the number of operation cycle exceeds the set limit helps preventive maintenance. This can also be used to indicate the requirement for oil sampling for dielectric testing in case of an oil circuit breaker.

The change of state can be detected from the binary input of the auxiliary contact. There is a possibility to set an initial value for the counter which can be used to initialize this functionality after a period of operation or in case of refurbished primary equipment.

**Accumulation of  $I^y t$** 

Accumulation of  $I^y t$  calculates the accumulated energy  $\Sigma I^y t$ , where the factor  $y$  is known as the current exponent. The factor  $y$  depends on the type of the circuit breaker. For oil circuit breakers, the factor  $y$  is normally 2. In case of a high-voltage system, the factor  $y$  can be 1.4...1.5.

**Remaining life of the breaker**

Every time the breaker operates, the life of the circuit breaker reduces due to wearing. The wearing in the breaker depends on the tripping current, and the remaining life of the breaker is estimated from the circuit breaker trip curve provided by the manufacturer.

**Example for estimating the remaining life of a circuit breaker**



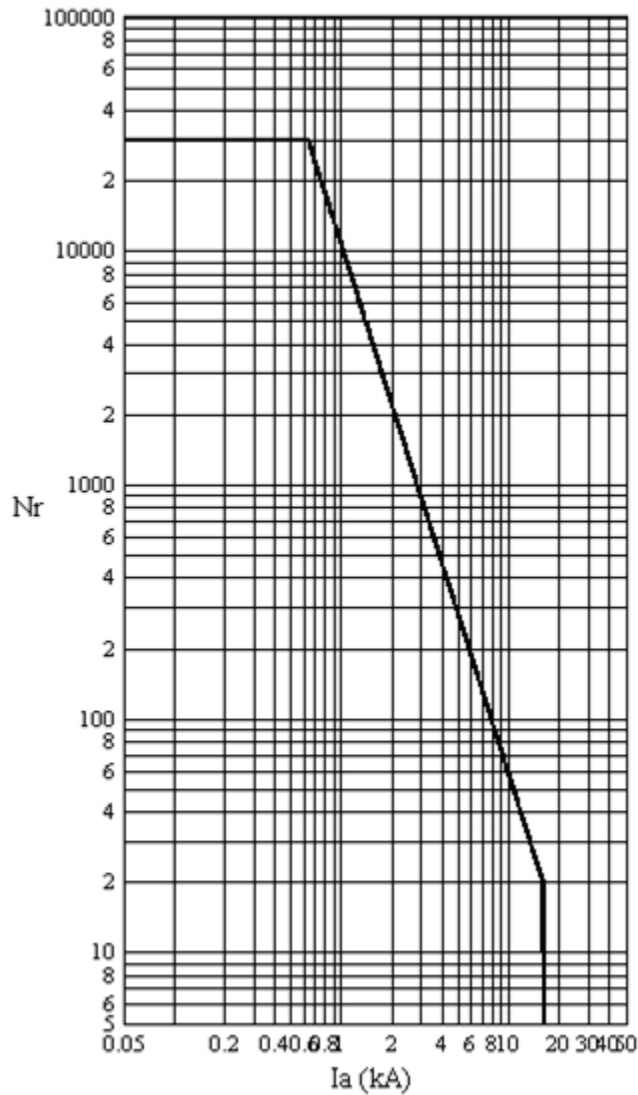


Figure 410: Trip Curves for a typical 12 kV, 630 A, 16 kA vacuum interrupter

- Nr        the number of closing-opening operations allowed for the circuit breaker
- Ia        the current at the time of tripping of the circuit breaker

**Calculation of Directional Coef**

The directional coefficient is calculated according to the formula:

$$Directional\ Coef = \frac{\log\left(\frac{B}{A}\right)}{\log\left(\frac{I_f}{I_r}\right)} = -2.2609$$

- $I_r$             Rated operating current = 630 A
- $I_f$             Rated fault current = 16 kA
- A                Op number rated = 30000
- B                Op number fault = 20

**Calculation for estimating the remaining life**

*Figure 410* shows that there are 30,000 possible operations at the rated operating current of 630 A and 20 operations at the rated fault current 16 kA. Therefore, if the tripping current is 10 kA, one operation at 10 kA is equivalent to 30,000/60=500 operations at the rated current. It is also assumed that prior to this tripping, the remaining life of the circuit breaker is 15,000 operations. Therefore, after one operation of 10 kA, the remaining life of the circuit breaker is 15,000-500=14,500 at the rated operating current.

$$Remaining\ life\ reduction = \left(\frac{I}{I_r}\right)^{-Directional\ Coef}$$

**Spring-charged indication**

For normal operation of the circuit breaker, the circuit breaker spring should be charged within a specified time. Therefore, detecting long spring-charging time indicates that it is time for the circuit breaker maintenance. The last value of the spring-charging time can be used as a service value.

**Gas pressure supervision**

The gas pressure supervision monitors the gas pressure inside the arc chamber. When the pressure becomes too low compared to the required value, the circuit breaker operations are locked. A binary input is available based on the pressure levels in the function, and alarms are generated based on these inputs.

**6.1.6 Signals**

**6.1.6.1 SSCBR Input signals**

**Table 711: SSCBR Input signals**

| Name | Type   | Default | Description     |
|------|--------|---------|-----------------|
| I_A  | SIGNAL | 0       | Phase A current |
| I_B  | SIGNAL | 0       | Phase B current |
| I_C  | SIGNAL | 0       | Phase C current |

*Table continues on the next page*

| Name         | Type    | Default | Description   |
|--------------|---------|---------|---|
| BLOCK        | BOOLEAN | 0=False | Block input status                                      |
| POSOPEN      | BOOLEAN | 0=False | Signal for open position of apparatus from I/O          |
| POSCLOSE     | BOOLEAN | 0=False | Signal for close position of apparatus from I/O         |
| OPEN_CB_EXE  | BOOLEAN | 0=False | Signal for open command to coil                         |
| CLOSE_CB_EXE | BOOLEAN | 0=False | Signal for close command to coil                        |
| PRES_ALM_IN  | BOOLEAN | 0=False | Binary pressure alarm input                             |
| PRES_LO_IN   | BOOLEAN | 0=False | Binary pressure input for lockout indication            |
| SPR_CHR_ST   | BOOLEAN | 0=False | CB spring charging started input                        |
| SPR_CHR      | BOOLEAN | 0=False | CB spring charged input                                 |
| RST_IPOW     | BOOLEAN | 0=False | Reset accumulation energy                               |
| RST_CB_WEAR  | BOOLEAN | 0=False | Reset input for CB remaining life and operation counter |
| RST_TRV_T    | BOOLEAN | 0=False | Reset input for CB closing and opening travel times     |
| RST_SPR_T    | BOOLEAN | 0=False | Reset input for the charging time of the CB spring      |

### 6.1.6.2

## SSCBR Output signals

Table 712: SSCBR Output signals

| Name         | Type    | Description                                    |
|--------------|---------|--|
| TRV_T_OP_ALM | BOOLEAN | CB open travel time exceeded set value         |
| TRV_T_CL_ALM | BOOLEAN | CB close travel time exceeded set value        |
| SPR_CHR_ALM  | BOOLEAN | Spring charging time has crossed the set value |
| OPR_ALM      | BOOLEAN | Number of CB operations exceeds alarm limit    |

*Table continues on the next page*

| Name        | Type    | Description   |
|-------------|---------|---|
| OPR_LO      | BOOLEAN | Number of CB operations exceeds lockout limit             |
| IPOW_ALM    | BOOLEAN | Accumulated currents power (Iyt),exceeded alarm limit     |
| IPOW_LO     | BOOLEAN | Accumulated currents power (Iyt),exceeded lockout limit   |
| CB_LIFE_ALM | BOOLEAN | Remaining life of CB exceeded alarm limit                 |
| MON_ALM     | BOOLEAN | CB 'not operated for long time' alarm                     |
| PRES_ALM    | BOOLEAN | Pressure below alarm level                                |
| PRES_LO     | BOOLEAN | Pressure below lockout level                              |
| OPENPOS     | BOOLEAN | CB is in open position                                    |
| INVALIDPOS  | BOOLEAN | CB is in invalid position (not positively open or closed) |
| CLOSEPOS    | BOOLEAN | CB is in closed position                                  |

## 6.1.7 Settings

### 6.1.7.1 SSCBR Settings

Table 713: SSCBR Non group settings (Basic)

| Parameter          | Values (Range) | Unit | Step | Default | Description                                     |
|--------------------|----------------|------|------|---------|---|
| Operation          | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On                              |
| Acc stop current   | 5.00...500.00  | A    | 0.01 | 10.00   | RMS current setting below which engy acm stops  |
| Open alarm time    | 0...200        | ms   | 1    | 40      | Alarm level setting for open travel time in ms  |
| Close alarm time   | 0...200        | ms   | 1    | 40      | Alarm level Setting for close travel time in ms |
| Spring charge time | 0...60000      | ms   | 10   | 15000   | Setting of alarm for spring charg-              |

Table continues on the next page

| Parameter            | Values (Range)   | Unit | Step | Default | Description   |
|----------------------|------------------|------|------|---------|---|
|                      |                  |      |      |         | ing time of CB in ms  |
| Alarm Op number      | 0...99999        |      | 1    | 200     | Alarm limit for number of operations                          |
| Lockout Op number    | 0...99999        |      | 1    | 300     | Lock out limit for number of operations                       |
| Current exponent     | 0.00...2.00      |      | 0.01 | 2.00    | Current exponent setting for energy calculation               |
| Difference Cor time  | -10...10         | ms   | 1    | 5       | Corr. factor for time dif in aux. and main contacts open time |
| Alm Acc currents Pwr | 0.00...20000.00  |      | 0.01 | 2500.00 | Setting of alarm level for accumulated currents power         |
| LO Acc currents Pwr  | 0.00...20000.00  |      | 0.01 | 2500.00 | Lockout limit setting for accumulated currents power          |
| Directional Coef     | -3.00...-0.50    |      | 0.01 | -1.50   | Directional coefficient for CB life calculation               |
| Initial CB Rmn life  | 0...99999        |      | 1    | 5000    | Initial value for the CB remaining life                       |
| Rated Op current     | 100.00...5000.00 | A    | 0.01 | 1000.00 | Rated operating current of the breaker                        |
| Rated fault current  | 500.00...7500.00 | A    | 0.01 | 5000.00 | Rated fault current of the breaker                            |
| Op number rated      | 1...99999        |      | 1    | 10000   | Number of operations possible at rated current                |
| Op number fault      | 1...10000        |      | 1    | 1000    | Number of operations possible at                              |

*Table continues on the next page*

| Parameter            | Values (Range)                         | Unit | Step | Default           | Description                                    |
|----------------------|--|------|------|-------------------|--|
|                      |  |      |      |                   | rated fault current                            |
| Inactive Alm days    | 0...9999                               |      | 1    | 2000              | Alarm limit value of the inactive days counter |
| Travel time Clc mode | 1=From Cmd to Pos<br>2=From Pos to Pos |      |      | 2=From Pos to Pos | Travel time calculation mode selection         |

Table 714: SSCBR Non group settings (Advanced)

| Parameter            | Values (Range)  | Unit | Step | Default | Description  |
|----------------------|-----------------|------|------|---------|--|
| Opening time Cor     | -100...100      | ms   | 1    | 10      | Correction factor for open travel time in ms       |
| Closing time Cor     | -100...100      | ms   | 1    | 10      | Correction factor for CB close travel time in ms   |
| Counter initial Val  | 0...99999       |      | 1    | 0       | The operation numbers counter initialization value |
| Ini Acc currents Pwr | 0.00...20000.00 |      | 0.01 | 0.00    | Initial value for accumulation energy (Iyt)        |
| Life alarm level     | 0...99999       |      | 1    | 500     | Alarm level for CB remaining life                  |
| Pressure alarm time  | 0...60000       | ms   | 1    | 10      | Time delay for gas pressure alarm in ms            |
| Pres lockout time    | 0...60000       | ms   | 10   | 10      | Time delay for gas pressure lockout in ms          |
| Ini inactive days    | 0...9999        |      | 1    | 0       | Initial value of the inactive days counter         |
| Inactive Alm hours   | 0...23          | h    | 1    | 0       | Alarm time of the inactive days counter in hours   |

## 6.1.8 Monitored data

### 6.1.8.1 SSCBR Monitored data

Table 715: SSCBR Monitored data

| Name      | Type    | Values (Range)   | Unit | Description                                    |
|-----------|---------|--|------|--|
| T_TRV_OP  | FLOAT32 | 0...60000  | ms   | Travel time of the CB during opening operation |
| T_TRV_CL  | FLOAT32 | 0...60000  | ms   | Travel time of the CB during closing operation |
| T_SPR_CHR | FLOAT32 | 0.00...99.99   | s    | The charging time of the CB spring             |
| NO_OPR    | INT32   | 0...99999  |      | Number of CB operation cycle                   |
| INA_DAYS  | INT32   | 0...9999   |      | The number of days CB has been inactive        |
| CB_LIFE_A | INT32   | -99999...99999   |      | CB Remaining life phase A                      |
| CB_LIFE_B | INT32   | -99999...99999   |      | CB Remaining life phase B                      |
| CB_LIFE_C | INT32   | -99999...99999   |      | CB Remaining life phase C                      |
| IPOW_A    | FLOAT32 | 0.000...30000.00<br>0                                  |      | Accumulated currents power (Iyt), phase A      |
| IPOW_B    | FLOAT32 | 0.000...30000.00<br>0                                  |      | Accumulated currents power (Iyt), phase B      |
| IPOW_C    | FLOAT32 | 0.000...30000.00<br>0                                  |      | Accumulated currents power (Iyt), phase C      |
| SSCBR     | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status   |

## 6.1.9 Technical data

Table 716: SSCBR Technical data

| Characteristic              | Value   |
|-----------------------------|---|
| Current measuring accuracy  | $\pm 1.5\%$ or $\pm 0.002 \times I_n$<br>(at currents in the range of $0.1 \dots 10 \times I_n$ )<br>$\pm 5.0\%$<br>(at currents in the range of $10 \dots 40 \times I_n$ ) |
| Operate time accuracy       | $\pm 1.0\%$ of the set value or $\pm 20$ ms   |
| Travelling time measurement | +10 ms / -0 ms  |

## 6.1.10 Technical revision history

Table 717: SSCBR Technical revision history

| Technical revision | Change   |
|--------------------|--|
| B                  | Added the possibility to reset spring charge time and breaker travel times.  |
| C                  | Removed the DIFTRVTOPALM and DIFTRVTCALM outputs and the corresponding <i>Open Dif alarm time</i> and <i>Close Dif alarm time</i> setting parameters.  |
| D                  | The <i>Operation cycle</i> setting parameter renamed to <i>Initial CB Rmn life</i> . The IPOW_A (_B, _C) range changed.  |
| E                  | Maximum value of initial circuit breaker remaining life time setting ( <i>Initial CB Rmn life</i> ) changed from 9999 to 99999. Added support for measuring circuit breaker travelling time from opening/ closing command and auxiliary contact state signal change. |
| F                  | <i>Alarm Op number</i> range increased from 9999 to 99999. <i>Lockout Op number</i> setting range increased from 9999 to 99999. <i>Counter initial value</i> setting range increased from 9999 to 99999.   |
| G                  | Modified for SSC600  |



## 7 Measurement functions

### 7.1 Basic measurements

#### 7.1.1 Measurement functions

#### 7.1.2 Measurement functionality

The functions can be enabled or disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

Some of the measurement functions operate on two alternative measurement modes: "DFT" and "RMS". The measurement mode is selected with the *X Measurement mode* setting. Depending on the measuring function if the measurement mode cannot be selected, the measuring mode is "DFT".

##### Demand value calculation

The demand values are calculated separately for each measurement function and per phase when applicable. The available measurement modes are "Linear" and "Logarithmic". The "Logarithmic" measurement mode is only effective for phase current and residual current demand value calculations. The demand value calculation mode is selected with the setting parameter **Configuration > Measurements > A demand Av mode**. The time interval for all demand value calculations is selected with the setting parameter **Configuration > Measurements > Demand interval**.

If the *Demand interval* setting is set to "15 minutes", for example, the demand values are updated every quarter of an hour. The demand time interval is synchronized to the real-time clock of the IED. When the demand time interval or calculation mode is changed, it initializes the demand value calculation. For the very first demand value calculation interval, the values are stated as invalid until the first refresh is available.

The "Linear" calculation mode uses the periodic sliding average calculation of the measured signal over the demand time interval. A new demand value is obtained once in a minute, indicating the analog signal demand over the demand time interval proceeding the update time. The actual rolling demand values are stored in the memory until the value is updated at the end of the next time interval.

The "Logarithmic" calculation mode uses the periodic calculation using a log10 function over the demand time interval to replicate thermal demand ammeters. The logarithmic demand calculates a snapshot of the analog signal every  $1/15 \times$  demand time interval.

Each measurement function has its own recorded data values. In IED, these are found in **Monitoring > Recorded data > Measurements**. In the technical manual these are listed in the monitored data section of each measurement function. These

values are periodically updated with the maximum and minimum demand values. The time stamps are provided for both values.

*Reset of Recorded data* initializes a present demand value to the minimum and maximum demand values.

**Value reporting**

The measurement functions are capable of reporting new values for network control center (SCADA system) based on various functions.

- Zero-point clamping
- Deadband supervision
- Limit value supervision



In the three-phase voltage measurement function VMMXU the supervision functions are based on the phase-to-phase voltages. However, the phase-to-earth voltage values are also reported with the phase-to-phase voltages.



GOOSE is an event based protocol service. Analog GOOSE uses the same event generation functions as vertical SCADA communication for updating the measurement values. Update interval of 500 ms is used for data that do not have zero-point clamping, deadband supervision or limit value supervision.

**Zero-point clamping**

A measured value under the zero-point clamping limit is forced to zero. This allows the noise in the input signal to be ignored. The active clamping function forces both the actual measurement value and the angle value of the measured signal to zero. In the three-phase or sequence measuring functions, each phase or sequence component has a separate zero-point clamping function. The zero-value detection operates so that once the measured value exceeds or falls below the value of the zero-clamping limit, new values are reported.

**Table 718: Zero-point clamping limits**

| Function  | Zero-clamping limit      |
|---|--------------------------|
| Three-phase current measurement (CMMXU)           | 1% of nominal (In)       |
| Three-phase voltage measurement (VMMXU)           | 1% of nominal (Un)       |
| Residual current measurement (RESCMMXU)           | 1% of nominal (In)       |
| Residual voltage measurement (RESVMMXU)           | 1% of nominal (Un)       |
| Phase sequence current measurement (CSMSQI)       | 1% of the nominal (In)   |
| Phase sequence voltage measurement (VSMSQI)       | 1% of the nominal (Un)   |
| Three-phase power and energy measurement (PEMMXU) | 1.5% of the nominal (Sn) |



When the frequency measurement function FMMXU is unable to measure the network frequency in the undervoltage situation, the measured values are set to the nominal and also the quality information of the data set accordingly. The undervoltage limit is fixed to 10 percent of the nominal for the frequency measurement.

**Limit value supervision**

The limit value supervision function indicates whether the measured value of X\_INST exceeds or falls below the set limits. The measured value has the corresponding range information X\_RANGE and has a value in the range of 0 to 4:

- 0: "normal"
- 1: "high"
- 2: "low"
- 3: "high-high"
- 4: "low-low"

The range information changes and the new values are reported.

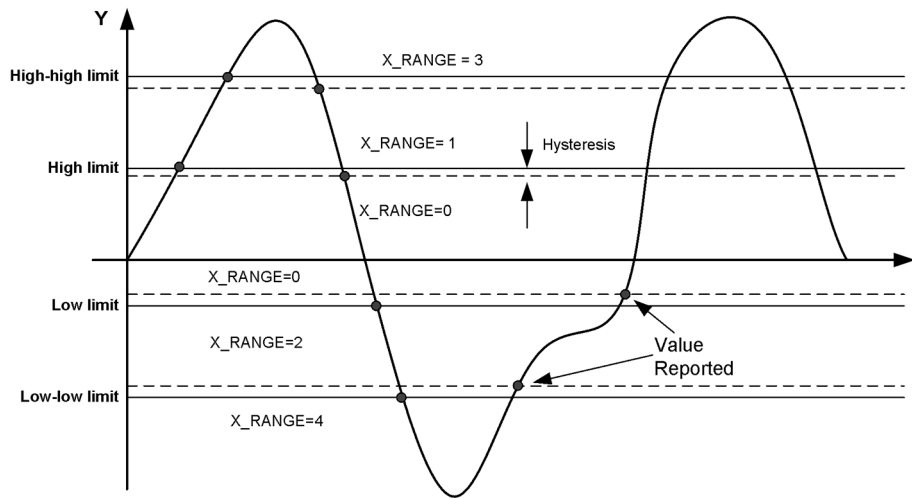


Figure 411: Presentation of operating limits

The range information can also be decoded into boolean output signals on some of the measuring functions and the number of phases required to exceed or undershoot the limit before activating the outputs and can be set with the Num of phases setting in the three-phase measurement functions CMMXU and VMMXU. The limit supervision boolean alarm and warning outputs can be blocked.

**Table 719: Settings for limit value supervision**

| Function                                | Settings for limit value supervision |                   |
|---|--------------------------------------|-------------------|
| Three-phase current measurement (CMMXU) | High limit                           | A high limit      |
|   | Low limit                            | A low limit       |
|   | High-high limit                      | A high high limit |
|   | Low-low limit                        | A low low limit   |
| Three-phase voltage measurement (VMMXU) | High limit                           | V high limit      |
|   | Low limit                            | V low limit       |
|   | High-high limit                      | V high high limit |
|   | Low-low limit                        | V low low limit   |
| Residual current measurement (RESCMMXU) | High limit                           | A high limit res  |
|   | Low limit                            | -                 |

Table continues on the next page

| Function  | Settings for limit value supervision |   |
|---|--------------------------------------|---|
|   | High-high limit                      | A Hi high limit res   |
|   | Low-low limit                        | -   |
| Frequency measurement (FMMXU)                     | High limit                           | F high limit  |
|   | Low limit                            | F low limit   |
|   | High-high limit                      | F high high limit   |
|   | Low-low limit                        | F low low limit   |
| Residual voltage measurement (RESVMMXU)           | High limit                           | V high limit res  |
|   | Low limit                            | -   |
|   | High-high limit                      | V Hi high limit res   |
|   | Low-low limit                        | -   |
| Phase sequence current measurement (CSMSQI)       | High limit                           | Ps Seq A high limit, Ng Seq A high limit, Zro A high limit    |
|   | Low limit                            | Ps Seq A low limit, Ng Seq A low limit, Zro A low limit       |
|   | High-high limit                      | Ps Seq A Hi high Lim, Ng Seq A Hi high Lim, Zro A Hi high Lim |
|   | Low-low limit                        | Ps Seq A low low Lim, Ng Seq A low low Lim, Zro A low low Lim |
| Phase sequence voltage measurement (VSMSQI)       | High limit                           | Ps Seq V high limit, Ng Seq V high limit, Zro V high limit    |
|   | Low limit                            | Ps Seq V low limit, Ng Seq V low limit, Zro V low limit       |
|   | High-high limit                      | Ps Seq V Hi high Lim, Ng Seq V Hi high Lim, Zro V Hi high Lim |
|   | Low-low limit                        | Ps Seq V low low Lim, Ng Seq V low low Lim,                   |
| Three-phase power and energy measurement (PEMMXU) | High limit                           | -   |
|   | Low limit                            | -   |
|   | High-high limit                      | -   |
|   | Low-low limit                        | -   |

**Deadband supervision**

The deadband supervision function reports the measured value according to integrated changes over a time period.

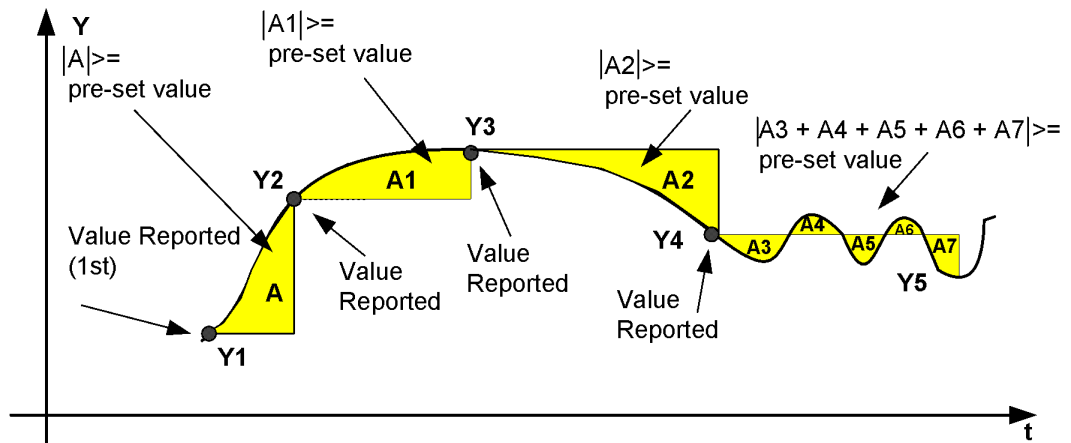


Figure 412: Integral deadband supervision

The deadband value used in the integral calculation is configured with the *X deadband* setting. The value represents the percentage of the difference between the maximum and minimum limit in the units of 0.001 percent x seconds.

The reporting delay of the integral algorithms in seconds is calculated with the formula:

$$t(s) = \frac{(\max - \min) \times \text{deadband} / 1000}{|\Delta Y| \times 100\%}$$

Example for CMMXU:

A deadband = 2500 (2.5% of the total measuring range of 40)

$$I\_INST\_A = I\_DB\_A = 0.30$$

If *I\_INST\_A* changes to 0.40, the reporting delay is:

$$t(s) = \frac{(40 - 0) \times 2500 / 1000}{|0.40 - 0.30| \times 100\%} = 10s$$

Table 720: Parameters for deadband calculation

| Function                                | Settings              | Maximum/minimum (=range) |
|---|-----------------------|--------------------------|
| Three-phase current measurement (CMMXU) | <i>A deadband</i>     | 40/0 (=40xIn)            |
| Three-phase voltage measurement (VMMXU) | <i>V Deadband</i>     | 4/0 (=4xUn)              |
| Residual current measurement (RESCMMXU) | <i>A deadband res</i> | 40/0 (=40xIn)            |
| Residual voltage measurement (RESVMMXU) | <i>V deadband res</i> | 4/0 (=4xUn)              |

Table continues on the next page

| Function  | Settings  | Maximum/minimum (=range)     |
|---|---|------------------------------|
| Frequency measurement (FMMXU)                     | <i>F deadband</i>   | 75/35 (=40 Hz) <sup>96</sup> |
| Phase sequence current measurement (CSMSQI)       | <i>Ps Seq A deadband, Ng Seq A deadband, Zro A deadband</i> | 40/0 (=40xIn)                |
| Phase sequence voltage measurement (VSMSQI)       | <i>Ps Seq V deadband, Ng Seq V deadband, Zro V deadband</i> | 4/0 (=4xUn)                  |
| Three-phase power and energy measurement (PEMMXU) | -   |                              |



In the three-phase power and energy measurement function PEMMXU, the deadband supervision is done separately for apparent power S, with the preset value of fixed 10 percent of the Sn, and the power factor PF, with the preset values fixed at 0.10. . All the power measurement-related values P, Q, S and PF are reported simultaneously when either one of the S or PF values exceeds the preset limit.

#### Power and energy calculation

The three-phase power is calculated from the phase-to-earth voltages and phase-to-earth currents. The power measurement function is capable of calculating a complex power based on the fundamental frequency component phasors (DFT).

$$\bar{S} = (\bar{U}_A \cdot \bar{I}_A^* + \bar{U}_B \cdot \bar{I}_B^* + \bar{U}_C \cdot \bar{I}_C^*)$$

Once the complex apparent power is calculated, P, Q, S and PF are calculated with the equations:

$$P = \text{Re}(\bar{S})$$

$$Q = \text{Im}(\bar{S})$$

$$S = |\bar{S}| = \sqrt{P^2 + Q^2}$$

$$\text{Cos}\phi = \frac{P}{S}$$

Depending on the unit multiplier selected with *Power unit Mult*, the calculated power values are presented in units of kVA/kW/kVAr or in units of MVA/MW/MVAr.

<sup>96</sup> The value provided is for REF615, RET615 and REM615 in 50 Hz network. The value for 60 Hz network is 90/36 (=54 Hz). For REG615 the values are 75/10 (=65 Hz) in 50 Hz network and 90/12 (=78 Hz) in 60 Hz network.

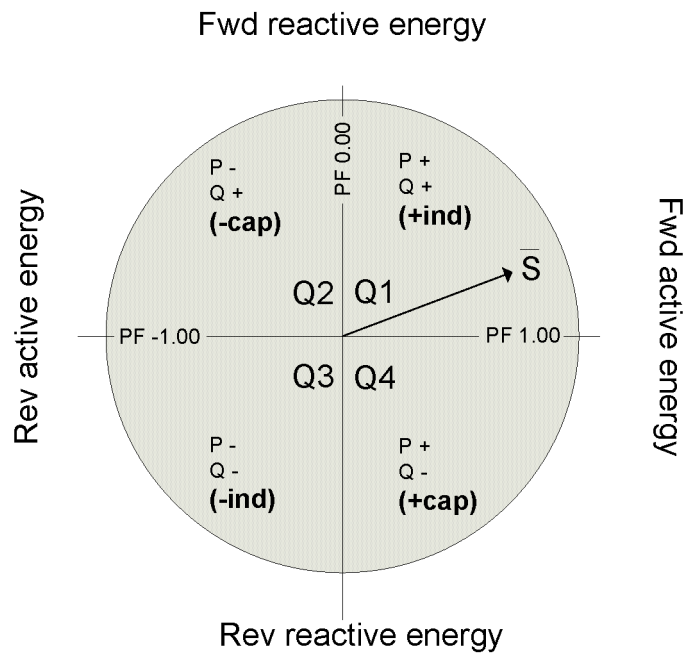


Figure 413: Complex power and power quadrants

Table 721: Power quadrants

| Quadrant | Current | P | Q | PF        | Power |
|----------|---------|---|---|-----------|-------|
| Q1       | Lagging | + | + | 0...+1.00 | +ind  |
| Q2       | Lagging | - | + | 0...-1.00 | -cap  |
| Q3       | Leading | - | - | 0...-1.00 | -ind  |
| Q4       | Leading | + | - | 0...+1.00 | +cap  |

The active power P direction can be selected between forward and reverse with *Active power Dir* and correspondingly the reactive power Q direction can be selected with *Reactive power Dir*. This affects also the accumulated energy directions.

The accumulated energy is calculated separately as forward active (EA\_FWD\_ACM), reverse active (EA\_RV\_ACM), forward reactive (ER\_FWD\_ACM) and reverse reactive (ER\_RV\_ACM). Depending on the value of the unit multiplier selected with *Energy unit Mult*, the calculated power values are presented in units of kWh/kVArh or in units of MWh/MVArh.

When the energy counter reaches its defined maximum value, the counter value is reset and restarted from zero. Changing the value of the *Energy unit Mult* setting resets the accumulated energy values to the initial values, that is, EA\_FWD\_ACM to *Forward Wh Initial*, EA\_RV\_ACM to *Reverse Wh Initial*, ER\_FWD\_ACM to *Forward VARh Initial* and ER\_RV\_ACM to *Reverse VARh Initial*. It is also possible to reset the accumulated energy to initial values through a parameter or with the RSTACM input.

### Sequence components

The phase-sequence components are calculated using the phase currents and phase voltages. More information on calculating the phase-sequence components can be found in [Chapter 10.6 Calculated measurements](#) in this manual.

## 7.1.3 Measurement function applications

The measurement functions are used for power system measurement, supervision and reporting to WHMI, a monitoring tool within PCM600, or to the station level, for example, with IEC 61850. The possibility to continuously monitor the measured values of active power, reactive power, currents, voltages, power factors and so on, is vital for efficient production, transmission, and distribution of electrical energy. It provides a fast and easy overview of the present status of the power system to the system operator. Additionally, it can be used during testing and commissioning of protection and control IEDs to verify the proper operation and connection of instrument transformers, that is, the current transformers (CTs) and voltage transformers (VTs). The proper operation of the IED analog measurement chain can be verified during normal service by a periodic comparison of the measured value from the IED to other independent meters.

When the zero signal is measured, the noise in the input signal can still produce small measurement values. The zero point clamping function can be used to ignore the noise in the input signal and, hence, prevent the noise to be shown in the user display. The zero clamping is done for the measured analog signals and angle values.

The demand values are used to neglect sudden changes in the measured analog signals when monitoring long time values for the input signal. The demand values are linear average values of the measured signal over a settable demand interval. The demand values are calculated for the measured analog three-phase current signals.

The limit supervision indicates, if the measured signal exceeds or goes below the set limits. Depending on the measured signal type, up to two high limits and up to two low limits can be set for the limit supervision.

The deadband supervision reports a new measurement value if the input signal has gone out of the deadband state. The deadband supervision can be used in value reporting between the measurement point and operation control. When the deadband supervision is properly configured, it helps in keeping the communication load in minimum and yet measurement values are reported frequently enough.

## 7.1.4 Three-phase current measurement CMMXU

### 7.1.4.1 Identification

| Function description            | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---------------------------------|--------------------------|--------------------------|-------------------------------|
| Three-phase current measurement | CMMXU                    | 3I                       | 3I                            |



### 7.1.4.2 Function block

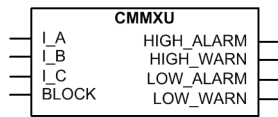


Figure 414: Function block

### 7.1.4.3 Signals

#### CMMXU Input signals

Table 722: CMMXU Input signals

| Name  | Type    | Default | Description                         |
|-------|---------|---------|-------------------------------------|
| I_A   | SIGNAL  | 0       | Phase A current                     |
| I_B   | SIGNAL  | 0       | Phase B current                     |
| I_C   | SIGNAL  | 0       | Phase C current                     |
| BLOCK | BOOLEAN | 0=False | Block signal for all binary outputs |

#### CMMXU Output signals

Table 723: CMMXU Output signals

| Name       | Type    | Description  |
|------------|---------|--------------|
| HIGH_ALARM | BOOLEAN | High alarm   |
| HIGH_WARN  | BOOLEAN | High warning |
| LOW_WARN   | BOOLEAN | Low warning  |
| LOW_ALARM  | BOOLEAN | Low alarm    |

### 7.1.4.4 Settings

#### CMMXU Settings

Table 724: CMMXU Non group settings (Basic)

| Parameter     | Values (Range)               | Unit | Step | Default      | Description          |
|---------------|------------------------------|------|------|--------------|----------------------|
| Operation     | 1=on<br>5=off                |      |      | 1=on         | Operation Off / On   |
| Num of phases | 1=1 out of 3<br>2=2 out of 3 |      |      | 1=1 out of 3 | Number of phases re- |

Table continues on the next page

| Parameter         | Values (Range) | Unit | Step | Default | Description  |
|-------------------|----------------|------|------|---------|--|
|                   | 3=3 out of 3   |      |      |         | quired by limit supervision  |
| A high high limit | 0.00...40.00   | xIn  | 1    | 1.40    | High alarm current limit   |
| A high limit      | 0.00...40.00   | xIn  | 1    | 1.20    | High warning current limit   |
| A low limit       | 0.00...40.00   | xIn  | 1    | 0.00    | Low warning current limit  |
| A low low limit   | 0.00...40.00   | xIn  | 1    | 0.00    | Low alarm current limit  |
| A deadband        | 100...100000   |      | 1    | 2500    | Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s) |

Table 725: CMMXU Non group settings (Advanced)

| Parameter        | Values (Range) | Unit | Step | Default | Description                   |
|------------------|----------------|------|------|---------|-------------------------------|
| Measurement mode | 1=RMS<br>2=DFT |      |      | 2=DFT   | Selects used measurement mode |

### 7.1.4.5

## Monitored data

### CMMXU Monitored data

Table 726: CMMXU Monitored data

| Name  | Type    | Values (Range) | Unit | Description                        |
|-------|---------|----------------|------|------------------------------------|
| IL1-A | FLOAT32 | 0.00...40.00   | xIn  | Measured current amplitude phase A |
| IL2-A | FLOAT32 | 0.00...40.00   | xIn  | Measured current amplitude phase B |
| IL3-A | FLOAT32 | 0.00...40.00   | xIn  | Measured current amplitude phase C |

*Table continues on the next page*

| Name                | Type      | Values (Range)    | Unit | Description                         |
|---------------------|-----------|-------------------|------|-------------------------------------|
| Max demand IL1      | FLOAT32   | 0.00...40.00      | xIn  | Maximum demand for Phase A          |
| Max demand IL2      | FLOAT32   | 0.00...40.00      | xIn  | Maximum demand for Phase B          |
| Max demand IL3      | FLOAT32   | 0.00...40.00      | xIn  | Maximum demand for Phase C          |
| Min demand IL1      | FLOAT32   | 0.00...40.00      | xIn  | Minimum demand for Phase A          |
| Min demand IL2      | FLOAT32   | 0.00...40.00      | xIn  | Minimum demand for Phase B          |
| Min demand IL3      | FLOAT32   | 0.00...40.00      | xIn  | Minimum demand for Phase C          |
| Time max demand IL1 | Timestamp |                   |      | Time of maximum demand phase A      |
| Time max demand IL2 | Timestamp |                   |      | Time of maximum demand phase B      |
| Time max demand IL3 | Timestamp |                   |      | Time of maximum demand phase C      |
| Time min demand IL1 | Timestamp |                   |      | Time of minimum demand phase A      |
| Time min demand IL2 | Timestamp |                   |      | Time of minimum demand phase B      |
| Time min demand IL3 | Timestamp |                   |      | Time of minimum demand phase C      |
| BLOCK               | BOOLEAN   | 0=False<br>1=True |      | Block signal for all binary outputs |
| HIGH_ALARM          | BOOLEAN   | 0=False<br>1=True |      | High alarm                          |
| HIGH_WARN           | BOOLEAN   | 0=False<br>1=True |      | High warning                        |
| LOW_WARN            | BOOLEAN   | 0=False           |      | Low warning                         |

*Table continues on the next page*

| Name      | Type    | Values (Range)  | Unit | Description                                     |
|-----------|---------|---|------|---|
|           |         | 1=True  |      |   |
| LOW_ALARM | BOOLEAN | 0=False<br>1=True                                       |      | Low alarm                                       |
| I_INST_A  | FLOAT32 | 0.00...40.00  | xIn  | IL1 Amplitude, magnitude of instantaneous value |
| I_ANGL_A  | FLOAT32 | -180.00...180.00  | deg  | IL1 current angle                               |
| I_DB_A    | FLOAT32 | 0.00...40.00  | xIn  | IL1 Amplitude, magnitude of reported value      |
| I_DMD_A   | FLOAT32 | 0.00...40.00  | xIn  | Demand value of IL1 current                     |
| I_RANGE_A | Enum    | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low |      | IL1 Amplitude range                             |
| I_INST_B  | FLOAT32 | 0.00...40.00  | xIn  | IL2 Amplitude, magnitude of instantaneous value |
| I_ANGL_B  | FLOAT32 | -180.00...180.00  | deg  | IL2 current angle                               |
| I_DB_B    | FLOAT32 | 0.00...40.00  | xIn  | IL2 Amplitude, magnitude of reported value      |
| I_DMD_B   | FLOAT32 | 0.00...40.00  | xIn  | Demand value of IL2 current                     |
| I_RANGE_B | Enum    | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low |      | IL2 Amplitude range                             |
| I_INST_C  | FLOAT32 | 0.00...40.00  | xIn  | IL3 Amplitude, magnitude of instantaneous value |
| I_ANGL_C  | FLOAT32 | -180.00...180.00  | deg  | IL3 current angle                               |
| I_DB_C    | FLOAT32 | 0.00...40.00  | xIn  | IL3 Amplitude, magnitude of reported value      |

*Table continues on the next page*

| Name      | Type    | Values (Range)  | Unit | Description                 |
|-----------|---------|---|------|-----------------------------|
| I_DMD_C   | FLOAT32 | 0.00...40.00  | xIn  | Demand value of IL3 current |
| I_RANGE_C | Enum    | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low |      | IL3 Amplitude range         |

### 7.1.4.6 Technical data

Table 727: CMMXU Technical data

| Characteristic           | Value  |
|--------------------------|--|
| Operation accuracy       | Depending on the frequency of the measured current: $f_n \pm 2$ Hz                               |
|                          | $\pm 0.5\%$ or $\pm 0.002 \times I_n$<br>(at currents in the range of $0.01...4.00 \times I_n$ ) |
| Suppression of harmonics | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$<br>RMS: No suppression         |

### 7.1.4.7 Technical revision history

Table 728: CMMXU Technical revision history

| Technical revision | Change   |
|--------------------|--|
| B                  | Menu changes   |
| C                  | Phase current angle values added to Monitored data view. Minimum demand value and time added to recorded data. Logarithmic demand calculation mode added and demand interval setting moved under Measurement menu as general setting to all demand calculations. |
| D                  | Internal improvement.  |
| E                  | Internal improvement.  |

## 7.1.5 Three-phase voltage measurement VMMXU

### 7.1.5.1 Identification

| Function description            | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---------------------------------|--------------------------|--------------------------|-------------------------------|
| Three-phase voltage measurement | VMMXU                    | 3U                       | 3V                            |

### 7.1.5.2 Function block

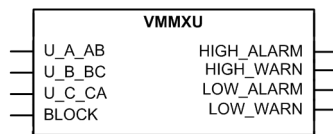


Figure 415: Function block

### 7.1.5.3 Signals

#### VMMXU Input signals

Table 729: VMMXU Input signals

| Name   | Type    | Default | Description   |
|--------|---------|---------|---|
| U_A_AB | SIGNAL  | 0       | Phase to earth voltage A or phase to phase voltage AB |
| U_B_BC | SIGNAL  | 0       | Phase to earth voltage B or phase to phase voltage BC |
| U_C_CA | SIGNAL  | 0       | Phase to earth voltage C or phase to phase voltage CA |
| BLOCK  | BOOLEAN | 0=False | Block signal for all binary outputs                   |

#### VMMXU Output signals

Table 730: VMMXU Output signals

| Name       | Type    | Description  |
|------------|---------|--------------|
| HIGH_ALARM | BOOLEAN | High alarm   |
| HIGH_WARN  | BOOLEAN | High warning |
| LOW_WARN   | BOOLEAN | Low warning  |
| LOW_ALARM  | BOOLEAN | Low alarm    |

## 7.1.5.4 Settings

### VMMXU Settings

**Table 731: VMMXU Non group settings (Basic)**

| Parameter         | Values (Range)                               | Unit | Step | Default      | Description  |
|-------------------|--|------|------|--------------|--|
| Operation         | 1=on<br>5=off                                |      |      | 1=on         | Operation Off / On   |
| Num of phases     | 1=1 out of 3<br>2=2 out of 3<br>3=3 out of 3 |      |      | 1=1 out of 3 | Number of phases required by limit supervision   |
| V high high limit | 0.00...4.00                                  | xUn  | 1    | 1.40         | High alarm voltage limit   |
| V high limit      | 0.00...4.00                                  | xUn  | 1    | 1.20         | High warning voltage limit   |
| V low limit       | 0.00...4.00                                  | xUn  | 1    | 0.00         | Low warning voltage limit  |
| V low low limit   | 0.00...4.00                                  | xUn  | 1    | 0.00         | Low alarm voltage limit  |
| V deadband        | 100...100000                                 |      | 1    | 10000        | Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s) |

**Table 732: VMMXU Non group settings (Advanced)**

| Parameter        | Values (Range) | Unit | Step | Default | Description                   |
|------------------|----------------|------|------|---------|-------------------------------|
| Measurement mode | 1=RMS<br>2=DFT |      |      | 2=DFT   | Selects used measurement mode |

## 7.1.5.5 Monitored data

**VMMXU Monitored data****Table 733: VMMXU Monitored data**

| Name       | Type    | Values (Range)  | Unit | Description  |
|------------|---------|---|------|--|
| U12-kV     | FLOAT32 | 0.00...4.00   | xUn  | Measured phase to phase voltage amplitude phase AB |
| U23-kV     | FLOAT32 | 0.00...4.00   | xUn  | Measured phase to phase voltage amplitude phase BC |
| U31-kV     | FLOAT32 | 0.00...4.00   | xUn  | Measured phase to phase voltage amplitude phase CA |
| BLOCK      | BOOLEAN | 0=False<br>1=True                                       |      | Block signal for all binary outputs                |
| HIGH_ALARM | BOOLEAN | 0=False<br>1=True                                       |      | High alarm   |
| HIGH_WARN  | BOOLEAN | 0=False<br>1=True                                       |      | High warning                                       |
| LOW_WARN   | BOOLEAN | 0=False<br>1=True                                       |      | Low warning  |
| LOW_ALARM  | BOOLEAN | 0=False<br>1=True                                       |      | Low alarm  |
| U_INST_AB  | FLOAT32 | 0.00...4.00   | xUn  | U12 Amplitude, magnitude of instantaneous value    |
| U_ANGL_AB  | FLOAT32 | -180.00...180.00  | deg  | U12 angle  |
| U_DB_AB    | FLOAT32 | 0.00...4.00   | xUn  | U12 Amplitude, magnitude of reported value         |
| U_DMD_AB   | FLOAT32 | 0.00...4.00   | xUn  | Demand value of U12 voltage                        |
| U_RANGE_AB | Enum    | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low |      | U12 Amplitude range                                |

*Table continues on the next page*



| Name       | Type    | Values (Range)  | Unit | Description                                     |
|------------|---------|---|------|---|
| U_INST_BC  | FLOAT32 | 0.00...4.00   | xUn  | U23 Amplitude, magnitude of instantaneous value |
| U_ANGL_BC  | FLOAT32 | -180.00...180.00  | deg  | U23 angle                                       |
| U_DB_BC    | FLOAT32 | 0.00...4.00   | xUn  | U23 Amplitude, magnitude of reported value      |
| U_DMD_BC   | FLOAT32 | 0.00...4.00   | xUn  | Demand value of U23 voltage                     |
| U_RANGE_BC | Enum    | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low |      | U23 Amplitude range                             |
| U_INST_CA  | FLOAT32 | 0.00...4.00   | xUn  | U31 Amplitude, magnitude of instantaneous value |
| U_ANGL_CA  | FLOAT32 | -180.00...180.00  | deg  | U31 angle                                       |
| U_DB_CA    | FLOAT32 | 0.00...4.00   | xUn  | U31 Amplitude, magnitude of reported value      |
| U_DMD_CA   | FLOAT32 | 0.00...4.00   | xUn  | Demand value of U31 voltage                     |
| U_RANGE_CA | Enum    | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low |      | U31 Amplitude range                             |
| U_INST_A   | FLOAT32 | 0.00...5.00   | xUn  | UL1 Amplitude, magnitude of instantaneous value |
| U_ANGL_A   | FLOAT32 | -180.00...180.00  | deg  | UL1 angle                                       |
| U_DMD_A    | FLOAT32 | 0.00...5.00   | xUn  | Demand value of UL1 voltage                     |
| U_INST_B   | FLOAT32 | 0.00...5.00   | xUn  | UL2 Amplitude, magnitude of instantaneous value |
| U_ANGL_B   | FLOAT32 | -180.00...180.00  | deg  | UL2 angle                                       |

*Table continues on the next page*

| Name     | Type    | Values (Range)   | Unit | Description                                     |
|----------|---------|------------------|------|---|
| U_DMD_B  | FLOAT32 | 0.00...5.00      | xUn  | Demand value of UL2 voltage                     |
| U_INST_C | FLOAT32 | 0.00...5.00      | xUn  | UL3 Amplitude, magnitude of instantaneous value |
| U_ANGL_C | FLOAT32 | -180.00...180.00 | deg  | UL3 angle                                       |
| U_DMD_C  | FLOAT32 | 0.00...5.00      | xUn  | Demand value of UL3 voltage                     |

### 7.1.5.6 Technical data

Table 734: VMMXU Technical data

| Characteristic           | Value  |
|--------------------------|--|
| Operation accuracy       | Depending on the frequency of the voltage measured: $f_n \pm 2 \text{ Hz}$<br>At voltages in range $0.01...1.15 \times U_n$<br>$\pm 0.5\%$ or $\pm 0.002 \times U_n$ |
| Suppression of harmonics | DFT: $-50 \text{ dB}$ at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$<br>RMS: No suppression   |

### 7.1.5.7 Technical revision history

Table 735: VMMXU Technical revision history

| Technical revision | Change  |
|--------------------|---|
| B                  | Phase and phase-to-phase voltage angle values and demand values added to Monitored data view. |
| C                  | Internal improvement.   |
| D                  | Internal improvement.   |

## 7.1.6 Residual current measurement RESCMMXU

### 7.1.6.1 Identification

| Function description         | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|------------------------------|--------------------------|--------------------------|-------------------------------|
| Residual current measurement | RESCMMXU                 | Io                       | In                            |

### 7.1.6.2 Function block

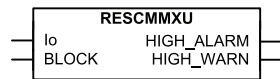


Figure 416: Function block

### 7.1.6.3 Signals

#### RESCMMXU Input signals

Table 736: RESCMMXU Input signals

| Name  | Type    | Default | Description                         |
|-------|---------|---------|-------------------------------------|
| Io    | SIGNAL  | 0       | Residual current                    |
| BLOCK | BOOLEAN | 0=False | Block signal for all binary outputs |

#### RESCMMXU Output signals

Table 737: RESCMMXU Output signals

| Name       | Type    | Description  |
|------------|---------|--------------|
| HIGH_ALARM | BOOLEAN | High alarm   |
| HIGH_WARN  | BOOLEAN | High warning |

### 7.1.6.4 Settings

#### RESCMMXU Settings

Table 738: RESCMMXU Non group settings (Basic)

| Parameter           | Values (Range) | Unit | Step | Default | Description  |
|---------------------|----------------|------|------|---------|--|
| Operation           | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On                                 |
| A Hi high limit res | 0.00...40.00   | xIn  | 1    | 0.20    | High alarm current limit                           |
| A high limit res    | 0.00...40.00   | xIn  | 1    | 0.05    | High warning current limit                         |
| A deadband res      | 100...100000   |      | 1    | 2500    | Deadband configuration value for integral calcula- |

| Parameter | Values (Range) | Unit | Step | Default | Description   |
|-----------|----------------|------|------|---------|---|
|           |                |      |      |         | tion. (percentage of difference between min and max as 0,001 % s) |

**Table 739: RESCMMXU Non group settings (Advanced)**

| Parameter        | Values (Range) | Unit | Step | Default | Description                   |
|------------------|----------------|------|------|---------|-------------------------------|
| Measurement mode | 1=RMS<br>2=DFT |      |      | 2=DFT   | Selects used measurement mode |

**7.1.6.5**

**Monitored data**

**RESCMMXU Monitored data**

**Table 740: RESCMMXU Monitored data**

| Name        | Type    | Values (Range)     | Unit | Description  |
|-------------|---------|--------------------|------|--|
| Io-A        | FLOAT32 | 0.00...40.00       | xIn  | Residual current   |
| BLOCK       | BOOLEAN | 0=False<br>1=True  |      | Block signal for all binary outputs                          |
| HIGH_ALARM  | BOOLEAN | 0=False<br>1=True  |      | High alarm   |
| HIGH_WARN   | BOOLEAN | 0=False<br>1=True  |      | High warning   |
| I_INST_RES  | FLOAT32 | 0.00...40.00       | xIn  | Residual current Amplitude, magnitude of instantaneous value |
| I_ANGL_RES  | FLOAT32 | -180.00...180.00   | deg  | Residual current angle                                       |
| I_DB_RES    | FLOAT32 | 0.00...40.00       | xIn  | Residual current Amplitude, magnitude of reported value      |
| I_DMD_RES   | FLOAT32 | 0.00...40.00       | xIn  | Demand value of residual current                             |
| I_RANGE_RES | Enum    | 0=normal<br>1=high |      | Residual current Amplitude range                             |

*Table continues on the next page*

| Name               | Type      | Values (Range)                    | Unit | Description                             |
|--------------------|-----------|-----------------------------------|------|---|
|                    |           | 2=low<br>3=high-high<br>4=low-low |      |   |
| Max demand lo      | FLOAT32   | 0.00...40.00                      | xIn  | Maximum demand for residual current     |
| Min demand lo      | FLOAT32   | 0.00...40.00                      | xIn  | Minimum demand for residual current     |
| Time max demand lo | Timestamp |                                   |      | Time of maximum demand residual current |
| Time min demand lo | Timestamp |                                   |      | Time of minimum demand residual current |

### 7.1.6.6

### Technical data

Table 741: RESCMMXU Technical data

| Characteristic           | Value  |
|--------------------------|--|
| Operation accuracy       | At the frequency $f = f_n$<br>$\pm 0.5\%$ or $\pm 0.002 \times I_n$<br>(at currents in the range of $0.01...4.00 \times I_n$ ) |
| Suppression of harmonics | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$<br>RMS: No suppression                                       |

### 7.1.6.7

### Technical revision history

Table 742: RESCMMXU Technical revision history

| Technical revision | Change  |
|--------------------|---|
| B                  | -   |
| C                  | Residual current angle and demand value added to Monitored data view. Recorded data added for minimum and maximum values with timestamps. |
| D                  | Monitored data Min demand lo maximum value range (RESCMSTA2.MinAmps.maxVal.f) is corrected to 40.00.                                      |
| E                  | Internal improvement.   |

## 7.1.7 Residual voltage measurement RESVMMXU

### 7.1.7.1 Identification

| Function description         | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|------------------------------|--------------------------|--------------------------|-------------------------------|
| Residual voltage measurement | RESVMMXU                 | Uo                       | Vn                            |

### 7.1.7.2 Function block

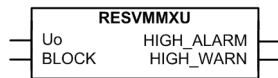


Figure 417: Function block

### 7.1.7.3 Signals

#### RESVMMXU Input signals

Table 743: RESVMMXU Input signals

| Name  | Type    | Default | Description                         |
|-------|---------|---------|-------------------------------------|
| Uo    | SIGNAL  | 0       | Residual voltage                    |
| BLOCK | BOOLEAN | 0=False | Block signal for all binary outputs |

#### RESVMMXU Output signals

Table 744: RESVMMXU Output signals

| Name       | Type    | Description  |
|------------|---------|--------------|
| HIGH_ALARM | BOOLEAN | High alarm   |
| HIGH_WARN  | BOOLEAN | High warning |

### 7.1.7.4 Settings

#### RESVMMXU Settings

Table 745: RESVMMXU Non group settings (Basic)

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on           |      |      | 1=on    | Operation Off / On |

Table continues on the next page

| Parameter           | Values (Range) | Unit | Step | Default | Description  |
|---------------------|----------------|------|------|---------|--|
|                     | 5=off          |      |      |         |  |
| V Hi high limit res | 0.00...4.00    | xUn  | 1    | 0.20    | High alarm voltage limit   |
| V high limit res    | 0.00...4.00    | xUn  | 1    | 0.05    | High warning voltage limit   |
| V deadband res      | 100...100000   |      | 1    | 10000   | Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s) |

**Table 746: RESVMMXU Non group settings (Advanced)**

| Parameter        | Values (Range) | Unit | Step | Default | Description                   |
|------------------|----------------|------|------|---------|-------------------------------|
| Measurement mode | 1=RMS<br>2=DFT |      |      | 2=DFT   | Selects used measurement mode |

### 7.1.7.5

## Monitored data

### RESVMMXU Monitored data

**Table 747: RESVMMXU Monitored data**

| Name       | Type    | Values (Range)    | Unit | Description  |
|------------|---------|-------------------|------|--|
| Uo-kV      | FLOAT32 | 0.00...4.00       | xUn  | Residual voltage   |
| BLOCK      | BOOLEAN | 0=False<br>1=True |      | Block signal for all binary outputs                          |
| HIGH_ALARM | BOOLEAN | 0=False<br>1=True |      | High alarm   |
| HIGH_WARN  | BOOLEAN | 0=False<br>1=True |      | High warning   |
| U_INST_RES | FLOAT32 | 0.00...4.00       | xUn  | Residual voltage Amplitude, magnitude of instantaneous value |

*Table continues on the next page*

| Name        | Type    | Values (Range)  | Unit | Description   |
|-------------|---------|---|------|---|
| U_ ANGL_RES | FLOAT32 | -180.00...180.00  | deg  | Residual voltage angle                                  |
| U_DB_RES    | FLOAT32 | 0.00...4.00   | xUn  | Residual voltage Amplitude, magnitude of reported value |
| U_DMD_RES   | FLOAT32 | 0.00...4.00   | xUn  | Demand value of residual voltage                        |
| U_RANGE_RES | Enum    | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low |      | Residual voltage Amplitude range                        |

### 7.1.7.6 Technical data

Table 748: RESVMMXU Technical data

| Characteristic           | Value   |
|--------------------------|---|
| Operation accuracy       | Depending on the frequency of the measured current: $f/f_n = \pm 2 \text{ Hz}$<br>$\pm 0.5\%$ or $\pm 0.002 \times U_n$ |
| Suppression of harmonics | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$<br>RMS: No suppression                                |

### 7.1.7.7 Technical revision history

Table 749: RESVMMXU Technical revision history

| Technical revision | Change  |
|--------------------|---|
| B                  | -   |
| C                  | Residual voltage angle and demand value added to Monitored data view. |
| D                  | Internal improvement.   |
| E                  | Internal improvement.   |

## 7.1.8 Frequency measurement FMMXU



### 7.1.8.1 Identification

| Function description  | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|-----------------------|--------------------------|--------------------------|-------------------------------|
| Frequency measurement | FMMXU                    | f                        | f                             |

### 7.1.8.2 Function block

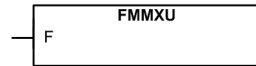


Figure 418: Function block

### 7.1.8.3 Functionality

The frequency measurement range is 35...75 Hz. The measured frequencies outside the measurement range are considered to be out of range and the minimum and maximum values are then shown in parentheses.

When the frequencies cannot be measured, for example, due to too low voltage amplitude, the default value for frequency measurement can be selected with the *Def frequency Sel* setting parameter. In the “Nominal” mode the frequency is set to 50 Hz (or 60 Hz) and in “Zero” mode the frequency is set to zero and shown in parentheses.

### 7.1.8.4 Signals

#### FMMXU Input signals

Table 750: FMMXU Input signals

| Name | Type   | Default | Description               |
|------|--------|---------|---------------------------|
| F    | SIGNAL | —       | Measured system frequency |

### 7.1.8.5 Settings

#### FMMXU Settings

Table 751: FMMXU Non group settings (Basic)

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on           |      |      | 1=on    | Operation Off / On |

Table continues on the next page

| Parameter         | Values (Range) | Unit | Step | Default | Description   |
|-------------------|----------------|------|------|---------|---|
|                   | 5=off          |      |      |         |   |
| F high high limit | 35.00...75.00  | Hz   | 1    | 60.00   | High alarm frequency limit  |
| F high limit      | 35.00...75.00  | Hz   | 1    | 55.00   | High warning frequency limit  |
| F low limit       | 35.00...75.00  | Hz   | 1    | 45.00   | Low warning frequency limit   |
| F low low limit   | 35.00...75.00  | Hz   | 1    | 40.00   | Low alarm frequency limit   |
| F deadband        | 100...100000   |      | 1    | 1000    | Deadband configuration value for integral calculation (percentage of difference between min and max as 0,001 % s) |

**Table 752: FMMXU Non group settings (Advanced)**

| Parameter         | Values (Range)      | Unit | Step | Default   | Description                 |
|-------------------|---------------------|------|------|-----------|-----------------------------|
| Def frequency Sel | 1=Nominal<br>2=Zero |      |      | 1=Nominal | Default frequency selection |

**7.1.8.6**

**Monitored data**

**FMMXU Monitored data**

**Table 753: FMMXU Monitored data**

| Name    | Type    | Values (Range) | Unit | Description                    |
|---------|---------|----------------|------|--------------------------------|
| f-Hz    | FLOAT32 | 35.00...75.00  | Hz   | Measured frequency             |
| F_INST  | FLOAT32 | 35.00...75.00  | Hz   | Frequency, instantaneous value |
| F_DB    | FLOAT32 | 35.00...75.00  | Hz   | Frequency, reported value      |
| F_RANGE | Enum    | 0=normal       |      | Measured frequency range       |

| Name | Type | Values (Range)                              | Unit | Description |
|------|------|---|------|-------------|
|      |      | 1=high<br>2=low<br>3=high-high<br>4=low-low |      |             |

### 7.1.8.7 Technical data

Table 754: FMMXU Technical data

| Characteristic     | Value  |
|--------------------|--|
| Operation accuracy | $\pm 5$ mHz<br>(in measurement range 35...75 Hz) |

### 7.1.8.8 Technical revision history

Table 755: FMMXU Technical revision history

| Technical revision | Change   |
|--------------------|--|
| B                  | Added new setting <i>Def frequency Sel.</i> Frequency measurement range lowered from 35 Hz to 10 Hz. |

## 7.1.9 Sequence current measurement CSMSQI

### 7.1.9.1 Identification

| Function description         | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|------------------------------|--------------------------|--------------------------|-------------------------------|
| Sequence current measurement | CSMSQI                   | I1, I2, I0               | I1, I2, I0                    |

### 7.1.9.2 Function block

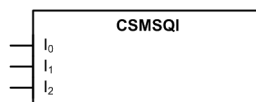


Figure 419: Function block

### 7.1.9.3 Signals

**CSMSQI Input signals****Table 756: CSMSQI Input signals**

| Name           | Type   | Default | Description               |
|----------------|--------|---------|---------------------------|
| I <sub>0</sub> | SIGNAL | 0       | Zero sequence current     |
| I <sub>1</sub> | SIGNAL | 0       | Positive sequence current |
| I <sub>2</sub> | SIGNAL | 0       | Negative sequence current |

**CSMSQI Output signals****7.1.9.4****Settings****CSMSQI Settings****Table 757: CSMSQI Non group settings (Basic)**

| Parameter            | Values (Range) | Unit | Step | Default | Description  |
|----------------------|----------------|------|------|---------|--|
| Operation            | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On                                       |
| Ps Seq A Hi high Lim | 0.00...40.00   | xIn  | 1    | 1.40    | High alarm current limit for positive sequence current   |
| Ps Seq A high limit  | 0.00...40.00   | xIn  | 1    | 1.20    | High warning current limit for positive sequence current |
| Ps Seq A low limit   | 0.00...40.00   | xIn  | 1    | 0.00    | Low warning current limit for positive sequence current  |
| Ps Seq A low low Lim | 0.00...40.00   | xIn  | 1    | 0.00    | Low alarm current limit for positive sequence current    |
| Ps Seq A deadband    | 100...100000   |      | 1    | 2500    | Deadband configuration value for posi-                   |

*Table continues on the next page*

| Parameter            | Values (Range) | Unit | Step | Default | Description  |
|----------------------|----------------|------|------|---------|--|
|                      |                |      |      |         | tive sequence current for integral calculation. (percentage of difference between min and max as 0,001 % s)                                      |
| Ng Seq A Hi high Lim | 0.00...40.00   | xIn  | 1    | 0.20    | High alarm current limit for negative sequence current   |
| Ng Seq A High limit  | 0.00...40.00   | xIn  | 1    | 0.05    | High warning current limit for negative sequence current   |
| Ng Seq A low limit   | 0.00...40.00   | xIn  | 1    | 0.00    | Low warning current limit for negative sequence current  |
| Ng Seq A low low Lim | 0.00...40.00   | xIn  | 1    | 0.00    | Low alarm current limit for negative sequence current  |
| Ng Seq A deadband    | 100...100000   |      | 1    | 2500    | Deadband configuration value for negative sequence current for integral calculation. (percentage of difference between min and max as 0,001 % s) |
| Zro A Hi high Lim    | 0.00...40.00   | xIn  | 1    | 0.20    | High alarm current limit for zero sequence current   |
| Zro A High limit     | 0.00...40.00   | xIn  | 1    | 0.05    | High warning current limit for zero se-  |

*Table continues on the next page*

| Parameter         | Values (Range) | Unit | Step | Default | Description  |
|-------------------|----------------|------|------|---------|--|
|                   |                |      |      |         | quence current   |
| Zro A low limit   | 0.00...40.00   | xIn  | 1    | 0.00    | Low warning current limit for zero sequence current  |
| Zro A low low Lim | 0.00...40.00   | xIn  | 1    | 0.00    | Low alarm current limit for zero sequence current  |
| Zro A deadband    | 100...100000   |      | 1    | 2500    | Deadband configuration value for zero sequence current for integral calculation. (percentage of difference between min and max as 0,001 % s) |

7.1.9.5

Monitored data

CSMSQI Monitored data

Table 758: CSMSQI Monitored data

| Name     | Type    | Values (Range)   | Unit | Description  |
|----------|---------|------------------|------|--|
| NgSeq-A  | FLOAT32 | 0.00...40.00     | xIn  | Measured negative sequence current                       |
| PsSeq-A  | FLOAT32 | 0.00...40.00     | xIn  | Measured positive sequence current                       |
| ZroSeq-A | FLOAT32 | 0.00...40.00     | xIn  | Measured zero sequence current                           |
| I2_INST  | FLOAT32 | 0.00...40.00     | xIn  | Negative sequence current amplitude, instantaneous value |
| I2_ANGL  | FLOAT32 | -180.00...180.00 | deg  | Negative sequence current angle                          |

Table continues on the next page

| Name     | Type    | Values (Range)  | Unit | Description  |
|----------|---------|---|------|--|
| I2_DB    | FLOAT32 | 0.00...40.00  | xIn  | Negative sequence current amplitude, reported value      |
| I2_RANGE | Enum    | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low |      | Negative sequence current amplitude range                |
| I1_INST  | FLOAT32 | 0.00...40.00  | xIn  | Positive sequence current amplitude, instantaneous value |
| I1_ANGL  | FLOAT32 | -180.00...180.00  | deg  | Positive sequence current angle                          |
| I1_DB    | FLOAT32 | 0.00...40.00  | xIn  | Positive sequence current amplitude, reported value      |
| I1_RANGE | Enum    | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low |      | Positive sequence current amplitude range                |
| I0_INST  | FLOAT32 | 0.00...40.00  | xIn  | Zero sequence current amplitude, instantaneous value     |
| I0_ANGL  | FLOAT32 | -180.00...180.00  | deg  | Zero sequence current angle                              |
| I0_DB    | FLOAT32 | 0.00...40.00  | xIn  | Zero sequence current amplitude, reported value          |
| I0_RANGE | Enum    | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low |      | Zero sequence current amplitude range                    |

### 7.1.9.6 Technical data

Table 759: CSMSQI Technical data

| Characteristic           | Value   |
|--------------------------|---|
| Operation accuracy       | Depending on the frequency of the measured current: $f/f_n = \pm 2$ Hz<br><br>$\pm 1.0\%$ or $\pm 0.002 \times I_n$<br>at currents in the range of $0.01 \dots 4.00 \times I_n$ |
| Suppression of harmonics | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$   |

### 7.1.9.7 Technical revision history

Table 760: CSMSQI Technical revision history

| Technical revision | Change  |
|--------------------|---|
| A                  | -   |
| B                  | Sequence current angle values added to the Monitored data view. |
| C                  | Internal improvement.   |

## 7.1.10 Sequence voltage measurement VSMSQI

### 7.1.10.1 Identification

| Function description         | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|------------------------------|--------------------------|--------------------------|-------------------------------|
| Sequence voltage measurement | VSMSQI                   | U1, U2, U0               | V1, V2, V0                    |

### 7.1.10.2 Function block

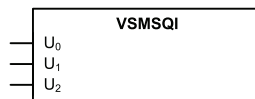


Figure 420: Function block

### 7.1.10.3 Signals

#### VSMSQI Input signals



**Table 761: VSMSQI Input signals**

| Name           | Type   | Default | Description                     |
|----------------|--------|---------|---------------------------------|
| U <sub>0</sub> | SIGNAL | 0       | Zero sequence voltage           |
| U <sub>1</sub> | SIGNAL | 0       | Positive phase sequence voltage |
| U <sub>2</sub> | SIGNAL | 0       | Negative phase sequence voltage |

**VSMSQI Output signals****7.1.10.4 Settings****VSMSQI Settings****Table 762: VSMSQI Non group settings (Basic)**

| Parameter            | Values (Range) | Unit | Step | Default | Description  |
|----------------------|----------------|------|------|---------|--|
| Operation            | 1=on<br>5=off  |      |      | 1=on    | Operation Off / On   |
| Ps Seq V Hi high Lim | 0.00...4.00    | xUn  | 1    | 1.40    | High alarm voltage limit for positive sequence voltage             |
| Ps Seq V high limit  | 0.00...4.00    | xUn  | 1    | 1.20    | High warning voltage limit for positive sequence voltage           |
| Ps Seq V low limit   | 0.00...4.00    | xUn  | 1    | 0.00    | Low warning voltage limit for positive sequence voltage            |
| Ps Seq V low low Lim | 0.00...4.00    | xUn  | 1    | 0.00    | Low alarm voltage limit for positive sequence voltage              |
| Ps Seq V deadband    | 100...100000   |      | 1    | 10000   | Deadband configuration value for positive sequence voltage for in- |

*Table continues on the next page*

| Parameter            | Values (Range) | Unit | Step | Default | Description  |
|----------------------|----------------|------|------|---------|--|
|                      |                |      |      |         | tegral calculation. (percentage of difference between min and max as 0,001 % s)  |
| Ng Seq V Hi high Lim | 0.00...4.00    | xUn  | 1    | 0.20    | High alarm voltage limit for negative sequence voltage   |
| Ng Seq V High limit  | 0.00...4.00    | xUn  | 1    | 0.05    | High warning voltage limit for negative sequence voltage   |
| Ng Seq V low limit   | 0.00...4.00    | xUn  | 1    | 0.00    | Low warning voltage limit for negative sequence voltage  |
| Ng Seq V low low Lim | 0.00...4.00    | xUn  | 1    | 0.00    | Low alarm voltage limit for negative sequence voltage  |
| Ng Seq V deadband    | 100...100000   |      | 1    | 10000   | Deadband configuration value for negative sequence voltage for integral calculation. (percentage of difference between min and max as 0,001 % s) |
| Zro V Hi high Lim    | 0.00...4.00    | xUn  | 1    | 0.20    | High alarm voltage limit for zero sequence voltage   |
| Zro V High limit     | 0.00...4.00    | xUn  | 1    | 0.05    | High warning voltage limit for zero sequence voltage   |

Table continues on the next page

| Parameter         | Values (Range) | Unit | Step | Default | Description  |
|-------------------|----------------|------|------|---------|--|
| Zro V low limit   | 0.00...4.00    | xUn  | 1    | 0.00    | Low warning voltage limit for zero sequence voltage  |
| Zro V low low Lim | 0.00...4.00    | xUn  | 1    | 0.00    | Low alarm voltage limit for zero sequence voltage  |
| Zro V dead-band   | 100...100000   |      | 1    | 10000   | Deadband configuration value for zero sequence voltage for integral calculation. (percentage of difference between min and max as 0,001 % s) |

### 7.1.10.5

## Monitored data

### VSMSQI Monitored data

**Table 763: VSMSQI Monitored data**

| Name      | Type    | Values (Range)   | Unit | Description  |
|-----------|---------|------------------|------|--|
| NgSeq-kV  | FLOAT32 | 0.00...4.00      | xUn  | Measured negative sequence voltage                       |
| PsSeq-kV  | FLOAT32 | 0.00...4.00      | xUn  | Measured positive sequence voltage                       |
| ZroSeq-kV | FLOAT32 | 0.00...4.00      | xUn  | Measured zero sequence voltage                           |
| U2_INST   | FLOAT32 | 0.00...4.00      | xUn  | Negative sequence voltage amplitude, instantaneous value |
| U2_ANGL   | FLOAT32 | -180.00...180.00 | deg  | Negative sequence voltage angle                          |

*Table continues on the next page*

| Name     | Type    | Values (Range)  | Unit | Description  |
|----------|---------|---|------|--|
| U2_DB    | FLOAT32 | 0.00...4.00   | xUn  | Negative sequence voltage amplitude, reported value      |
| U2_RANGE | Enum    | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low |      | Negative sequence voltage amplitude range                |
| U1_INST  | FLOAT32 | 0.00...4.00   | xUn  | Positive sequence voltage amplitude, instantaneous value |
| U1_ANGL  | FLOAT32 | -180.00...180.00  | deg  | Positive sequence voltage angle                          |
| U1_DB    | FLOAT32 | 0.00...4.00   | xUn  | Positive sequence voltage amplitude, reported value      |
| U1_RANGE | Enum    | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low |      | Positive sequence voltage amplitude range                |
| U0_INST  | FLOAT32 | 0.00...4.00   | xUn  | Zero sequence voltage amplitude, instantaneous value     |
| U0_ANGL  | FLOAT32 | -180.00...180.00  | deg  | Zero sequence voltage angle                              |
| U0_DB    | FLOAT32 | 0.00...4.00   | xUn  | Zero sequence voltage amplitude, reported value          |
| U0_RANGE | Enum    | 0=normal<br>1=high<br>2=low<br>3=high-high<br>4=low-low |      | Zero sequence voltage amplitude range                    |

## 7.1.10.6 Technical data

Table 764: VSMSQI Technical data

| Characteristic           | Value  |
|--------------------------|--|
| Operation accuracy       | Depending on the frequency of the voltage measured: $f_n \pm 2 \text{ Hz}$<br>At voltages in range $0.01 \dots 1.15 \times U_n$<br>$\pm 1.0\%$ or $\pm 0.002 \times U_n$ |
| Suppression of harmonics | DFT: $-50 \text{ dB}$ at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$  |

## 7.1.11 Three-phase power and energy measurement PEMMXU

### 7.1.11.1 Identification

| Function description                     | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--|--------------------------|--------------------------|-------------------------------|
| Three-phase power and energy measurement | PEMMXU                   | P, E                     | P, E                          |

### 7.1.11.2 Function block

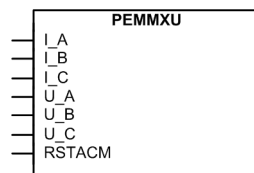


Figure 421: Function block

### 7.1.11.3 Signals

#### PEMMXU Input signals

Table 765: PEMMXU Input signals

| Name | Type   | Default | Description     |
|------|--------|---------|-----------------|
| I_A  | SIGNAL | 0       | Phase A current |
| I_B  | SIGNAL | 0       | Phase B current |
| I_C  | SIGNAL | 0       | Phase C current |
| U_A  | SIGNAL | 0       | Phase A voltage |
| U_B  | SIGNAL | 0       | Phase B voltage |

Table continues on the next page

| Name   | Type    | Default | Description                         |
|--------|---------|---------|-------------------------------------|
| U_C    | SIGNAL  | 0       | Phase C voltage                     |
| RSTACM | BOOLEAN | 0=False | Reset of accumulated energy reading |

**PEMMXU Output signals**

**7.1.11.4**

**Settings**

**PEMMXU Settings**

**Table 766: PEMMXU Non group settings (Basic)**

| Parameter          | Values (Range)         | Unit | Step | Default   | Description   |
|--------------------|------------------------|------|------|-----------|---|
| Operation          | 1=on<br>5=off          |      |      | 1=on      | Operation Off / On  |
| Power unit Mult    | 3=Kilo<br>6=Mega       |      |      | 3=Kilo    | Unit multiplier for presentation of the power related values  |
| Energy unit Mult   | 3=Kilo<br>6=Mega       |      |      | 3=Kilo    | Unit multiplier for presentation of the energy related values |
| Active power Dir   | 1=Forward<br>2=Reverse |      |      | 1=Forward | Direction of active power flow: Forward, Reverse              |
| Reactive power Dir | 1=Forward<br>2=Reverse |      |      | 1=Forward | Direction of reactive power flow: Forward, Reverse            |

**Table 767: PEMMXU Non group settings (Advanced)**

| Parameter          | Values (Range) | Unit | Step | Default | Description                                    |
|--------------------|----------------|------|------|---------|--|
| Forward Wh Initial | 0...999999999  |      | 1    | 0       | Preset Initial value for forward active energy |
| Reverse Wh Initial | 0...999999999  |      | 1    | 0       | Preset Initial value for re-                   |

*Table continues on the next page*

| Parameter            | Values (Range) | Unit | Step | Default | Description                                      |
|----------------------|----------------|------|------|---------|--|
|                      |                |      |      |         | verse active energy                              |
| Forward VARh Initial | 0...999999999  |      | 1    | 0       | Preset Initial value for forward reactive energy |
| Reverse VARh Initial | 0...999999999  |      | 1    | 0       | Preset Initial value for reverse reactive energy |

### 7.1.11.5

## Monitored data

### PEMMXU Monitored data

**Table 768: PEMMXU Monitored data**

| Name   | Type    | Values (Range)       | Unit | Description                                      |
|--------|---------|----------------------|------|--|
| S-kVA  | FLOAT32 | -999999.9...999999.9 | kVA  | Total Apparent Power                             |
| P-kW   | FLOAT32 | -999999.9...999999.9 | kW   | Total Active Power                               |
| Q-kVAr | FLOAT32 | -999999.9...999999.9 | kVAr | Total Reactive Power                             |
| PF     | FLOAT32 | -1.00...1.00         |      | Average Power factor                             |
| RSTACM | BOOLEAN | 0=False<br>1=True    |      | Reset of accumulated energy reading              |
| S_INST | FLOAT32 | -999999.9...999999.9 | kVA  | Apparent power, magnitude of instantaneous value |
| S_DB   | FLOAT32 | -999999.9...999999.9 | kVA  | Apparent power, magnitude of reported value      |
| S_DMD  | FLOAT32 | -999999.9...999999.9 | kVA  | Demand value of apparent power                   |
| P_INST | FLOAT32 | -999999.9...999999.9 | kW   | Active power, magnitude of instantaneous value   |
| P_DB   | FLOAT32 | -999999.9...999999.9 | kW   | Active power, magnitude of reported value        |

*Table continues on the next page*

| Name         | Type    | Values (Range)           | Unit  | Description                                      |
|--------------|---------|--------------------------|-------|--|
| P_DMD        | FLOAT32 | -999999.9...9999<br>99.9 | kW    | Demand value of active power                     |
| Q_INST       | FLOAT32 | -999999.9...9999<br>99.9 | kVAr  | Reactive power, magnitude of instantaneous value |
| Q_DB         | FLOAT32 | -999999.9...9999<br>99.9 | kVAr  | Reactive power, magnitude of reported value      |
| Q_DMD        | FLOAT32 | -999999.9...9999<br>99.9 | kVAr  | Demand value of reactive power                   |
| PF_INST      | FLOAT32 | -1.00...1.00             |       | Power factor, magnitude of instantaneous value   |
| PF_DB        | FLOAT32 | -1.00...1.00             |       | Power factor, magnitude of reported value        |
| PF_DMD       | FLOAT32 | -1.00...1.00             |       | Demand value of power factor                     |
| EA_RV_ACM    | INT64   | 0...999999999            | kWh   | Accumulated reverse active energy value          |
| ER_RV_ACM    | INT64   | 0...999999999            | kVArh | Accumulated reverse reactive energy value        |
| EA_FWD_ACM   | INT64   | 0...999999999            | kWh   | Accumulated forward active energy value          |
| ER_FWD_ACM   | INT64   | 0...999999999            | kVArh | Accumulated forward reactive energy value        |
| Max demand S | FLOAT32 | -999999.9...9999<br>99.9 | kVA   | Maximum demand value of apparent power           |
| Min demand S | FLOAT32 | -999999.9...9999<br>99.9 | kVA   | Minimum demand value of apparent power           |
| Max demand P | FLOAT32 | -999999.9...9999<br>99.9 | kW    | Maximum demand value of active power             |
| Min demand P | FLOAT32 | -999999.9...9999<br>99.9 | kW    | Minimum demand value of active power             |
| Max demand Q | FLOAT32 | -999999.9...9999<br>99.9 | kVAr  | Maximum demand value of reactive power           |

*Table continues on the next page*



| Name           | Type      | Values (Range)       | Unit | Description                            |
|----------------|-----------|----------------------|------|--|
| Min demand Q   | FLOAT32   | -999999.9...999999.9 | kVAr | Minimum demand value of reactive power |
| Time max dmd S | Timestamp |                      |      | Time of maximum demand                 |
| Time min dmd S | Timestamp |                      |      | Time of minimum demand                 |
| Time max dmd P | Timestamp |                      |      | Time of maximum demand                 |
| Time min dmd P | Timestamp |                      |      | Time of minimum demand                 |
| Time max dmd Q | Timestamp |                      |      | Time of maximum demand                 |
| Time min dmd Q | Timestamp |                      |      | Time of minimum demand                 |

### 7.1.11.6

### Technical data

**Table 769: PEMMXU Technical data**

| Characteristic           | Value  |
|--------------------------|--|
| Operation accuracy       | At all three currents in range $0.10...1.20 \times I_n$<br>At all three voltages in range $0.50...1.15 \times U_n$<br>At the frequency $f_n \pm 1$ Hz  |
|                          | $\pm 1.5\%$ for apparent power S<br>$\pm 1.5\%$ for active power P and active energy <sup>97</sup><br>$\pm 1.5\%$ for reactive power Q and reactive energy <sup>98</sup><br>$\pm 0.015$ for power factor |
| Suppression of harmonics | DFT: -50 dB at $f = n \times f_n$ , where $n = 2, 3, 4, 5, \dots$  |

<sup>97</sup> |PF| >0.5 which equals  $|\cos\phi| >0.5$

<sup>98</sup> |PF| <0.86 which equals  $|\sin\phi| >0.5$

### 7.1.11.7 Technical revision history

Table 770: PEMMXU Technical revision history

| Technical revision | Change   |
|--------------------|--|
| B                  | Demand values added to Monitored data. Recorded data added to store minimum and maximum demand values with timestamps. |
| C                  | Internal improvement.  |
| D                  | Internal improvement.  |

## 7.2 Disturbance recorder RDRE

### 7.2.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|----------------------|--------------------------|--------------------------|-------------------------------|
| Disturbance recorder | RDRE                     | DR                       | DFR                           |

### 7.2.2 Functionality

The IED is provided with a disturbance recorder featuring up to 20 analog measurements from IEC 61850-9-2 LE senders and 512 binary signal channels. The analog channels can be set to record either the waveform or the trend of the currents and voltages measured.

The analog channels can be set to trigger the recording function when the measured value falls below or exceeds the set values. The binary signal channels can be set to start a recording either on the rising or the falling edge of the binary signal or on both.

By default, the binary channels are set to record external or internal relay signals, for example, the start or trip signals of the relay stages, or external blocking or control signals. Binary relay signals, such as protection start and trip signals, or an external relay control signal via a binary input, can be set to trigger the recording. Recorded information is stored in a non-volatile memory and can be uploaded for subsequent fault analysis.

#### 7.2.2.1 Recorded analog inputs

All analogue channels from all received IEC 61850-9-2 LE streams are automatically recorded if the Append SMV streams setting is set as TRUE.

### 7.2.2.2 Triggering alternatives

The recording can be triggered by any or several of the following alternatives:

- Triggering according to the state change of any or several of the binary channels of the disturbance recorder. The user can set the level sensitivity with the *Level trigger mode* parameter of the corresponding binary channel.
- Triggering on limit violations of the analog channels of the disturbance recorder (high and low limit)
- Manual triggering via the *Trig recording* parameter (WHMI or communication)
- Periodic triggering.

Regardless of the triggering type, each recording generates the Recording started and Recording made events. The Recording made event indicates that the recording has been stored to the non-volatile memory. In addition, every analog channel and binary channel of the disturbance recorder has its own *Channel triggered* parameter. Manual trigger has the *Manual triggering* parameter and periodic trigger has the *Periodic triggering* parameter.

#### Triggering by binary channels

Input signals for the binary channels of the disturbance recorder can be formed from any of the digital signals that can be dynamically mapped. A change in the status of a monitored signal triggers the recorder according to the configuration and settings. Triggering on the rising edge of a digital input signal means that the recording sequence starts when the input signal is activated. Correspondingly, triggering on the falling edge means that the recording sequence starts when the active input signal resets. It is also possible to trigger from both edges. In addition, if preferred, the monitored signal can be non-triggering. The trigger setting can be set individually for each binary channel of the disturbance recorder with the *Level trigger mode* parameter of the corresponding binary channel.

#### Manual triggering

The recorder can be triggered manually via the WHMI or via communication by setting the *Trig recording* parameter to TRUE.

#### Periodic triggering

Periodic triggering means that the recorder automatically makes a recording at certain time intervals. The user can adjust the interval with the *Periodic trig time* parameter. If the value of the parameter is changed, the new setting takes effect when the next periodic triggering occurs. Setting the parameter to zero disables the triggering alternative and the setting becomes valid immediately. If a new non-zero setting needs to be valid immediately, the user should first set the *Periodic trig time* parameter to zero and then to the new value. The user can monitor the time remaining to the next triggering with the Time to trigger monitored data which counts downwards.

### 7.2.2.3 Length of recordings

The user can define the length of a recording with the *Record length* parameter. The length is given as the number of fundamental cycles.

The recordings contain data from all analog and binary channels of the disturbance recorder, at the sample rate of 80 samples per fundamental cycle.

The user can view the number of recordings currently in memory with the Number of recordings monitored data. The currently used space for disturbance recordings can be viewed with the Rec. memory used monitored data. It is shown as a percentage value.



The maximum number of recordings is 100.

### 7.2.2.4 Uploading of recordings

The IED stores COMTRADE files to the C:\COMTRADE\ folder. The files can be uploaded with the PCM tool or any appropriate computer software that can access the C:\COMTRADE\ folder.

One complete disturbance recording consists of two COMTRADE file types: the configuration file and the data file. The file name is the same for both file types. The configuration file has .CFG and the data file .DAT as the file extension.

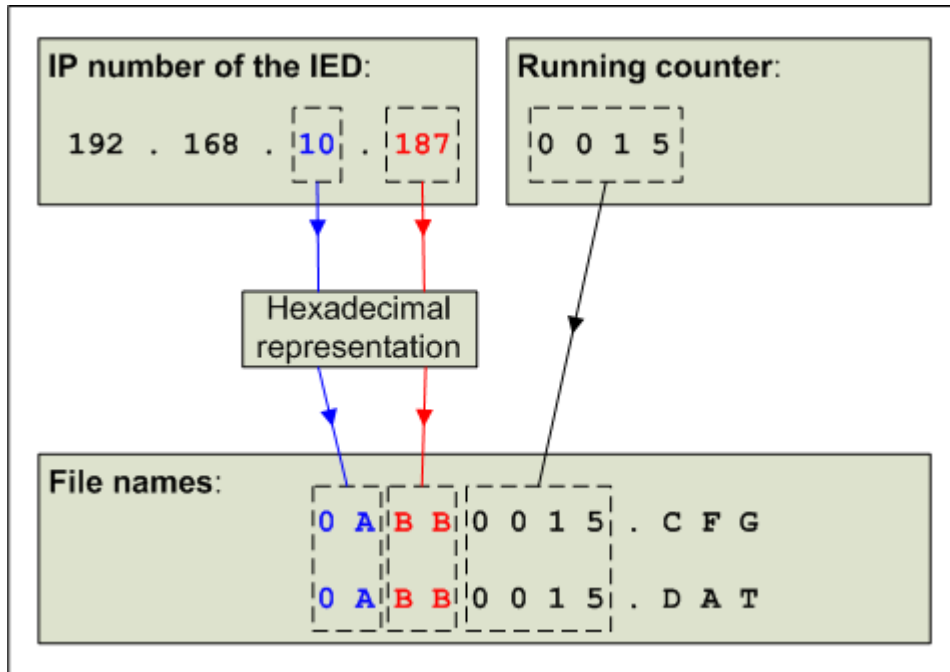


Figure 422: Disturbance recorder file naming

The naming convention of 8+3 characters is used in COMTRADE file naming. The file name is composed of the last two octets of the IED's IP number and a running counter, which has a range of 1...9999. A hexadecimal representation is used for the IP number octets. The appropriate file extension is added to the end of the file name.

### 7.2.2.5 Deleting recordings

There are several ways to delete disturbance recordings. The recordings can be deleted individually or all at once.

Individual disturbance recordings can be deleted with PCM600 or any appropriate computer software, which can access the IED's C:\COMTRADE folder. The

disturbance recording is not removed from the IED's memory until both of the corresponding COMTRADE files, .CFG and .DAT, are deleted. The user may have to delete both of the files types separately, depending on the software used.

Deleting all disturbance recordings at once is done either with PCM600 or any appropriate computer software, or from the WHMI via the **Clear > Disturbance records** menu. Deleting all disturbance recordings at once also clears the pre-trigger recording in progress.

### 7.2.2.6 Storage mode

The disturbance recorder can capture data in two modes: waveform and trend mode. The user can set the storage mode individually for each trigger source with the *Storage mode* parameter of the corresponding analog channel or binary channel, the *Stor. mode manual* parameter for manual trigger and the *Stor. mode periodic* parameter for periodic trigger.

In the waveform mode, the samples are captured according to the *Storage rate* and *Pre-trg length* parameters.

In the trend mode, one value is recorded for each enabled analog channel, once per fundamental cycle. The recorded values are RMS values, which are scaled to peak level. The binary channels of the disturbance recorder are also recorded once per fundamental cycle in the trend mode.



Only post-trigger data is captured in trend mode.

The trend mode enables recording times of  $32 * \text{Record length}$ .

### 7.2.2.7 Pre-trigger and post-trigger data

The waveforms of the disturbance recorder analog channels and the states of the disturbance recorder binary channels are constantly recorded into the history memory of the recorder. The user can adjust the percentage of the data duration preceding the triggering, that is, the so-called pre-trigger time, with the *Pre-trg length* parameter. The duration of the data following the triggering, that is, the so-called post-trigger time, is the difference between the recording length and the pre-trigger time. Changing the pre-trigger time resets the history data and the current recording under collection.

### 7.2.2.8 Operation modes

Disturbance recorder has two operation modes: saturation and overwrite mode. The user can change the operation mode of the disturbance recorder with the *Operation mode* parameter.

#### Saturation mode

In saturation mode, the captured recordings cannot be overwritten with new recordings. Capturing the data is stopped when the recording memory is full, that is, when the maximum number of recordings is reached. In this case, the event is sent via the state change (TRUE) of the *Memory full* parameter. When there is memory available again, another event is generated via the state change (FALSE) of the *Memory full* parameter.

### Overwrite mode

When the operation mode is "Overwrite" and the recording memory is full, the oldest recording is overwritten with the pre-trigger data collected for the next recording. Each time a recording is overwritten, the event is generated via the state change of the *Overwrite of rec.* parameter. The overwrite mode is recommended, if it is more important to have the latest recordings in the memory. The saturation mode is preferred, when the oldest recordings are more important.

New triggerings are blocked in both the saturation and the overwrite mode until the previous recording is completed. On the other hand, a new triggering can be accepted before all pre-trigger samples are collected for the new recording. In such a case, the recording is as much shorter as there were pre-trigger samples lacking.

### 7.2.2.9

### Exclusion mode

Exclusion mode is on, when the value set with the *Exclusion time* parameter is higher than zero. During the exclusion mode, new triggerings are ignored if the triggering reason is the same as in the previous recording. The *Exclusion time* parameter controls how long the exclusion of triggerings of same type is active after a triggering. The exclusion mode only applies to the analog and binary channel triggerings, not to periodic and manual triggerings.

When the value set with the *Exclusion time* parameter is zero, the exclusion mode is disabled and there are no restrictions on the triggering types of the successive recordings.

The exclusion time setting is global for all inputs, but there is an individual counter for each analog and binary channel of the disturbance recorder, counting the remaining exclusion time. The user can monitor the remaining exclusion time with the *Exclusion time rem* parameter (only visible via communication, IEC 61850 data ExclTmRmn) of the corresponding analog or binary channel. The *Exclusion time rem* parameter counts downwards.

## 7.2.3

### Configuration

The disturbance recorder can be configured with PCM600 or any tool supporting the IEC 61850 standard.

The disturbance recorder can be enabled or disabled with the *Operation* parameter under the **Configuration/Disturbance recorder/General** menu.

One analog signal type of the IED is mapped to each of the analog channels of the disturbance recorder.

Any external or internal digital signal of the IED which can be dynamically mapped can be connected to the binary channels of the disturbance recorder. These signals can be, for example, the start and trip signals from protection function blocks or the external binary inputs of the IED. The connection is made with dynamic mapping to the binary channel of the disturbance recorder using Application Configuration of PCM600. It is also possible to connect several digital signals to one binary channel of the disturbance recorder. In that case, the signals can be combined with logical functions, for example AND and OR. The name of the binary channel can be configured and modified by writing the new name to the *Channel id text* parameter of the corresponding binary channel.

Note that the *Channel id text* parameter is used in COMTRADE configuration files as a channel identifier.

The recording always contains all binary channels of the disturbance recorder. If one of the binary channels is disabled, the recorded state of the channel is continuously FALSE and the state changes of the corresponding channel are not recorded. The corresponding channel name for disabled binary channels in the COMTRADE configuration file is Unused BI.

To enable or disable a binary channel of the disturbance recorder, the *Operation* parameter of the corresponding channel is set to "on" or "off".

The states of manual triggering and periodic triggering are not included in the recording, but they create a state change to the *Periodic triggering* and *Manual triggering* status parameters, which in turn create events.

The TRIGGERED output can be used to control the indication LEDs of the IED. The TRIGGERED output is TRUE due to the triggering of the disturbance recorder, until all the data for the corresponding recording has been recorded.



The IP number of the IED and the content of the *Bay name* parameter are both included in the COMTRADE configuration file for identification purposes.

## 7.2.4

### Application

The disturbance recorder is used for post-fault analysis and for verifying the correct operation of protection IEDs and circuit breakers. It can record both analog and binary signal information. The analog inputs are recorded as instantaneous values and converted to primary peak value units when the IED converts the recordings to the COMTRADE format.



COMTRADE is the general standard format used in storing disturbance recordings.

The binary channels are sampled once per task execution of the disturbance recorder. The task execution interval for the disturbance recorder is the same as for the protection functions. During the COMTRADE conversion, the digital status values are repeated so that the sampling frequencies of the analog and binary channels correspond to each other. This is required by the COMTRADE standard.



The disturbance recorder follows the 1999 version of the COMTRADE standard and uses the binary data file format.

## 7.2.5 Settings

**Table 771: RDRE Non-group general settings**

| Parameter           | Values (Range)                | Unit                          | Step | Default | Description  |
|---------------------|-------------------------------|-------------------------------|------|---------|--|
| Operation           | 1=on<br>5=off                 |                               | 1    | 1=on    | Disturbance recorder on/off                                |
| Record length       | 10...500                      | fundamental cycles            | 1    | 50      | Size of the recording in fundamental cycles                |
| Pre-trg length      | 0...100                       | %                             | 1    | 50      | Length of the recording preceding the triggering           |
| Operation mode      | 1=Saturation<br>2=Overwrite   |                               | 1    | 1       | Operation mode of the recorder                             |
| Exclusion time      | 0...1 000 000                 | ms                            | 1    | 0       | The time during which triggerings of same type are ignored |
| Storage rate        | 80                            | samples per fundamental cycle |      | 80      | Storage rate of the waveform recording                     |
| Periodic trig time  | 0...604 800                   | s                             | 10   | 0       | Time between periodic triggerings                          |
| Stor. mode periodic | 0=Waveform<br>1=Trend / cycle |                               | 1    | 0       | Storage mode for periodic triggering                       |
| Stor. mode manual   | 0=Waveform<br>1=Trend / cycle |                               | 1    | 0       | Storage mode for manual triggering                         |

**Table 772: RDRE Non-group binary channel settings**

| Parameter          | Values (Range)                                | Unit | Step | Default  | Description                               |
|--------------------|---|------|------|----------|---|
| Operation          | 1=on<br>5=off                                 |      | 1    | 5=off    | Binary channel is enabled or disabled     |
| Level trigger mode | 1=Positive or Rising<br>2=Negative or Falling |      | 1    | 1=Rising | Level trigger mode for the binary channel |

*Table continues on the next page*



| Parameter       | Values (Range)                   | Unit | Step | Default             | Description   |
|-----------------|----------------------------------|------|------|---------------------|---|
|                 | 3=Both<br>4=Level trigger off    |      |      |                     |   |
| Storage mode    | 0=Waveform<br>1=Trend / cycle    |      | 1    | 0                   | Storage mode for the binary channel                                     |
| Channel id text | 0 to 64 characters, alphanumeric |      |      | DR binary channel X | Identification text for the analog channel used in the COM-TRADE format |

Table 773: RDRE Control data

| Parameter        | Values (Range)      | Unit | Step | Default | Description                              |
|------------------|---------------------|------|------|---------|--|
| Trig recording   | 0=Cancel<br>1=Trig  |      |      |         | Trigger the disturbance recording        |
| Clear recordings | 0=Cancel<br>1=Clear |      |      |         | Clear all recordings currently in memory |

## 7.2.6

### Monitored data

Table 774: RDRE Monitored data

| Parameter            | Values (Range) | Unit | Step | Default | Description   |
|----------------------|----------------|------|------|---------|---|
| Number of recordings | 0...100        |      |      |         | Number of recordings currently in memory  |
| Rem. amount of rec.  | 0...100        |      |      |         | Remaining amount of recordings that fit into the available recording memory, when current settings are used |
| Rec. memory used     | 0...100        | %    |      |         | Storage mode for the binary channel   |
| Time to trigger      | 0...604 800    | s    |      |         | Time remaining to the   |

| Parameter | Values (Range) | Unit | Step | Default | Description              |
|-----------|----------------|------|------|---------|--------------------------|
|           |                |      |      |         | next periodic triggering |

## 7.2.7 Technical revision history

Table 775: RDRE Technical revision history

| Technical revision | Change  |
|--------------------|---|
| B                  | ChNum changed to EChNum (RADR's).<br>RADR9...12 added (Analog channel 9 -12).<br>RBDR33...64 added (Binary channel 33 - 64).              |
| C                  | New channels added to parameter <i>Channel selection</i> . Selection names for <i>Trig Recording</i> and <i>Clear Recordings</i> updated. |
| D                  | Symbols in the <i>Channel selection</i> setting are updated.  |
| E                  | New channels IL1C, IL2C and IL3C added to <i>Channel selection</i> parameter.   |
| F                  | Internal Improvement.   |
| G                  | Internal Improvement.   |
| H                  | Modified for SSC600   |

## 7.3 Tap changer position indicator TPOSYLTC

### 7.3.1 Identification

| Function description            | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---------------------------------|--------------------------|--------------------------|-------------------------------|
| Tap changer position indication | TPOSYLTC                 | TPOSM                    | 84M                           |

## 7.3.2 Function block

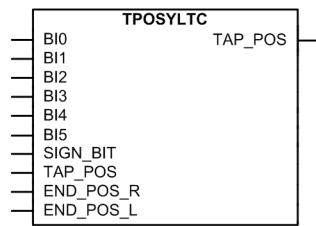


Figure 423: Function block

## 7.3.3 Functionality

The tap changer position indication function TPOSYLTC is used for transformer tap position supervision. The binary inputs can be used for converting a binary-coded tap changer position to a tap position status indication. RTD sensor information and tap position supervision through mA is possible, if the bay level merging unit or relay is equipped with RTD card and if the measurements are sent to the protective device via GOOSE message.

There are three user-selectable conversion modes available for the 7-bit binary inputs where MSB is used as the SIGN bit: the natural binary-coded boolean input to the signed integer output, binary coded decimal BCD input to the signed integer output and binary reflected GRAY coded input to the signed integer output.

## 7.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off". When the function is disabled, the tap position quality information is changed accordingly. When the tap position information is not available, it is recommended to disable this function with the *Operation* setting.

The operation of the tap changer position indication function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

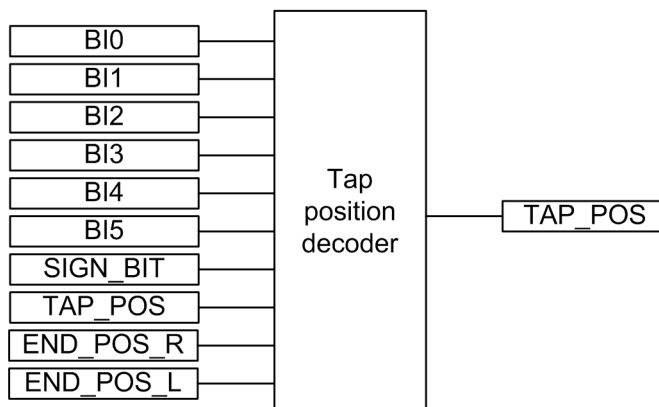


Figure 424: Functional module diagram

### Tap position decoder

When there is a wired connection to the `TAP_POS` input connector, the corresponding tap changer position is decoded from the `mA` or `RTD` input. With SSC600 this needs to be measured with a bay level merging unit or relay, and sent to the protective device via GOOSE message. When there is no wired connection to the `TAP_POS` connector, the binary inputs are expected to be used for the tap changer position information. The tap changer position value and quality are internally shared to other functions. The value is available in the Monitored data view or as a `TAP_POS` output signal.

The function has three alternative user selectable operation modes: "NAT2INT", "BCD2INT" and "GRAY2INT". The operation mode is selected with the *Operation mode* setting. Each operation mode can be used to convert a maximum of 6-bit coded input to an 8-bit signed short integer output. For less than 6-bit input, for example 19 positions with 5 bits when the BCD coding is used, the rest of the bits can be set to `FALSE` (0).

The operation mode "NAT2INT" is selected when the natural binary coding is used for showing the position of the transformer tap changer. The basic principle of the natural binary coding is to calculate the sum of the bits set to `TRUE` (1). The LSB has the factor 1. Each following bit has the previous factor multiplied by 2. This is also called dual coding.

The operation mode "BCD2INT" is selected when the binary-coded decimal coding is used for showing the position of the transformer tap changer. The basic principle with the binary-coded decimal coding is to calculate the sum of the bits set to `TRUE` (1). The four bits nibble (BI3...BI0) have a typical factor to the natural binary coding. The sum of the values should not be more than 9. If the nibble sum is greater than 9, the tap position output validity is regarded as bad.

The operation mode "GRAY2INT" is selected when the binary-reflected Gray coding is used for showing the position of the transformer tap changer. The basic principle of the Gray coding is that only one actual bit changes value with consecutive positions. This function is based on the common binary-reflected Gray code which is used with some tap changers. Changing the bit closest to the right side bit gives a new pattern.

An additional separate input, `SIGN_BIT`, can be used for negative values. If the values are positive, the input is set to `FALSE` (0). If the `SIGN_BIT` is set to `TRUE` (1) making the number negative, the remaining bits are identical to those of the coded positive number.

The tap position validity is set to good in all valid cases. The quality is set to bad in invalid combinations in the binary inputs. For example, when the "BCD2INT" mode is selected and the input binary combination is "0001101", the quality is set to bad. For negative values, when the `SIGN_BIT` is set to `TRUE` (1) and the input binary combination is "1011011", the quality is set to bad.

If the tap changer has auxiliary contacts for indicating the extreme positions of the tap changer, their status can be connected to `END_POS_R` and `END_POS_L` inputs. The `END_POS_R` (End position raise or highest allowed tap position reached) status refers to the extreme position that results in the highest number of the taps in the tap changer. Similarly, `END_POS_L` (End position lower or lowest allowed tap position reached) status refers to the extreme position that results in the lowest number of the taps in the tap changer. `TAP_POS` output is dedicated for transferring the validated tap position for the functions that need tap position information, for example OLATCC and TRxPTDF. It includes both the actual position information

and the status of reached end positions, assuming that inputs `END_POS_R` and `END_POS_L` are connected.

**Table 776: Truth table of the decoding modes**

| Inputs   |     |     |     |     |     |     | TAP_POS outputs |             |              |
|----------|-----|-----|-----|-----|-----|-----|-----------------|-------------|--------------|
| SIGN_BIT | BI5 | BI4 | BI3 | BI2 | BI1 | BI0 | NAT2I<br>NT     | BCD2I<br>NT | GRAY2<br>INT |
| ...      |     | ... |     | ... |     | ... | ...             | ...         | ...          |
| 1        | 0   | 0   | 0   | 0   | 1   | 1   | -3              | -3          | -2           |
| 1        | 0   | 0   | 0   | 0   | 1   | 0   | -2              | -2          | -3           |
| 1        | 0   | 0   | 0   | 0   | 0   | 1   | -1              | -1          | -1           |
| 0        | 0   | 0   | 0   | 0   | 0   | 0   | 0               | 0           | 0            |
| 0        | 0   | 0   | 0   | 0   | 0   | 1   | 1               | 1           | 1            |
| 0        | 0   | 0   | 0   | 0   | 1   | 0   | 2               | 2           | 3            |
| 0        | 0   | 0   | 0   | 0   | 1   | 1   | 3               | 3           | 2            |
| 0        | 0   | 0   | 0   | 1   | 0   | 0   | 4               | 4           | 7            |
| 0        | 0   | 0   | 0   | 1   | 0   | 1   | 5               | 5           | 6            |
| 0        | 0   | 0   | 0   | 1   | 1   | 0   | 6               | 6           | 4            |
| 0        | 0   | 0   | 0   | 1   | 1   | 1   | 7               | 7           | 5            |
| 0        | 0   | 0   | 1   | 0   | 0   | 0   | 8               | 8           | 15           |
| 0        | 0   | 0   | 1   | 0   | 0   | 1   | 9               | 9           | 14           |
| 0        | 0   | 0   | 1   | 0   | 1   | 0   | 10              | 9           | 12           |
| 0        | 0   | 0   | 1   | 0   | 1   | 1   | 11              | 9           | 13           |
| 0        | 0   | 0   | 1   | 1   | 0   | 0   | 12              | 9           | 8            |
| 0        | 0   | 0   | 1   | 1   | 0   | 1   | 13              | 9           | 9            |
| 0        | 0   | 0   | 1   | 1   | 1   | 0   | 14              | 9           | 11           |
| 0        | 0   | 0   | 1   | 1   | 1   | 1   | 15              | 9           | 10           |
| 0        | 0   | 1   | 0   | 0   | 0   | 0   | 16              | 10          | 31           |
| 0        | 0   | 1   | 0   | 0   | 0   | 1   | 17              | 11          | 30           |
| 0        | 0   | 1   | 0   | 0   | 1   | 0   | 18              | 12          | 28           |
| 0        | 0   | 1   | 0   | 0   | 1   | 1   | 19              | 13          | 29           |
| 0        | 0   | 1   | 0   | 1   | 0   | 0   | 20              | 14          | 24           |
| 0        | 0   | 1   | 0   | 1   | 0   | 1   | 21              | 15          | 25           |
| 0        | 0   | 1   | 0   | 1   | 1   | 0   | 22              | 16          | 27           |
| 0        | 0   | 1   | 0   | 1   | 1   | 1   | 23              | 17          | 26           |
| 0        | 0   | 1   | 1   | 0   | 0   | 0   | 24              | 18          | 16           |
| 0        | 0   | 1   | 1   | 0   | 0   | 1   | 25              | 19          | 17           |
| 0        | 0   | 1   | 1   | 0   | 1   | 0   | 26              | 19          | 19           |
| 0        | 0   | 1   | 1   | 0   | 1   | 1   | 27              | 19          | 18           |
| 0        | 0   | 1   | 1   | 1   | 0   | 0   | 28              | 19          | 23           |

*Table continues on the next page*

| Inputs |   |     |   |     |   |     | TAP_POS outputs |     |     |
|--------|---|-----|---|-----|---|-----|-----------------|-----|-----|
| 0      | 0 | 1   | 1 | 1   | 0 | 1   | 29              | 19  | 22  |
| 0      | 0 | 1   | 1 | 1   | 1 | 0   | 30              | 19  | 20  |
| 0      | 0 | 1   | 1 | 1   | 1 | 1   | 31              | 19  | 21  |
| 0      | 1 | 0   | 0 | 0   | 0 | 0   | 32              | 20  | 63  |
| 0      | 1 | 0   | 0 | 0   | 0 | 1   | 33              | 21  | 62  |
| 0      | 1 | 0   | 0 | 0   | 1 | 0   | 34              | 22  | 60  |
| 0      | 1 | 0   | 0 | 0   | 1 | 1   | 35              | 23  | 61  |
| 0      | 1 | 0   | 0 | 1   | 0 | 0   | 36              | 24  | 56  |
| ...    |   | ... |   | ... |   | ... | ...             | ... | ... |

### 7.3.5 Application

TPOSYLTC provides tap position information for other functions as a signed integer value that can be fed to the tap position input.

The position information of the tap changer can be coded in various methods for many applications, for example, the differential protection algorithms. In this function, the binary inputs in the transformer terminal connector are used as inputs to the function. The coding method can be chosen by setting the mode parameter. The available coding methods are BCD, Gray and Natural binary coding. Since the number of binary inputs are limited to seven, the coding functions are limited to seven bits including the sign bit and thus the six bits are used in the coding functions. The position limits for the tap positions at BCD, Gray and Natural binary coding are ±39, ±63 and ±63 respectively.

In this example, the transformer tap changer position indication is wired as a mA signal from the corresponding measuring transducer. The actual mA signal needs to be measured by the bay level merging unit or relay and sent to the protective device with GOOSE message. Since the values received with GOOSE message are floating point numbers (at least with ABB 615 series relays), the float to integer (T\_F32\_INT8) conversion is needed before the tap position information can be fed to TPOSYLTC. When there is a wired connection to the TAP\_POS connector, the validated tap changer position is presented in the TAP\_POS output that is connected to other functions, for example, OLATCC1. When there is no wired connection to the TAP\_POS connector, the binary inputs are expected to be used for the tap changer position information.

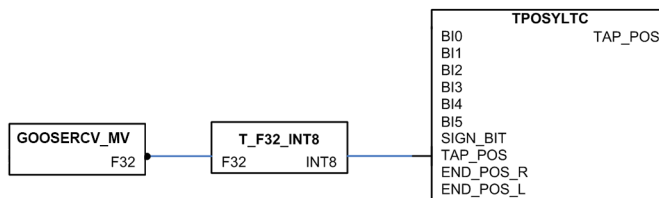


Figure 425: RTD/analog input configuration example

## 7.3.6 Signals

### 7.3.6.1 TPOSYLTC Input signals

Table 777: TPOSYLTC Input signals

| Name      | Type    | Default | Description  |
|-----------|---------|---------|--|
| BI0       | BOOLEAN | 0=False | Binary input 1   |
| BI1       | BOOLEAN | 0=False | Binary input 2   |
| BI2       | BOOLEAN | 0=False | Binary input 3   |
| BI3       | BOOLEAN | 0=False | Binary input 4   |
| BI4       | BOOLEAN | 0=False | Binary input 5   |
| BI5       | BOOLEAN | 0=False | Binary input 6   |
| SIGN_BIT  | BOOLEAN | 0=False | Binary input sign bit                                      |
| END_POS_R | BOOLEAN | 0=False | End position raise or highest allowed tap position reached |
| END_POS_L | BOOLEAN | 0=False | End position lower or lowest allowed tap position reached  |
| TAP_POS   | INT8    | 0       | Tap position indication                                    |

### 7.3.6.2 TPOSYLTC Output signals

Table 778: TPOSYLTC Output signals

| Name    | Type | Description             |
|---------|------|-------------------------|
| TAP_POS | INT8 | Tap position indication |

## 7.3.7 Settings

### 7.3.7.1 TPOSYLTC Settings

Table 779: TPOSYLTC Non group settings (Basic)

| Parameter      | Values (Range)         | Unit | Step | Default   | Description              |
|----------------|------------------------|------|------|-----------|--------------------------|
| Operation      | 1=on<br>5=off          |      |      | 1=on      | Operation Off / On       |
| Operation mode | 1=NAT2INT<br>2=BCD2INT |      |      | 2=BCD2INT | Operation mode selection |

| Parameter | Values (Range) | Unit | Step | Default | Description |
|-----------|----------------|------|------|---------|-------------|
|           | 3=GRAY2INT     |      |      |         |             |

### 7.3.8 Monitored data

#### 7.3.8.1 TPOSYLTC Monitored data

Table 780: TPOSYLTC Monitored data

| Name      | Type    | Values (Range)    | Unit | Description  |
|-----------|---------|-------------------|------|--|
| BI0       | BOOLEAN | 0=False<br>1=True |      | Binary input 1   |
| BI1       | BOOLEAN | 0=False<br>1=True |      | Binary input 2   |
| BI2       | BOOLEAN | 0=False<br>1=True |      | Binary input 3   |
| BI3       | BOOLEAN | 0=False<br>1=True |      | Binary input 4   |
| BI4       | BOOLEAN | 0=False<br>1=True |      | Binary input 5   |
| BI5       | BOOLEAN | 0=False<br>1=True |      | Binary input 6   |
| SIGN_BIT  | BOOLEAN | 0=False<br>1=True |      | Binary input sign bit                                      |
| END_POS_R | BOOLEAN | 0=False<br>1=True |      | End position raise or highest allowed tap position reached |
| END_POS_L | BOOLEAN | 0=False<br>1=True |      | End position lower or lowest allowed tap position reached  |
| TAP_POS   | INT8    | -63...63          |      | Tap position indication                                    |



### 7.3.9 Technical data

Table 781: TPOSYLTC Technical data

| Description                     | Value          |
|---------------------------------|----------------|
| Response time for binary inputs | Typical 100 ms |

### 7.3.10 Technical revision history

Table 782: TPOSYLTC Technical revision history

| Technical revision | Change  |
|--------------------|---|
| B                  | Added new input TAP_POS   |
| C                  | Internal improvement  |
| D                  | Added new inputs END_TPOS_R and<br>END_TPOS_L<br>Added a new output TAP_POS |

## 8 Control functions

### 8.1 Circuit breaker control CBXCBR, Disconnecter control DCXSWI and Earthing switch control ESXSWI

#### 8.1.1 Identification

| Function description    | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|-------------------------|--------------------------|--------------------------|-------------------------------|
| Circuit breaker control | CBXCBR                   | I<->O CB                 | I<->O CB                      |
| Disconnecter control    | DCXSWI                   | I<->O DCC                | I<->O DCC                     |
| Earthing switch control | ESXSWI                   | I<->O ESC                | I<->O ESC                     |

#### 8.1.2 Function block

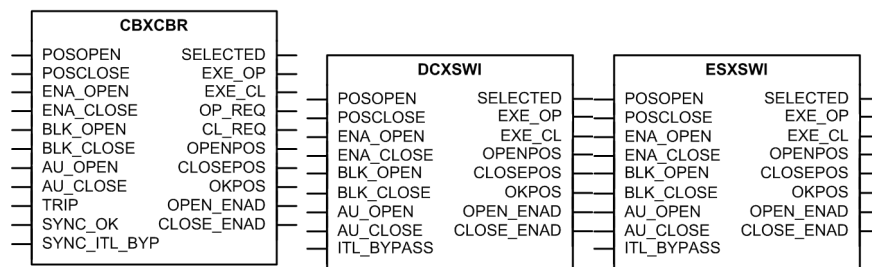


Figure 426: Function block

#### 8.1.3 Functionality

CBXCBR, DCXSWI and ESXSWI are intended for circuit breaker, disconnecter and earthing switch control and status information purposes. These functions execute commands and evaluate block conditions and different time supervision conditions. The functions perform an execution command only if all conditions indicate that a switch operation is allowed. If erroneous conditions occur, the functions indicate an appropriate cause value. The functions are designed according to the IEC 61850-7-4 standard with logical nodes CILO, CSWI and XSWI/XCBR.

The circuit breaker, disconnecter and earthing switch control functions have an operation counter for closing and opening cycles. The counter value can be read and written remotely from the place of operation or via WHMI.

## 8.1.4 Operation principle

### Status indication and validity check

The object state is defined by two digital inputs, POSOPEN and POSCLOSE, which are also available as outputs OPENPOS and CLOSEPOS together with the OKPOS according to *AAStatus indication and validity check*. The debouncing and short disturbances in an input are eliminated by filtering. The binary input filtering time can be adjusted separately for each digital input used by the function block. The validity of the digital inputs that indicate the object state is used as additional information in indications and event logging. The reporting of faulty or intermediate position of the apparatus occurs after the *Event delay* setting, assuming that the circuit breaker is still in a corresponding state.

**Table 783: Status indication**

| Input   |          | Status                       | Output  |         |          |
|---------|----------|------------------------------|---------|---------|----------|
| POSOPEN | POSCLOSE | POSITION<br>(Monitored data) | OKPOS   | OPENPOS | CLOSEPOS |
| 1=True  | 0=False  | 1=Open                       | 1=True  | 1=True  | 0=False  |
| 0=False | 1=True   | 2=Closed                     | 1=True  | 0=False | 1=True   |
| 1=True  | 1=True   | 3=Faulty/Bad (11)            | 0=False | 0=False | 0=False  |
| 0=False | 0=False  | 0=Intermediate (00)          | 0=False | 0=False | 0=False  |

### Enabling and blocking

CBXCBR, DCXSWI and ESXSWI have an enabling and blocking functionality for interlocking and synchrocheck purposes.

### Circuit breaker control CBXCBR

Normally, the CB closing is enabled (that is, CLOSE\_ENAD signal is TRUE) by activating both ENA\_CLOSE and SYNC\_OK inputs. Typically, the ENA\_CLOSE comes from the interlocking, and SYNC\_OK comes from the synchronism and energizing check. The input SYNC\_ITL\_BYP can be used for bypassing this control. The SYNC\_ITL\_BYP input can be used to activate CLOSE\_ENAD discarding the ENA\_CLOSE and SYNC\_OK input states. However, the BLK\_CLOSE input always blocks the CLOSE\_ENAD output.

The CB opening (OPEN\_ENAD) logic is the same as CB closing logic, except that SYNC\_OK is used only in closing. The SYNC\_ITL\_BYP input is used in both CLOSE\_ENAD and OPEN\_ENAD logics.

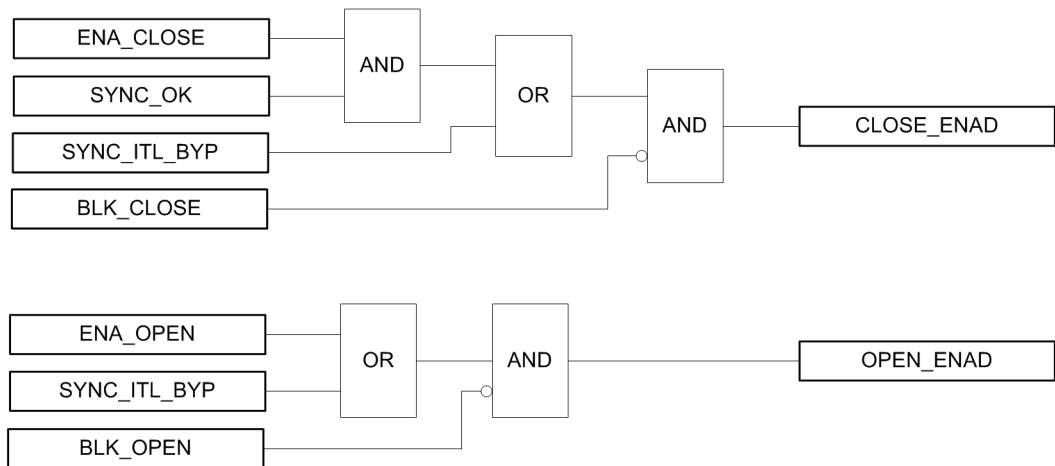


Figure 427: Enabling and blocking logic for `CLOSE_ENAD` and `OPEN_ENAD` signals

### Disconnecter control DCXSWI and earthing switch control ESXSWI

Normally, the switch closing is enabled (that is, the `CLOSE_ENAD` signal is TRUE) by activating the `ENA_CLOSE` input. The input `ITL_BYPASS` can be used for bypassing this control. The `ITL_BYPASS` input can be used to activate the `CLOSE_ENAD` discarding the `ENA_CLOSE` input state. However, the `BLK_CLOSE` input always blocks the `CLOSE_ENAD` output.

The CB opening (`OPEN_ENAD`) logic is identical to CB closing logic. The `ITL_BYPASS` input is used in both `CLOSE_ENAD` and `OPEN_ENAD` logics.

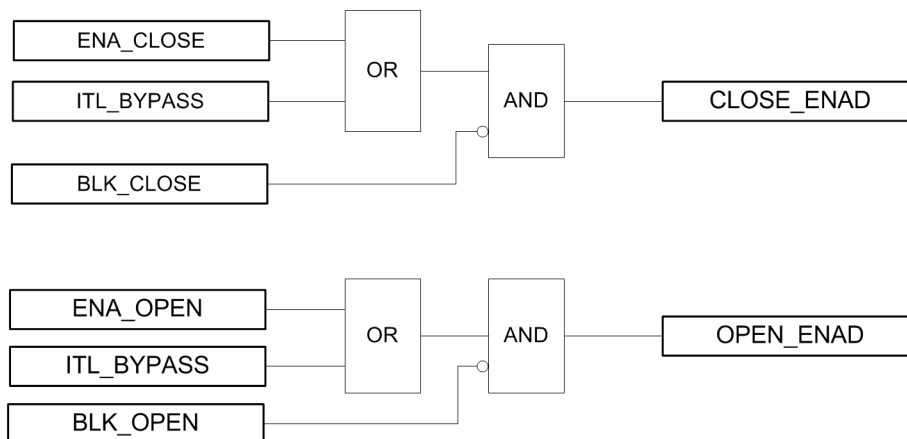


Figure 428: Enabling and blocking logic for `CLOSE_ENAD` and `OPEN_ENAD` signals

### Opening and closing operations

The opening and closing operations are available via communication, binary inputs or WHMI commands. As a prerequisite for control commands, there are enabling and blocking functionalities for both opening and closing commands (`CLOSE_ENAD` and `OPEN_ENAD` signals). If the control command is executed against the blocking or if the enabling of the corresponding command is not valid, CBXCBR, DCXSWI and ESXSWI generate an error message.

When close command is given from communication, via WHMI or activating the AU\_CLOSE input, it is carried out (the EXE\_CL output) only if CLOSE\_ENAD is TRUE.

If the SECRSYN function is used in “Command” mode, the CL\_REQ output can be used in CBXCBR. Initially, the SYNC\_OK input is FALSE. When the close command given, it activates the CL\_REQ output, which should be routed to SECRSYN. The close command is then processed only after SYNC\_OK is received from SECRSYN.



When using SECRSYN in the “Command” mode, the CBXCBR setting *Operation timeout* should be set longer than SECRSYN setting *Maximum Syn time*.

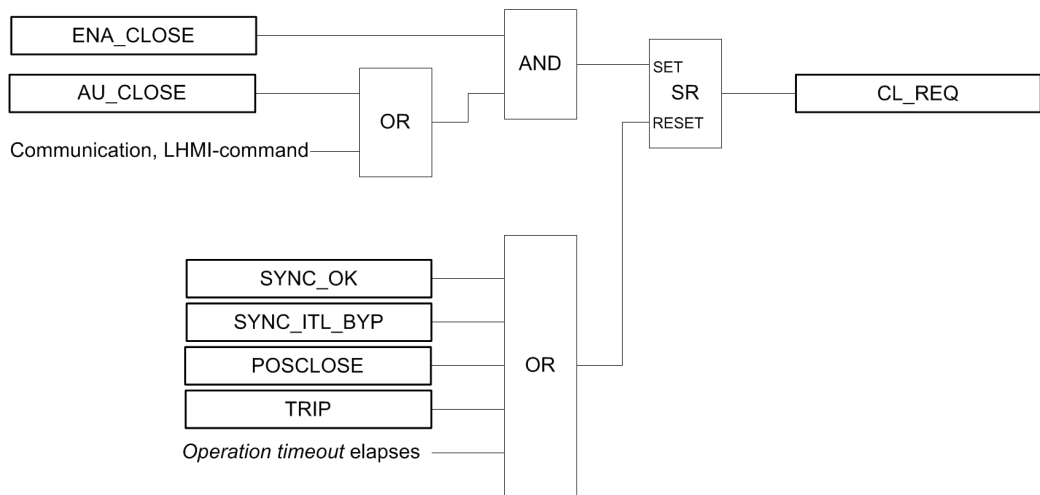


Figure 429: Condition for enabling the close request (CL\_REQ) for CBXCBR

When the open command is given from communication, via WHMI or activating the AU\_OPEN input, it is processed only if OPEN\_ENAD is TRUE. OP\_REQ output is also available.

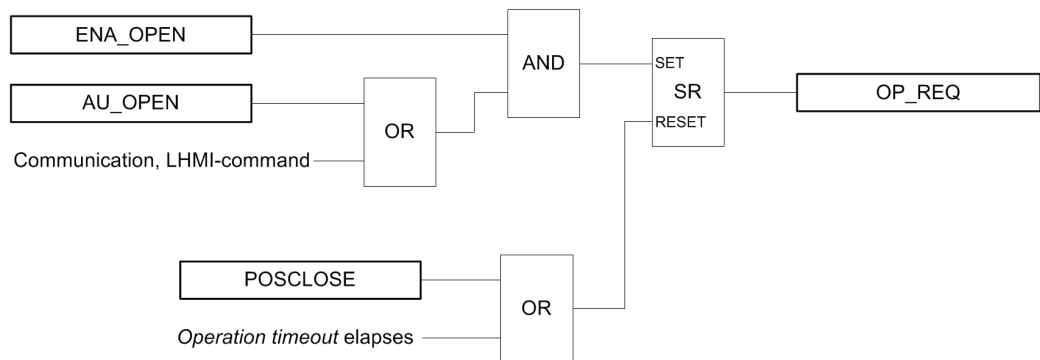


Figure 430: Condition for enabling the open request (OP\_REQ) for CBXCBR

**OPEN and CLOSE outputs**

The EXE\_OP output is activated when the open command is given (AU\_OPEN, via communication or from WHMI) and OPEN\_ENAD signal is TRUE. In addition, the protection trip commands can be routed through the CBXCBR function by using the TRIP input. When the TRIP input is TRUE, the EXE\_OP output is activated immediately and bypassing all enabling or blocking conditions.

The `EXE_CL` output is activated when the close command is given (`AU_CLOSE`, via communication or from WHMI) and `CLOSE_ENAD` signal is TRUE. When the `TRIP` input is "TRUE", CB closing is not allowed.

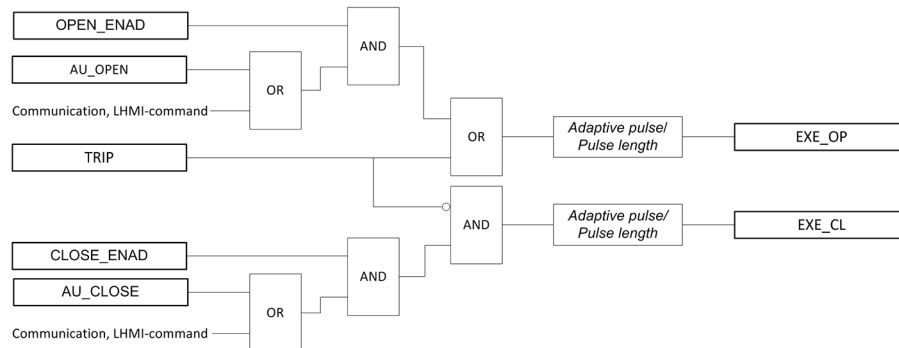


Figure 431: OPEN and CLOSE outputs logic for CBXCBR

### Opening and closing pulse widths

The pulse width type can be defined with the *Adaptive pulse* setting. The function provides two modes to characterize the opening and closing pulse widths. When the *Adaptive pulse* is set to "TRUE", it causes a variable pulse width, which means that the output pulse is deactivated when the object state shows that the apparatus has entered the correct state. If apparatus fails to enter the correct state, the output pulse is deactivated after the set *Operation timeout* setting, and an error message is displayed. When the *Adaptive pulse* is set to "FALSE", the functions always use the maximum pulse width, defined by the user-configurable *Pulse length* setting. The *Pulse length* setting is the same for both the opening and closing commands. When the apparatus already is in the right position, the maximum pulse length is given.



The *Pulse length* setting does not affect the length of the trip pulse.

### Control methods

The command execution mode can be set with the *Control model* setting. The alternatives for command execution are direct control and secured object control, which can be used to secure controlling.

The secured object control SBO is an important feature of the communication protocols that support horizontal communication, because the command reservation and interlocking signals can be transferred with a bus. All secured control operations require two-step commands: a selection step and an execution step. The secured object control is responsible for the several tasks.

- Command authority: ensures that the command source is authorized to operate the object
- Mutual exclusion: ensures that only one command source at a time can control the object
- Interlocking: allows only safe commands
- Execution: supervises the command execution
- Command canceling: cancels the controlling of a selected object.

In direct operation, a single message is used to initiate the control action of a physical device. The direct operation method uses less communication network capacity and bandwidth than the SBO method, because the procedure needs fewer messages for accurate operation.

The “status-only” mode means that control is not possible (non-controllable) via communication or from WHMI. However, it is possible to control a disconnecter (DCXSWI) from AU\_OPEN and AU\_CLOSE inputs.



AU\_OPEN and AU\_CLOSE control the object directly regardless of the set *Control model*. These inputs can be used when control is wanted to be implemented purely based on ACT logic and no additional exception handling is needed. However, in case of simultaneous open and close control, the open control is always prioritized.

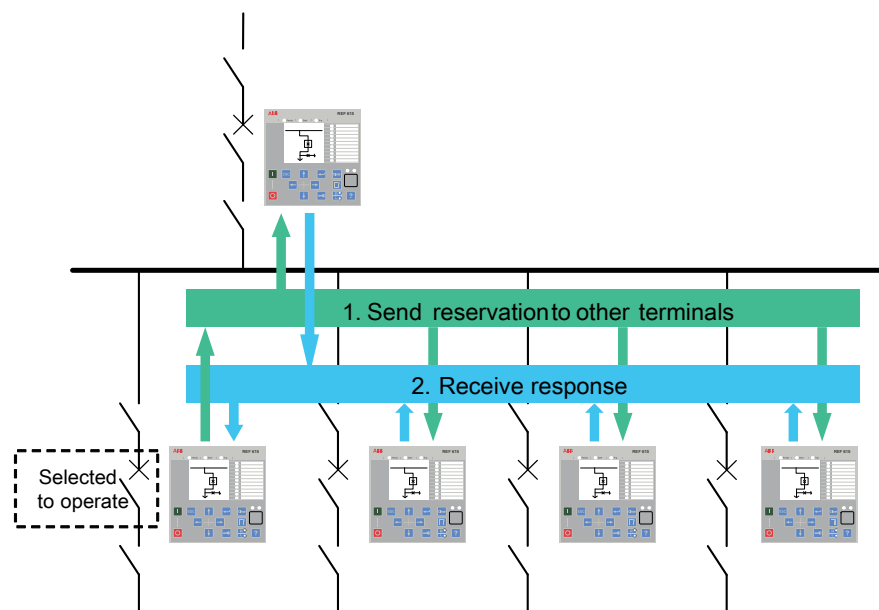


Figure 432: Control procedure in the SBO method

### Local/Remote operations

The local/remote selection affects the CBXCBR, DCXSWI and ESXSWI.

- Local: the opening and closing via communication is disabled.
- Remote: the opening and closing via WHMI is disabled.
- AU\_OPEN and AU\_CLOSE inputs function regardless of the local/remote selection.

## 8.1.5 Application

In the field of distribution and sub-transmission automation, reliable control and status indication of primary switching components both locally and remotely is in a significant role. They are needed especially in modern remotely controlled substations.

Control and status indication facilities are implemented in the same package with CBXCBR, DCXSWI and ESXSWI. When primary components are controlled in the energizing phase, for example, the correct execution sequence of the control

commands must be ensured. This can be achieved, for example, with interlocking based on the status indication of the related primary components.

## 8.1.6 Signals

### 8.1.6.1 CBXCBR Input signals

Table 784: CBXCBR Input signals

| Name         | Type    | Default | Description   |
|--------------|---------|---------|---|
| POSOPEN      | BOOLEAN | 0=False | Signal for open position of apparatus from I/O <sup>99</sup>  |
| POSCLOSE     | BOOLEAN | 0=False | Signal for close position of apparatus from I/O <sup>1)</sup> |
| ENA_OPEN     | BOOLEAN | 1=True  | Enables opening   |
| ENA_CLOSE    | BOOLEAN | 1=True  | Enables closing   |
| BLK_OPEN     | BOOLEAN | 0=False | Blocks opening  |
| BLK_CLOSE    | BOOLEAN | 0=False | Blocks closing  |
| AU_OPEN      | BOOLEAN | 0=False | Auxiliary open <sup>1)</sup> <sup>100</sup>                   |
| AU_CLOSE     | BOOLEAN | 0=False | Auxiliary close <sup>1)</sup> <sup>2)</sup>                   |
| TRIP         | BOOLEAN | 0=False | Trip signal   |
| SYNC_OK      | BOOLEAN | 1=True  | Synchronism-check OK  |
| SYNC_ITL_BYP | BOOLEAN | 0=False | Discards ENA_OPEN and ENA_CLOSE interlocking when TRUE        |

### 8.1.6.2 DCXSWI Input signals

Table 785: DCXSWI Input signals

| Name      | Type    | Default | Description               |
|-----------|---------|---------|---------------------------|
| POSOPEN   | BOOLEAN | 0=False | Apparatus open position   |
| POSCLOSE  | BOOLEAN | 0=False | Apparatus closed position |
| ENA_OPEN  | BOOLEAN | 1=True  | Enables opening           |
| ENA_CLOSE | BOOLEAN | 1=True  | Enables closing           |
| BLK_OPEN  | BOOLEAN | 0=False | Blocks opening            |

*Table continues on the next page*

<sup>99</sup> Not available for monitoring

<sup>100</sup> Always direct operation



| Name       | Type    | Default | Description   |
|------------|---------|---------|---|
| BLK_CLOSE  | BOOLEAN | 0=False | Blocks closing  |
| AU_OPEN    | BOOLEAN | 0=False | Executes the command for open direction <sup>101102</sup> |
| AU_CLOSE   | BOOLEAN | 0=False | Executes the command for close direction <sup>1) 2)</sup> |
| ITL_BYPASS | BOOLEAN | 0=False | Discards ENA_OPEN and ENA_CLOSE interlocking when TRUE    |

### 8.1.6.3 ESXSWI Input signals

Table 786: ESXSWI Input signals

| Name       | Type    | Default | Description  |
|------------|---------|---------|--|
| POSOPEN    | BOOLEAN | 0=False | Apparatus open position                                  |
| POSCLOSE   | BOOLEAN | 0=False | Apparatus closed position                                |
| ENA_OPEN   | BOOLEAN | 1=True  | Enables opening  |
| ENA_CLOSE  | BOOLEAN | 1=True  | Enables closing  |
| BLK_OPEN   | BOOLEAN | 0=False | Blocks opening   |
| BLK_CLOSE  | BOOLEAN | 0=False | Blocks closing   |
| AU_OPEN    | BOOLEAN | 0=False | Executes the command for open direction                  |
| AU_CLOSE   | BOOLEAN | 0=False | Executes the command for close direction <sup>1)2)</sup> |
| ITL_BYPASS | BOOLEAN | 0=False | Discards ENA_OPEN and ENA_CLOSE interlocking when TRUE   |

<sup>101</sup> Not available for monitoring

<sup>102</sup> Always direct operation

<sup>103</sup> Not available for monitoring

<sup>104</sup> Always direct operation

### 8.1.6.4 CBXCBR Output signals

Table 787: CBXCBR Output signals

| Name       | Type    | Description                                     |
|------------|---------|---|
| SELECTED   | BOOLEAN | Object selected                                 |
| EXE_OP     | BOOLEAN | Executes the command for open direction         |
| EXE_CL     | BOOLEAN | Executes the command for close direction        |
| OP_REQ     | BOOLEAN | Open request                                    |
| CL_REQ     | BOOLEAN | Close request                                   |
| OPENPOS    | BOOLEAN | Signal for open position of apparatus from I/O  |
| CLOSEPOS   | BOOLEAN | Signal for close position of apparatus from I/O |
| OKPOS      | BOOLEAN | Apparatus position is ok                        |
| OPEN_ENAD  | BOOLEAN | Opening is enabled based on the input status    |
| CLOSE_ENAD | BOOLEAN | Closing is enabled based on the input status    |

### 8.1.6.5 DCXSWI Output signals

Table 788: DCXSWI Output signals

| Name       | Type    | Description                                  |
|------------|---------|--|
| SELECTED   | BOOLEAN | Object selected                              |
| EXE_OP     | BOOLEAN | Executes the command for open direction      |
| EXE_CL     | BOOLEAN | Executes the command for close direction     |
| OPENPOS    | BOOLEAN | Apparatus open position                      |
| CLOSEPOS   | BOOLEAN | Apparatus closed position                    |
| OKPOS      | BOOLEAN | Apparatus position is ok                     |
| OPEN_ENAD  | BOOLEAN | Opening is enabled based on the input status |
| CLOSE_ENAD | BOOLEAN | Closing is enabled based on the input status |

## 8.1.6.6 ESXSWI Output signals

Table 789: ESXSWI Output signals

| Name       | Type    | Description                                  |
|------------|---------|--|
| SELECTED   | BOOLEAN | Object selected                              |
| EXE_OP     | BOOLEAN | Executes the command for open direction      |
| EXE_CL     | BOOLEAN | Executes the command for close direction     |
| OPENPOS    | BOOLEAN | Apparatus open position                      |
| CLOSEPOS   | BOOLEAN | Apparatus closed position                    |
| OKPOS      | BOOLEAN | Apparatus position is ok                     |
| OPEN_ENAD  | BOOLEAN | Opening is enabled based on the input status |
| CLOSE_ENAD | BOOLEAN | Closing is enabled based on the input status |

## 8.1.7 Settings

### 8.1.7.1 CBXCBR Settings

Table 790: CBXCBR Non group settings (Basic)

| Parameter       | Values (Range)   | Unit | Step  | Default                      | Description                 |
|-----------------|--|------|-------|------------------------------|-----------------------------|
| Operation       | 1=on<br>5=off  |      |       | 1=on                         | Operation mode on/off       |
| Select time-out | 10000...30000<br>0   | ms   | 10000 | 30000                        | Select time-out in ms       |
| Pulse length    | 10...60000   | ms   | 1     | 200                          | Open and close pulse length |
| Control model   | 0=status-only<br>1=direct-with-normal-security<br>4=sbo-with-enhanced-security |      |       | 4=sbo-with-enhanced-security | Select control model        |

*Table continues on the next page*

| Parameter         | Values (Range) | Unit | Step | Default                 | Description                      |
|-------------------|----------------|------|------|-------------------------|----------------------------------|
| Operation timeout | 10...60000     | ms   | 1    | 500                     | Timeout for negative termination |
| Identification    |                |      |      | CBXCBR1 switch position | Control Object identification    |

Table 791: CBXCBR Non group settings (Advanced)

| Parameter         | Values (Range)    | Unit | Step | Default | Description                              |
|-------------------|-------------------|------|------|---------|--|
| Operation counter | 0...10000         |      | 1    | 0       | Breaker operation cycles                 |
| Adaptive pulse    | 0=False<br>1=True |      |      | 1=True  | Stop in right position                   |
| Event delay       | 0...10000         | ms   | 1    | 200     | Event delay of the intermediate position |
| Vendor            |                   |      |      | 0       | External equipment vendor                |
| Serial number     |                   |      |      | 0       | External equipment serial number         |
| Model             |                   |      |      | 0       | External equipment model                 |

### 8.1.7.2

### DCXSWI Settings

Table 792: DCXSWI Non group settings (Basic)

| Parameter       | Values (Range)     | Unit | Step  | Default | Description                 |
|-----------------|--------------------|------|-------|---------|-----------------------------|
| Operation       | 1=on<br>5=off      |      |       | 1=on    | Operation mode on/off       |
| Select time-out | 10000...30000<br>0 | ms   | 10000 | 30000   | Select time-out in ms       |
| Pulse length    | 10...60000         | ms   | 1     | 100     | Open and close pulse length |

*Table continues on the next page*

| Parameter         | Values (Range)   | Unit | Step | Default                      | Description                      |
|-------------------|--|------|------|------------------------------|----------------------------------|
| Control model     | 0=status-only<br>1=direct-with-normal-security<br>4=sbo-with-enhanced-security |      |      | 4=sbo-with-enhanced-security | Select control model             |
| Operation timeout | 10...60000   | ms   | 1    | 30000                        | Timeout for negative termination |
| Identification    |  |      |      | DCXSWI1 switch position      | Control Object identification    |

Table 793: DCXSWI Non group settings (Advanced)

| Parameter         | Values (Range)    | Unit | Step | Default | Description                              |
|-------------------|-------------------|------|------|---------|--|
| Operation counter | 0...10000         |      | 1    | 0       | Breaker operation cycles                 |
| Adaptive pulse    | 0=False<br>1=True |      |      | 1=True  | Stop in right position                   |
| Event delay       | 0...60000         | ms   | 1    | 10000   | Event delay of the intermediate position |
| Vendor            |                   |      |      | 0       | External equipment vendor                |
| Serial number     |                   |      |      | 0       | External equipment serial number         |
| Model             |                   |      |      | 0       | External equipment model                 |

### 8.1.7.3

### ESXSWI Settings

Table 794: ESXSWI Non group settings (Basic)

| Parameter | Values (Range) | Unit | Step | Default | Description           |
|-----------|----------------|------|------|---------|-----------------------|
| Operation | 1=on           |      |      | 1=on    | Operation mode on/off |

*Table continues on the next page*

| Parameter         | Values (Range)   | Unit | Step  | Default                      | Description                      |
|-------------------|--|------|-------|------------------------------|----------------------------------|
|                   | 5=off  |      |       |                              |                                  |
| Select time-out   | 10000...30000<br>0   | ms   | 10000 | 30000                        | Select time-out in ms            |
| Pulse length      | 10...60000   | ms   | 1     | 100                          | Open and close pulse length      |
| Control model     | 0=status-only<br>1=direct-with-normal-security<br>4=sbo-with-enhanced-security |      |       | 4=sbo-with-enhanced-security | Select control model             |
| Operation timeout | 10...60000   | ms   | 1     | 30000                        | Timeout for negative termination |
| Identification    |  |      |       | ESXSWI1<br>switch position   | Control Object identification    |

Table 795: ESXSWI Non group settings (Advanced)

| Parameter         | Values (Range)    | Unit | Step | Default | Description                              |
|-------------------|-------------------|------|------|---------|--|
| Operation counter | 0...10000         |      | 1    | 0       | Breaker operation cycles                 |
| Adaptive pulse    | 0=False<br>1=True |      |      | 1=True  | Stop in right position                   |
| Event delay       | 0...60000         | ms   | 1    | 10000   | Event delay of the intermediate position |
| Vendor            |                   |      |      | 0       | External equipment vendor                |
| Serial number     |                   |      |      | 0       | External equipment serial number         |
| Model             |                   |      |      | 0       | External equipment model                 |

## 8.1.8 Monitored data

### 8.1.8.1 CBXCBR Monitored data

Table 796: CBXCBR Monitored data

| Name     | Type  | Values (Range)                                   | Unit | Description                   |
|----------|-------|--|------|-------------------------------|
| POSITION | Dbpos | 0=intermediate<br>1=open<br>2=closed<br>3=faulty |      | Apparatus position indication |

### 8.1.8.2 DCXSWI Monitored data

Table 797: DCXSWI Monitored data

| Name     | Type  | Values (Range)                                   | Unit | Description                   |
|----------|-------|--|------|-------------------------------|
| POSITION | Dbpos | 0=intermediate<br>1=open<br>2=closed<br>3=faulty |      | Apparatus position indication |

### 8.1.8.3 ESXSWI Monitored data

Table 798: ESXSWI Monitored data

| Name     | Type  | Values (Range)                                   | Unit | Description                   |
|----------|-------|--|------|-------------------------------|
| POSITION | Dbpos | 0=intermediate<br>1=open<br>2=closed<br>3=faulty |      | Apparatus position indication |

## 8.1.9 Technical revision history

Table 799: CBXCBR Technical revision history

| Technical revision | Change   |
|--------------------|--|
| B                  | Interlocking bypass input (ITL_BYPASS) and opening enabled (OPEN_ENAD)/closing enabled (CLOSE_ENAD) outputs added. |

*Table continues on the next page*

| Technical revision | Change  |
|--------------------|---|
|                    | ITL_BYPASS bypasses the ENA_OPEN and ENA_CLOSE states.  |
| C                  | Internal improvement.   |
| D                  | Added inputs TRIP and SYNC_OK. Renamed input ITL_BYPASS to SYNC_ITL_BYP. Added outputs CL_REQ and OP_REQ. Outputs OPENPOS and CLOSEPOS are forced to "FALSE" in case status is Faulty (11). |
| E                  | Modified for SSC600   |

Table 800: DCXSWI Technical revision history

| Technical revision | Change  |
|--------------------|---|
| B                  | Maximum and default values changed to 60 s and 10 s respectively for <i>Event delay</i> settings. Default value changed to 30 s for <i>Operation timeout</i> setting. |
| C                  | Outputs OPENPOS and CLOSEPOS are forced to "FALSE" in case status is Faulty (11).   |
| D                  | Modified for SSC600   |

Table 801: ESXSWI Technical revision history

| Technical revision | Change  |
|--------------------|---|
| B                  | Maximum and default values changed to 60 s and 10 s respectively for <i>Event delay</i> settings. Default value changed to 30 s for <i>Operation timeout</i> setting. |
| C                  | Outputs OPENPOS and CLOSEPOS are forced to "FALSE" in case status is Faulty (11).   |
| D                  | Modified for SSC600   |

## 8.2 Disconnecter position indicator DCSXSWI and earthing switch indication ESSXSWI



## 8.2.1 Identification

| Function description             | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|----------------------------------|--------------------------|--------------------------|-------------------------------|
| Disconnecter position indication | DCSXSXI                  | I<->O DC                 | I<->O DC                      |
| Earthing switch indication       | ESSXSXI                  | I<->O ES                 | I<->O ES                      |

## 8.2.2 Function block

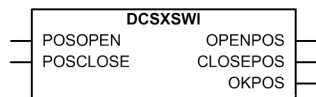


Figure 433: Function block

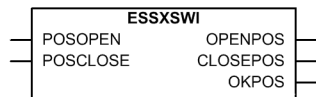


Figure 434: Function block

## 8.2.3 Functionality

The functions DCSXSXI and ESSXSXI indicate remotely and locally the open, close and undefined states of the disconnecter and earthing switch. The functionality of both is identical, but each one is allocated for a specific purpose visible in the function names. For example, the status indication of disconnectors or circuit breaker truck can be monitored with the DCSXSXI function.

The functions are designed according to the IEC 61850-7-4 standard with the logical node XSXI.

## 8.2.4 Operation principle

### Status indication and validity check

The object state is defined by the two digital inputs POSOPEN and POSCLOSE, which are also available as outputs OPENPOS and CLOSEPOS together with the OKPOS according to [Table 802](#). The debounces and short disturbances in an input are eliminated by filtering. The binary input filtering time can be adjusted separately for each digital input used by the function block. The validity of digital inputs that indicate the object state is used as additional information in indications and event logging.

**Table 802: Status indication**

| Input   |          | Status                          | Output  |         |          |
|---------|----------|---------------------------------|---------|---------|----------|
| POSOPEN | POSCLOSE | POSITION<br>(Monitored<br>data) | OKPOS   | OPENPOS | CLOSEPOS |
| 1=True  | 0=False  | 1=Open                          | 1=True  | 1=True  | 0=False  |
| 0=False | 1=True   | 2=Closed                        | 1=True  | 0=False | 1=True   |
| 1=True  | 1=True   | 3=Faulty/Bad<br>(11)            | 0=False | 0=False | 0=False  |
| 0=False | 0=False  | 0=Intermedi-<br>ate (00)        | 0=False | 0=False | 0=False  |

## 8.2.5 Application

In the field of distribution and sub-transmission automation, the reliable control and status indication of primary switching components both locally and remotely is in a significant role. These features are needed especially in modern remote controlled substations. The application area of DCSXSWI and ESSXSWI functions covers remote and local status indication of, for example, disconnectors, air-break switches and earthing switches, which represent the lowest level of power switching devices without short-circuit breaking capability.

## 8.2.6 Signals

### 8.2.6.1 DCSXSWI Input signals

**Table 803: DCSXSWI Input signals**

| Name     | Type    | Default | Description  |
|----------|---------|---------|--|
| POSOPEN  | BOOLEAN | 0=False | Signal for open position of apparatus from I/O                 |
| POSCLOSE | BOOLEAN | 0=False | Signal for closed position of apparatus from I/O <sup>1)</sup> |

<sup>105</sup> Not available for monitoring

### 8.2.6.2 ESSXSWI Input signals

Table 804: ESSXSWI Input signals

| Name     | Type    | Default | Description  |
|----------|---------|---------|--|
| POSOPE   | BOOLEAN | 0=False | Signal for open position of apparatus from I/O                 |
| POSCLOSE | BOOLEAN | 0=False | Signal for closed position of apparatus from I/O <sup>1)</sup> |

### 8.2.6.3 DCSXSWI Output signals

Table 805: DCSXSWI Output signals

| Name     | Type    | Description               |
|----------|---------|---------------------------|
| OPENPOS  | BOOLEAN | Apparatus open position   |
| CLOSEPOS | BOOLEAN | Apparatus closed position |
| OKPOS    | BOOLEAN | Apparatus position is ok  |

### 8.2.6.4 ESSXSWI Output signals

Table 806: ESSXSWI Output signals

| Name     | Type    | Description               |
|----------|---------|---------------------------|
| OPENPOS  | BOOLEAN | Apparatus open position   |
| CLOSEPOS | BOOLEAN | Apparatus closed position |
| OKPOS    | BOOLEAN | Apparatus position is ok  |

## 8.2.7 Settings

### 8.2.7.1 DCSXSWI Settings

Table 807: DCSXSWI Non group settings (Basic)

| Parameter      | Values (Range) | Unit | Step | Default                  | Description                   |
|----------------|----------------|------|------|--------------------------|-------------------------------|
| Identification |                |      |      | DCSXSWI1 switch position | Control Object identification |

<sup>106</sup> Not available for monitoring

**Table 808: DCSXSWI Non group settings (Advanced)**

| Parameter     | Values (Range) | Unit | Step | Default | Description                              |
|---------------|----------------|------|------|---------|--|
| Event delay   | 0...60000      | ms   | 1    | 30000   | Event delay of the intermediate position |
| Vendor        |                |      |      | 0       | External equipment vendor                |
| Serial number |                |      |      | 0       | External equipment serial number         |
| Model         |                |      |      | 0       | External equipment model                 |

### 8.2.7.2

### ESSXSWI Settings

**Table 809: ESSXSWI Non group settings (Basic)**

| Parameter      | Values (Range) | Unit | Step | Default                  | Description                   |
|----------------|----------------|------|------|--------------------------|-------------------------------|
| Identification |                |      |      | ESSXSWI1 switch position | Control Object identification |

**Table 810: ESSXSWI Non group settings (Advanced)**

| Parameter     | Values (Range) | Unit | Step | Default | Description                              |
|---------------|----------------|------|------|---------|--|
| Event delay   | 0...60000      | ms   | 1    | 30000   | Event delay of the intermediate position |
| Vendor        |                |      |      | 0       | External equipment vendor                |
| Serial number |                |      |      | 0       | External equipment serial number         |
| Model         |                |      |      | 0       | External equipment model                 |

## 8.2.8 Monitored data

### 8.2.8.1 DCSXSWI Monitored data

Table 811: DCSXSWI Monitored data

| Name     | Type  | Values (Range)                                   | Unit | Description                   |
|----------|-------|--|------|-------------------------------|
| POSITION | Dbpos | 0=intermediate<br>1=open<br>2=closed<br>3=faulty |      | Apparatus position indication |

### 8.2.8.2 ESSXSWI Monitored data

Table 812: ESSXSWI Monitored data

| Name     | Type  | Values (Range)                                   | Unit | Description                   |
|----------|-------|--|------|-------------------------------|
| POSITION | Dbpos | 0=intermediate<br>1=open<br>2=closed<br>3=faulty |      | Apparatus position indication |

## 8.2.9 Technical revision history

Table 813: DCSXSWI Technical revision history

| Technical revision | Change  |
|--------------------|---|
| B                  | Maximum and default values changed to 60 s and 30 s respectively for <i>Event delay</i> settings. |
| C                  | Outputs OPENPOS and CLOSEPOS are forced to "FALSE" in case status is Faulty (11).                 |

Table 814: ESSXSWI Technical revision history

| Technical revision | Change  |
|--------------------|---|
| B                  | Maximum and default values changed to 60 s and 30 s respectively for <i>Event delay</i> settings. |
| C                  | Outputs OPENPOS and CLOSEPOS are forced to "FALSE" in case status is Faulty (11).                 |

## 8.3 Synchronism and energizing check SECRSYN

### 8.3.1 Identification

| Function description             | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|----------------------------------|--------------------------|--------------------------|-------------------------------|
| Synchronism and energizing check | SECRSYN                  | SYNC                     | 25                            |

### 8.3.2 Function block

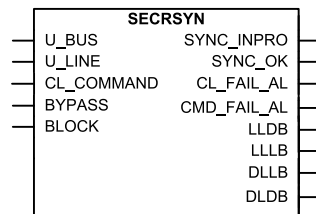


Figure 435: Function block

### 8.3.3 Functionality

The synchronism and energizing check function SECRSYN checks the condition across the circuit breaker from separate power system parts and gives the permission to close the circuit breaker. SECRSYN includes the functionality of synchrocheck and energizing check.

Asynchronous operation mode is provided for asynchronously running systems. The main purpose of the asynchronous operation mode is to provide a controlled closing of circuit breakers when two asynchronous systems are connected.

The synchrocheck operation mode checks that the voltages on both sides of the circuit breaker are perfectly synchronized. It is used to perform a controlled reconnection of two systems which are divided after islanding and it is also used to perform a controlled reconnection of the system after reclosing.

The energizing check function checks that at least one side is dead to ensure that closing can be done safely.

The function contains a blocking functionality. It is possible to block function outputs and timers if desired.

### 8.3.4 Analog channel configuration

SECRSYN has two analog group inputs which must be properly configured.

**Table 815: Analog inputs**

| Input | Description                      |
|-------|----------------------------------|
| U3P1  | Three-phase voltages (bus side)  |
| U3P2  | Three-phase voltages (line side) |



See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

**Table 816: Special conditions**

| Condition                           | Description   |
|-------------------------------------|---|
| U3P1 connected to real measurements | The function requires that any two voltage channels from the bus side are connected.  |
| U3P2 connected to real measurements | The function requires that one voltage channel from the line side is connected to channel 1 or any two voltage channels from the line side. |

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

### 8.3.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

SECRSYN has two parallel functionalities, the synchro check and energizing check functionality. The operation of the synchronism and energizing check functionality can be described using a module diagram. All the modules in the diagram are explained in the next sections.

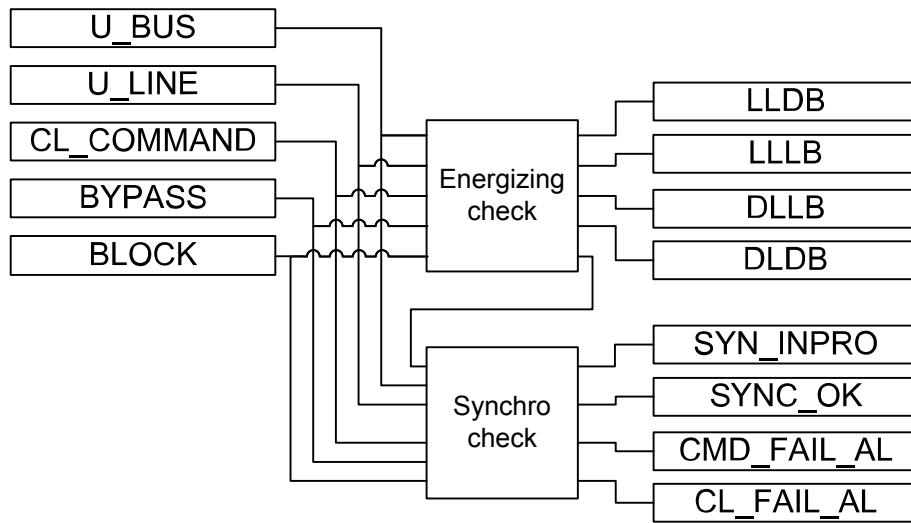


Figure 436: Functional module diagram

If Energizing check is passed, no further conditions need to be fulfilled to permit closing. Otherwise, Synchro check function can operate either with the U\_AB or U\_A voltages. The selection of used voltages is defined with the *VT connection* setting of the line voltage general parameters.



By default, voltages U\_BUS and U\_LINE are connected as presented in Figure 444. If necessary, connections can be switched by setting *Voltage source switch* to “True”.

**Energizing check**

The Energizing check function checks the energizing direction. Energizing is defined as a situation where a dead network part is connected to an energized section of the network. The conditions of the network sections to be controlled by the circuit breaker, that is, which side has to be live and which side dead, are determined by the setting. A situation where both sides are dead is possible as well. The actual value for defining the dead line or bus is given with the *Dead bus value* and *Dead line value* settings. Similarly, the actual values of live line or bus are defined with the *Live bus value* and *Live line value* settings.

**Table 817: Live dead mode of operation under which switching can be carried out**

| Live dead mode  | Description   |
|-----------------|---|
| Both Dead       | Both line and bus de-energized  |
| Live L, Dead B  | Bus de-energized and line energized                                   |
| Dead L, Live B  | Line de-energized and bus energized                                   |
| Dead Bus, L Any | Both line and bus de-energized or bus de-energized and line energized |
| Dead L, Bus Any | Both line and bus de-energized or line de-energized and bus energized |

Table continues on the next page



| Live dead mode | Description  |
|----------------|--|
| One Live, Dead | Bus de-energized and line energized or line de-energized and bus energized                                   |
| Not Both Live  | Both line and bus de-energized or bus de-energized and line energized or line de-energized and bus energized |

When the energizing direction corresponds to the settings, the situation has to be constant for a time set with the *Energizing time* setting before the circuit breaker closing is permitted. The purpose of this time delay is to ensure that the dead side remains de-energized and also that the situation is not caused by a temporary interference. If the conditions do not persist for a specified operation time, the timer is reset and the procedure is restarted when the conditions allow. The circuit breaker closing is not permitted if the measured voltage on the live side is greater than the set value of *Max energizing V*.

The measured energized state is available as a monitored data value ENERG\_STATE and as four function outputs LLDB (live line / dead bus), LLLB (live line / live bus), DLLB (dead line / live bus) and DLDB (dead line / dead bus), of which only one can be active at a time. It is also possible that the measured energized state indicates "Unknown" if at least one of the measured voltages is between the limits set with the dead and live setting parameters.

### Synchro check

The Synchro check function measures the difference between the line voltage and bus voltage. The function permits the closing of the circuit breaker when certain conditions are simultaneously fulfilled.

- The measured line and bus voltages are higher than the set values of *Live bus value* and *Live line value* (ENERG\_STATE equals to "Both Live").
- The measured bus and line frequency are both within the range of 95 to 105 percent of the value of  $f_n$ .
- The measured voltages for the line and bus are less than the set value of *Max energizing V*.

In case *Synchro check mode* is set to "Synchronous", the additional conditions must be fulfilled.

- In the synchronous mode, the closing is attempted so that the phase difference at closing is close to zero.
- The synchronous mode is only possible when the frequency slip is below 0.1 percent of the value of  $f_n$ .
- The voltage difference must not exceed the 1 percent of the value of  $U_n$ .

In case *Synchro check mode* is set to "Asynchronous", the additional conditions must be fulfilled.

- The measured difference of the voltages is less than the set value of *Difference voltage*.
- The measured difference of the phase angles is less than the set value of *Difference angle*.
- The measured difference in frequency is less than the set value of *Frequency difference*.
- The estimated breaker closing angle is decided to be less than the set value of *Difference angle*.

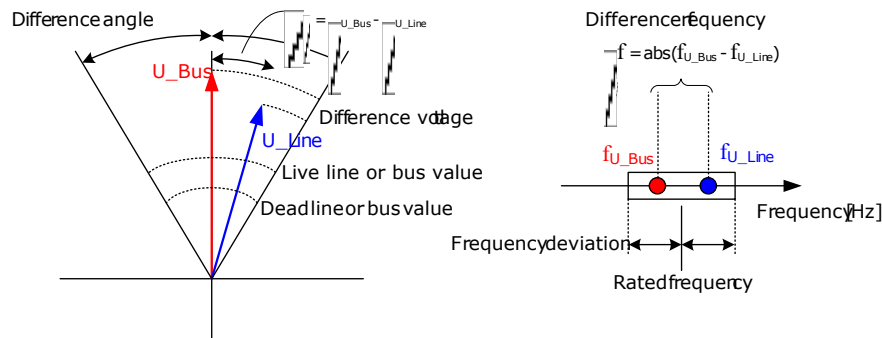


Figure 437: Conditions to be fulfilled when detecting synchronism between systems

When the frequency, phase angle and voltage conditions are fulfilled, the duration of the synchronism conditions is checked so as to ensure that they are still met when the condition is determined on the basis of the measured frequency and phase difference. Depending on the circuit breaker and the closing system, the delay from the moment the closing signal is given until the circuit breaker finally closes is about 50...250 ms. The selected *Closing time of CB* informs the function how long the conditions have to persist. The Synchro check function compensates for the measured slip frequency and the circuit breaker closing delay. The phase angle advance is calculated continuously with the formula.

$$\text{Closing angle} = \left| (\angle U_{Bus} - \angle U_{Line})^\circ + ((f_{Bus} - f_{line}) \times (T_{CB} + T_{PL}) \times 360^\circ) \right|$$

|                   |  |
|-------------------|--|
| $\angle U_{Bus}$  | Measured bus voltage phase angle   |
| $\angle U_{Line}$ | Measured line voltage phase angle  |
| $f_{Bus}$         | Measured bus frequency   |
| $f_{line}$        | Measured line frequency  |
| $T_{CB}$          | Total circuit breaker closing delay, including the delay of the IED output contacts defined with the <i>Closing time of CB</i> setting parameter value |

The closing angle is the estimated angle difference after the breaker closing delay.

The *Minimum Syn time* setting time can be set, if required, to demand the minimum time within which conditions must be simultaneously fulfilled before the SYNC\_OK output is activated.

The measured voltage, frequency and phase angle difference values between the two sides of the circuit breaker are available as monitored data values U\_DIFF\_MEAS, FR\_DIFF\_MEAS and PH\_DIFF\_MEAS. Also, the indications of the conditions that are not fulfilled and thus preventing the breaker closing permission are available as monitored data values U\_DIFF\_SYNC, PH\_DIF\_SYNC and FR\_DIFF\_SYNC. These monitored data values are updated only when the Synchro check is enabled with the *Synchro check mode* setting and the measured ENERG\_STATE is "Both Live".

### Continuous mode

The continuous mode is activated by setting the parameter *Control mode* to "Continuous". In the continuous control mode, Synchro check is continuously

checking the synchronism. When synchronism is detected (according to the settings), the `SYNC_OK` output is set to TRUE (logic '1') and it stays TRUE as long as the conditions are fulfilled. The command input is ignored in the continuous control mode. The mode is used for situations where Synchro check only gives the permission to the control block that executes the CB closing.

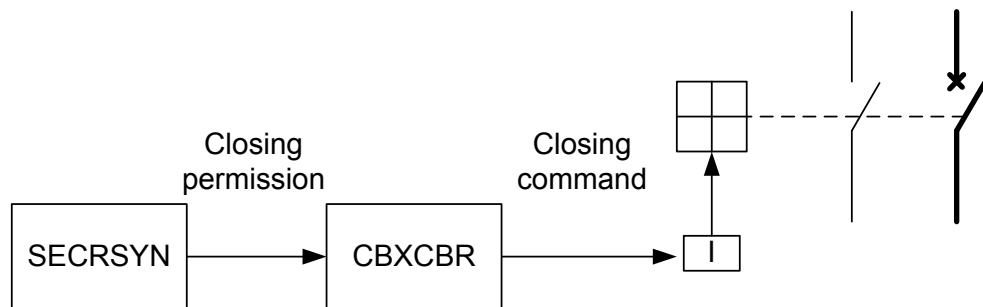


Figure 438: A simplified block diagram of the Synchro check function in the continuous mode operation

### Command mode

If *Control mode* is set to "Command", the purpose of the Synchro check functionality in the command mode is to find the instant when the voltages on both sides of the circuit breaker are in synchronism. The conditions for synchronism are met when the voltages on both sides of the circuit breaker have the same frequency and are in phase with a magnitude that makes the concerned busbars or lines such that they can be regarded as live.

In the command mode operation, an external command signal `CL_COMMAND`, besides the normal closing conditions, is needed for delivering the closing signal. In the command control mode operation, the Synchro check function itself closes the breaker via the `SYNC_OK` output when the conditions are fulfilled. In this case, the control function block delivers the command signal to close the Synchro check function for the releasing of a closing-signal pulse to the circuit breaker. If the closing conditions are fulfilled during a permitted check time set with *Maximum Syn time*, the Synchro check function delivers a closing signal to the circuit breaker after the command signal is delivered for closing.

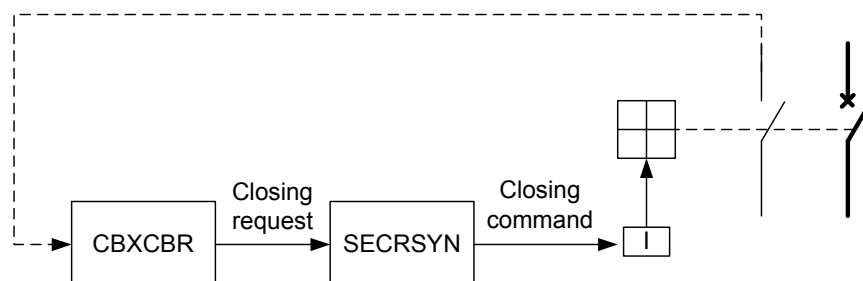


Figure 439: A simplified block diagram of SECRSYN in the command mode operation

The closing signal is delivered only once for each activated external closing command signal. The pulse length of the delivered closing is set with the *Close pulse* setting.

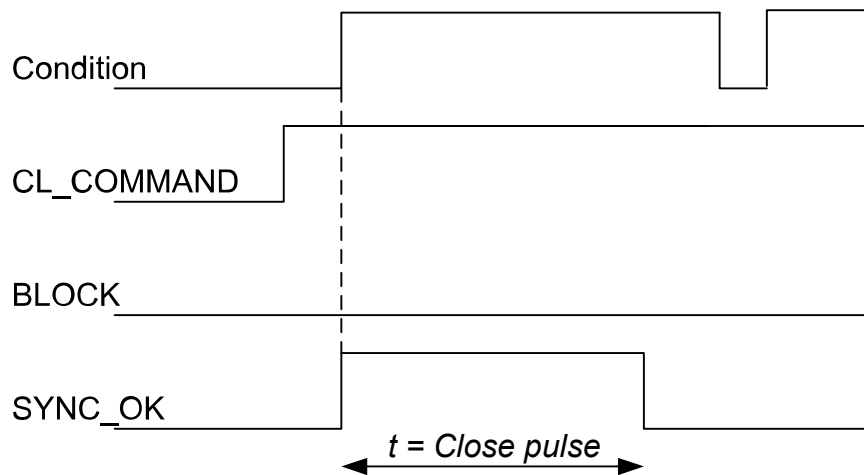


Figure 440: Determination of the pulse length of the closing signal

In the command control mode operation, there are alarms for a failed closing attempt (CL\_FAIL\_AL) and for a command signal that remains active too long (CMD\_FAIL\_AL).

If the conditions for closing are not fulfilled within the set time of *Maximum Syn time*, a failed closing attempt alarm is given. The CL\_FAIL\_AL alarm output signal is pulse-shaped and the pulse length is 500 ms. If the external command signal is removed too early, that is, before conditions are fulfilled and the closing pulse is given, the alarm timer is reset.

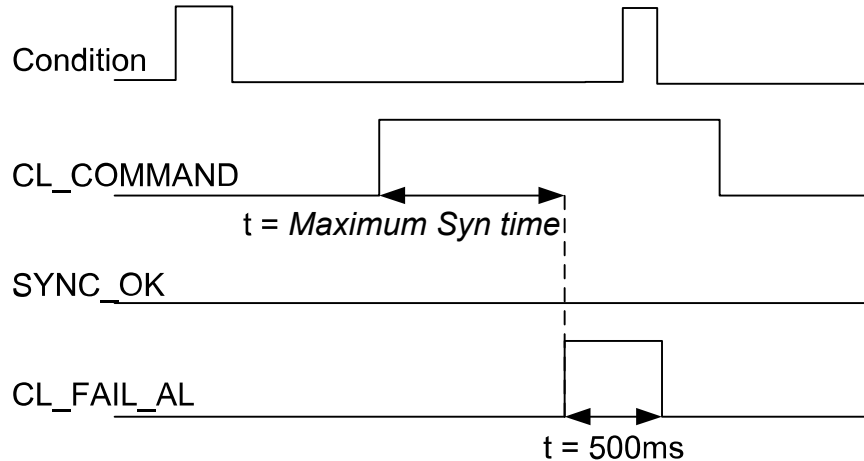


Figure 441: Determination of the checking time for closing

The control module receives information about the circuit breaker status and thus is able to adjust the command signal to be delivered to the Synchro check function. If the external command signal CL\_COMMAND is kept active longer than necessary, the CMD\_FAIL\_AL alarm output is activated. The alarm indicates that the control module has not removed the external command signal after the closing operation. To avoid unnecessary alarms, the duration of the command signal should be set in such a way that the maximum length of the signal is always below *Maximum Syn time* + 5s.

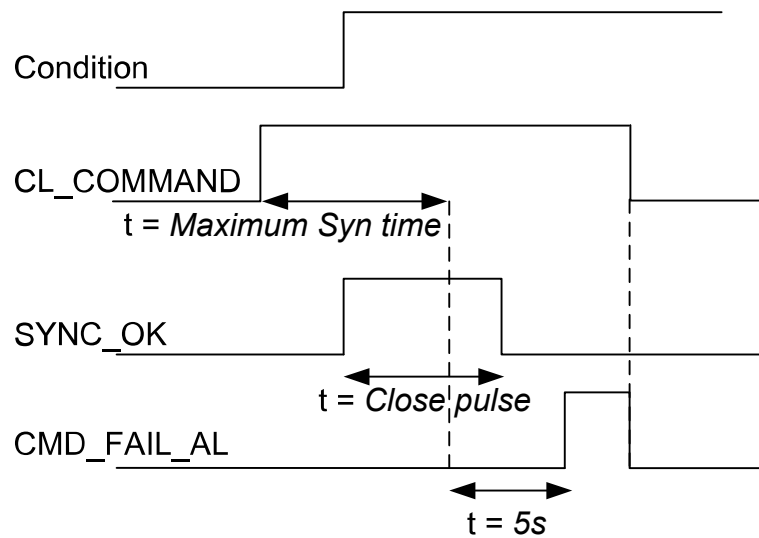


Figure 442: Determination of the alarm limit for a still-active command signal

Closing is permitted during *Maximum Syn time*, starting from the moment the external command signal `CL_COMMAND` is activated. The `CL_COMMAND` input must be kept active for the whole time that the closing conditions are waited to be fulfilled. Otherwise, the procedure is cancelled. If the closing-command conditions are fulfilled during *Maximum Syn time*, a closing pulse is delivered to the circuit breaker. If the closing conditions are not fulfilled during the checking time, the alarm `CL_FAIL_AL` is activated as an indication of a failed closing attempt. The closing pulse is not delivered if the closing conditions become valid after *Maximum Syn time* has elapsed. The closing pulse is delivered only once for each activated external command signal, and a new closing-command sequence cannot be started until the external command signal is reset and reactivated. The `SYNC_INPRO` output is active when the closing-command sequence is in progress and it is reset when the `CL_COMMAND` input is reset or *Maximum Syn time* has elapsed.

### Bypass mode

SECRSYN can be set to the bypass mode by setting the parameters *Synchrocheck mode* and *Live dead mode* to "Off" or alternatively by activating the `BYPASS` input.

In the bypass mode, the closing conditions are always considered to be fulfilled by SECRSYN. Otherwise, the operation is similar to the normal mode.

### Voltage angle difference adjustment

In application where the power transformer is located between the voltage measurement and the vector group connection gives phase difference to the voltages between the high- and low-voltage sides, the angle adjustment can be used to meet synchronism.

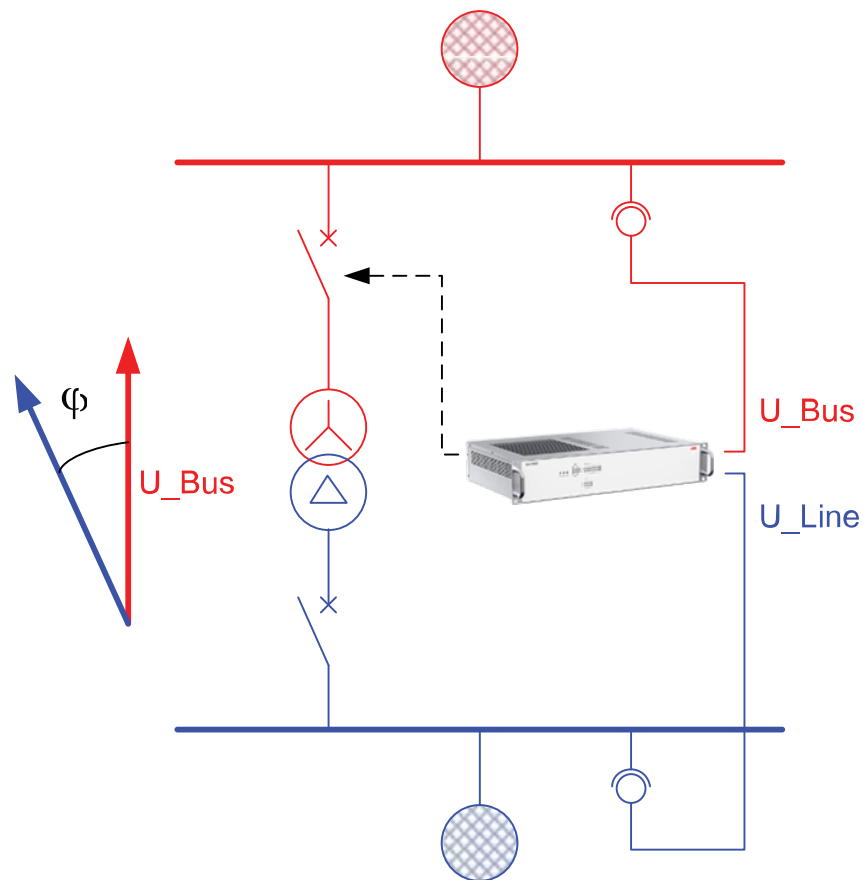


Figure 443: Angle difference when power transformer is in synchrocheck zone

The vector group of the power transformer is defined with clock numbers, where the value of the hour pointer defines the low-voltage-side phasor and the high-voltage-side phasor is always fixed to the clock number 12, which is same as zero. The angle between clock numbers is 30 degrees. When comparing phase angles, the  $U_{BUS}$  input is always the reference. This means that when the Yd11 power transformer is used, the low-voltage-side voltage phasor leads by 30 degrees or lags by 330 degrees the high-voltage-side phasor. The rotation of the phasors is counterclockwise.

The generic rule is that a low-voltage-side phasor lags the high-voltage-side phasor by clock number \* 30°. This is called angle difference adjustment and can be set for SECRSYN with the *Phase shift* setting.

### 8.3.6 Application

The main purpose of the synchrocheck function is to provide control over the closing of the circuit breakers in power networks to prevent the closing if the conditions for synchronism are not detected. This function is also used to prevent the reconnection of two systems which are divided after islanding and a three-pole reclosing.

The Synchro check function block includes both the synchronism check function and the energizing function to allow closing when one side of the breaker is dead.

Network and the generator running in parallel with the network are connected through the line AB. When a fault occurs between A and B, the IED protection opens the circuit breakers A and B, thus isolating the faulty section from the network and making the arc that caused the fault extinguish. The first attempt to recover is a delayed autoreclosure made a few seconds later. Then, the autoreclose function DARREC gives a command signal to the synchrocheck function to close the circuit breaker A. SECRSYN performs an energizing check, as the line AB is de-energized ( $U_{BUS} > \text{Live bus value}$ ,  $U_{LINE} < \text{Dead line value}$ ). After verifying the line AB is dead and the energizing direction is correct, the IED energizes the line ( $U_{BUS} \rightarrow U_{LINE}$ ) by closing the circuit breaker A. The PLC of the power plant discovers that the line has been energized and sends a signal to the other synchrocheck function to close the circuit breaker B. Since both sides of the circuit breaker B are live ( $U_{BUS} > \text{Live bus value}$ ,  $U_{LINE} > \text{Live bus value}$ ), the synchrocheck function controlling the circuit breaker B performs a synchrocheck and, if the network and the generator are in synchronism, closes the circuit breaker.

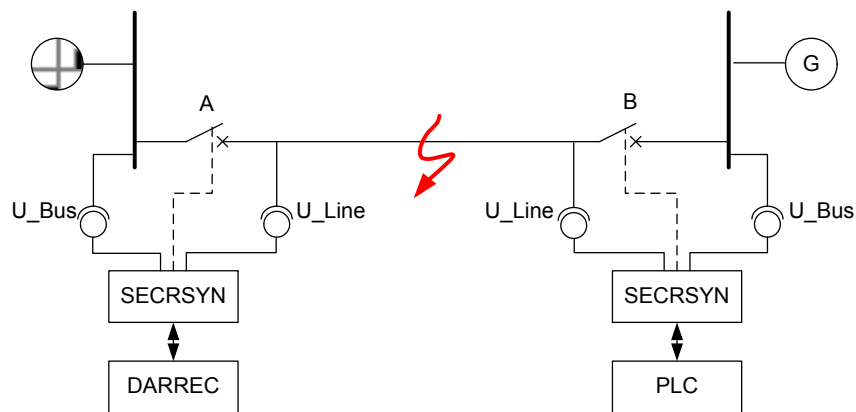


Figure 444: Synchrocheck function SECRSYN checking energizing conditions and synchronism

### Connections

A special attention is paid to the connection of the IED. Furthermore it is checked that the primary side wiring is correct.

A faulty wiring of the voltage inputs of the IED causes a malfunction in the synchrocheck function. If the wires of an energizing input have changed places, the polarity of the input voltage is reversed (180°). In this case, the IED permits the circuit breaker closing in a situation where the voltages are in opposite phases. This can damage the electrical devices in the primary circuit. Therefore, it is extremely important that the wiring from the voltage transformers to the terminals on the rear of the IED is consistent regarding the energizing inputs  $U_{BUS}$  (bus voltage) and  $U_{LINE}$  (line voltage).

The wiring should be verified by checking the reading of the phase difference measured between the  $U_{BUS}$  and  $U_{LINE}$  voltages. The phase difference measured by the IED has to be close to zero within the permitted accuracy tolerances. The measured phase differences are indicated in the WHMI. At the same time, it is recommended to check the voltage difference and the frequency differences presented in the monitored data view. These values should be within the permitted tolerances, that is, close to zero.

Synchrocheck requires two different measurement points for two voltages, this can be achieved by using two bay level merging units or relays, that both send the measurements separately via IEC 61850-9-2LE.

## 8.3.7 Signals

### 8.3.7.1 SECRSYN Input signals

Table 818: SECRSYN Input signals

| Name       | Type    | Default | Description   |
|------------|---------|---------|---|
| U_BUS      | SIGNAL  | 0       | Busbar voltage  |
| U_LINE     | SIGNAL  | 0       | Line voltage  |
| CL_COMMAND | BOOLEAN | 0=False | External closing request  |
| BYPASS     | BOOLEAN | 0=False | Request to bypass synchronism check and voltage check           |
| BLOCK      | BOOLEAN | 0=False | Blocking signal of the synchro check and voltage check function |

### 8.3.7.2 SECRSYN Output signals

Table 819: SECRSYN Output signals

| Name        | Type    | Description               |
|-------------|---------|---------------------------|
| SYNC_INPRO  | BOOLEAN | Synchronizing in progress |
| SYNC_OK     | BOOLEAN | Systems in synchronism    |
| CL_FAIL_AL  | BOOLEAN | CB closing failed         |
| CMD_FAIL_AL | BOOLEAN | CB closing request failed |
| LLDB        | BOOLEAN | Live Line, Dead Bus       |
| LLLDB       | BOOLEAN | Live Line, Live Bus       |
| DLLB        | BOOLEAN | Dead Line, Live Bus       |
| DLDB        | BOOLEAN | Dead Line, Dead Bus       |

## 8.3.8 Settings



### 8.3.8.1 SECRSYN Settings

**Table 820: SECRSYN Group settings (Basic)**

| Parameter            | Values (Range)   | Unit | Step  | Default     | Description                        |
|----------------------|--|------|-------|-------------|------------------------------------|
| Live dead mode       | -1=Off<br>1=Both Dead<br>2=Live L, Dead B<br>3=Dead L, Live B<br>4=Dead Bus, L Any<br>5=Dead L, Bus Any<br>6=One Live, Dead<br>7=Not Both Live |      |       | 1=Both Dead | Energizing check mode              |
| Difference voltage   | 0.01...0.50  | xUn  | 0.01  | 0.05        | Maximum voltage difference limit   |
| Difference frequency | 0.001...0.100  | xFn  | 0.001 | 0.001       | Maximum frequency difference limit |
| Difference angle     | 5...90   | deg  | 1     | 5           | Maximum angle difference limit     |

**Table 821: SECRSYN Non group settings (Basic)**

| Parameter          | Values (Range)                             | Unit | Step | Default         | Description                                 |
|--------------------|--|------|------|-----------------|---|
| Operation          | 1=on<br>5=off                              |      |      | 1=on            | Operation Off / On                          |
| Synchro check mode | 1=Off<br>2=Synchro-nous<br>3=Asynchro-nous |      |      | 3=Asynchro-nous | Synchro check operation mode                |
| Dead line value    | 0.1...0.8                                  | xUn  | 0.1  | 0.2             | Voltage low limit line for energizing check |

*Table continues on the next page*

| Parameter        | Values (Range) | Unit | Step | Default | Description                                  |
|------------------|----------------|------|------|---------|--|
| Live line value  | 0.2...1.0      | xUn  | 0.1  | 0.8     | Voltage high limit line for energizing check |
| Dead bus value   | 0.1...0.8      | xUn  | 0.1  | 0.2     | Voltage low limit bus for energizing check   |
| Live bus value   | 0.2...1.0      | xUn  | 0.1  | 0.5     | Voltage high limit bus for energizing check  |
| Max energizing V | 0.50...1.15    | xUn  | 0.01 | 1.05    | Maximum voltage for energizing               |

**Table 822: SECRSYN Non group settings (Advanced)**

| Parameter        | Values (Range)            | Unit | Step | Default      | Description  |
|------------------|---------------------------|------|------|--------------|--|
| Control mode     | 1=Continuous<br>2=Command |      |      | 1=Continuous | Selection of synchro check command or Continuous control mode    |
| Close pulse      | 200...60000               | ms   | 10   | 200          | Breaker closing pulse duration                                   |
| Phase shift      | -180...180                | deg  | 1    | 0            | Correction of phase difference between measured U_BUS and U_LINE |
| Minimum Syn time | 0...60000                 | ms   | 10   | 0            | Minimum time to accept synchronizing                             |
| Maximum Syn time | 100...600000<br>0         | ms   | 10   | 2000         | Maximum time to accept synchronizing                             |
| Energizing time  | 100...60000               | ms   | 10   | 100          | Time delay for energizing check                                  |

*Table continues on the next page*

| Parameter             | Values (Range)    | Unit | Step | Default | Description                 |
|-----------------------|-------------------|------|------|---------|-----------------------------|
| Closing time of CB    | 40...250          | ms   | 10   | 60      | Closing time of the breaker |
| Voltage source switch | 0=False<br>1=True |      |      | 0=False | Voltage source switch       |

## 8.3.9 Monitored data

### 8.3.9.1 SECRSYN Monitored data

Table 823: SECRSYN Monitored data

| Name         | Type    | Values (Range)  | Unit | Description   |
|--------------|---------|---|------|---|
| ENERG_STATE  | Enum    | 0=Unknown<br>1=Both Live<br>2=Live L, Dead B<br>3=Dead L, Live B<br>4=Both Dead |      | Energization state of Line and Bus                    |
| U_DIFF_MEAS  | FLOAT32 | 0.00...1.00   | xUn  | Calculated voltage amplitude difference               |
| FR_DIFF_MEAS | FLOAT32 | 0.000...0.100   | xFn  | Calculated voltage frequency difference               |
| PH_DIFF_MEAS | FLOAT32 | 0.00...180.00   | deg  | Calculated voltage phase angle difference             |
| U_DIFF_SYNC  | BOOLEAN | 0=False<br>1=True   |      | Voltage difference out of limit for synchronizing     |
| PH_DIF_SYNC  | BOOLEAN | 0=False<br>1=True   |      | Phase angle difference out of limit for synchronizing |
| FR_DIFF_SYNC | BOOLEAN | 0=False<br>1=True   |      | Frequency difference out of limit for synchronizing   |
| SECRSYN      | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked                                   |      | Status  |

| Name | Type | Values (Range) | Unit | Description |
|------|------|----------------|------|-------------|
|      |      | 5=off          |      |             |

### 8.3.10 Technical data

Table 824: SECRSYN Technical data

| Characteristic                              | Value  |
|---|--|
| Operation accuracy                          | Depending on the frequency of the voltage measured: $f_n \pm 1$ Hz<br>Voltage:<br>$\pm 3.0\%$ of the set value or $\pm 0.01 \times U_n$<br>Frequency:<br>$\pm 10$ mHz<br>Phase angle:<br>$\pm 3^\circ$ |
| Reset time                                  | <50 ms   |
| Reset ratio                                 | Typically 0.96   |
| Operate time accuracy in definite time mode | $\pm 1.0\%$ of the set value or $\pm 20$ ms  |

### 8.3.11 Technical revision history

Table 825: SECRSYN Technical revision history

| Technical revision | Change   |
|--------------------|--|
| B                  | Internal improvement.  |
| C                  | Added new setting <i>Voltage source switch</i> to switch the input signals U_BUS (bus voltage) and U_LINE (line voltage) between each other. |

## 8.4 Autoreclosing DARREC

### 8.4.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|----------------------|--------------------------|--------------------------|-------------------------------|
| Autoreclosing        | DARREC                   | O -> I                   | 79                            |

## 8.4.2 Function block

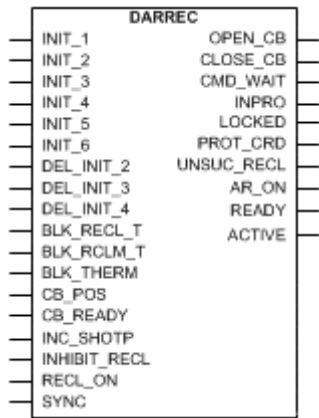


Figure 445: Function block

## 8.4.3 Functionality

About 80 to 85 percent of faults in the MV overhead lines are transient and automatically cleared with a momentary de-energization of the line. The rest of the faults, 15 to 20 percent, can be cleared by longer interruptions. The de-energization of the fault location for a selected time period is implemented through automatic reclosing, during which most of the faults can be cleared.

In case of a permanent fault, the automatic reclosing is followed by final tripping. A permanent fault must be located and cleared before the fault location can be re-energized.

The autoreclosing function DARREC can be used with any circuit breaker suitable for autoreclosing. The function provides five programmable autoreclosing shots which can perform one to five successive autoreclosings of desired type and duration, for instance one high-speed and one delayed autoreclosing.

When the reclosing is initiated with starting of the protection function, the autoreclosing function can execute the final trip of the circuit breaker in a short operate time, provided that the fault still persists when the last selected reclosing has been carried out.

### 8.4.3.1 Protection signal definition

The *Control line* setting defines which of the initiation signals are protection start and trip signals and which are not. With this setting, the user can distinguish the blocking signals from the protection signals. The *Control line* setting is a bit mask, that is, the lowest bit controls the INIT\_1 line and the highest bit the INIT\_6 line. Some example combinations of the *Control line* setting are as follows:

**Table 826: Control line setting definition**

| <i>Control line setting</i> | INIT_1 | INIT_2<br>DEL_INIT_2 | INIT_3<br>DEL_INIT_3 | INIT_4<br>DEL_INIT_4 | INIT_5 | INIT_6 |
|-----------------------------|--------|----------------------|----------------------|----------------------|--------|--------|
| 0                           | other  | other                | other                | other                | other  | other  |
| 1                           | prot   | other                | other                | other                | other  | other  |
| 2                           | other  | prot                 | other                | other                | other  | other  |
| 3                           | prot   | prot                 | other                | other                | other  | other  |
| 4                           | other  | other                | prot                 | other                | other  | other  |
| 5                           | prot   | other                | prot                 | other                | other  | other  |
| ...63                       | prot   | prot                 | prot                 | prot                 | prot   | prot   |

prot = protection signal

other = non-protection signal

When the corresponding bit or bits in both the *Control line* setting and the *INIT\_X* line are TRUE:

- The *CLOSE\_CB* output is blocked until the protection is reset
- If the *INIT\_X* line defined as the protection signal is activated during the discrimination time, the AR function goes to lockout
- If the *INIT\_X* line defined as the protection signal stays active longer than the time set by the *Max trip time* setting, the AR function goes to lockout (long trip)
- The *UNSUC\_RECL* output is activated after a pre-defined two minutes (alarming earth-fault).

### 8.4.3.2 Zone coordination

Zone coordination is used in the zone sequence between local protection units and downstream devices. At the falling edge of the *INC\_SHOTP* line, the value of the shot pointer is increased by one, unless a shot is in progress or the shot pointer already has the maximum value.

The falling edge of the *INC\_SHOTP* line is not accepted if any of the shots are in progress.

### 8.4.3.3 Master and slave scheme

With the cooperation between the AR units in the same IED or between IEDs, sequential reclosings of two breakers at a line end in a 1½-breaker, double breaker or ring-bus arrangement can be achieved. One unit is defined as a master and it executes the reclosing first. If the reclosing is successful and no trip takes place, the second unit, that is the slave, is released to complete the reclose shot. With persistent faults, the breaker reclosing is limited to the first breaker.

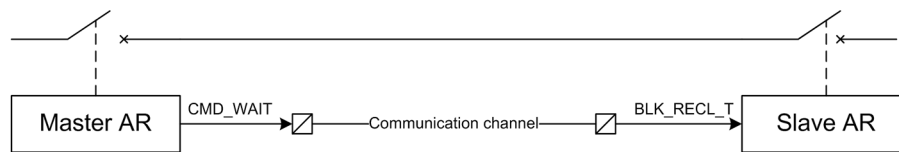


Figure 446: Master and slave scheme

If the AR unit is defined as a master by setting its terminal priority to high:

- The unit activates the `CMD_WAIT` output to the low priority slave unit whenever a shot is in progress, a reclosing is unsuccessful or the `BLK_RCLM_T` input is active
- The `CMD_WAIT` output is reset one second after the reclose command is given or if the sequence is unsuccessful when the reclaim time elapses.

If the AR unit is defined as a slave by setting its terminal priority to low:

- The unit waits until the master releases the `BLK_RECL_T` input (the `CMD_WAIT` output in the master). Only after this signal has been deactivated, the reclose time for the slave unit can be started.
- The slave unit is set to a lockout state if the `BLK_RECL_T` input is not released within the time defined by the *Max wait time* setting, which follows the initiation of an autoreclosing shot.

If the terminal priority of the AR unit is set to "none", the AR unit skips all these actions.

#### 8.4.3.4 Thermal overload blocking

An alarm or start signal from the thermal overload protection (T1PTTR) can be routed to the input `BLK_THERM` to block and hold the reclose sequence. The `BLK_THERM` signal does not affect the starting of the sequence. When the reclose time has elapsed and the `BLK_THERM` input is active, the shot is not ready until the `BLK_THERM` input deactivates. Should the `BLK_THERM` input remain active longer than the time set by the setting *Max Thm block time*, the AR function goes to lockout.

If the `BLK_THERM` input is activated when the auto wait timer is running, the auto wait timer is reset and the timer restarted when the `BLK_THERM` input deactivates.

#### 8.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off". Setting *Operation* to "Off" resets non-volatile counters.

The reclosing operation can be enabled and disabled with the *Reclosing operation* setting. This setting does not disable the function, only the reclosing functionality. The setting has three parameter values: "On", "External Ctl" and "Off". The setting value "On" enables the reclosing operation and "Off" disables it. When the setting value "External Ctl" is selected, the reclosing operation is controlled with the `RECL_ON` input. `AR_ON` is activated when reclosing operation is enabled.

The operation of DARREC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

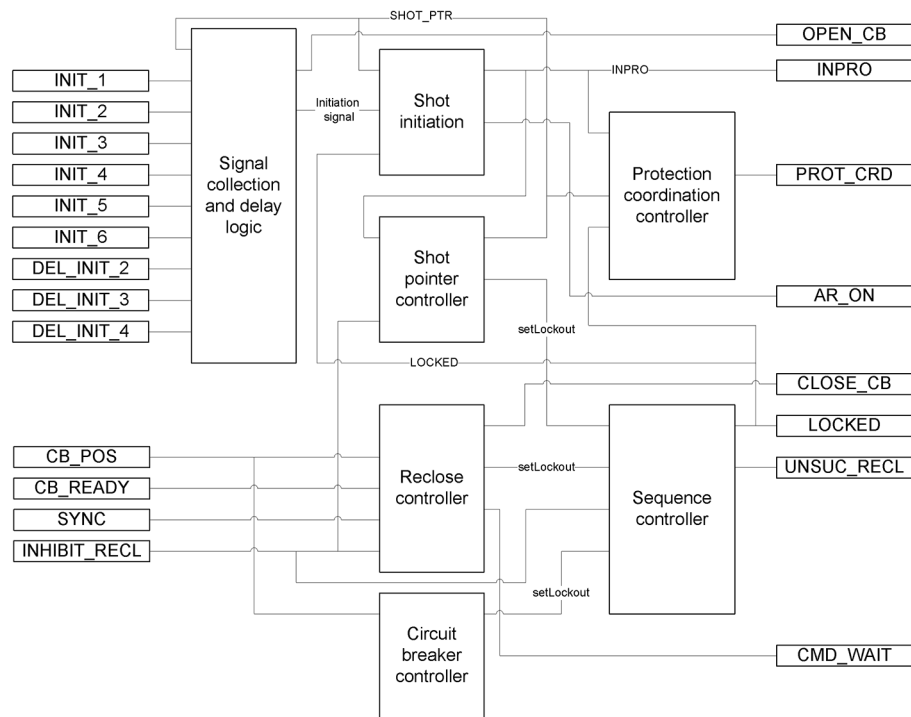


Figure 447: Functional module diagram

#### 8.4.4.1 Signal collection and delay logic

When the protection trips, the initiation of autoreclosing shots is in most applications executed with the `INIT_1 . . . 6` inputs. The `DEL_INIT2 . . . 4` inputs are not used. In some countries, starting the protection stage is also used for the shot initiation. This is the only time when the `DEL_INIT` inputs are used.



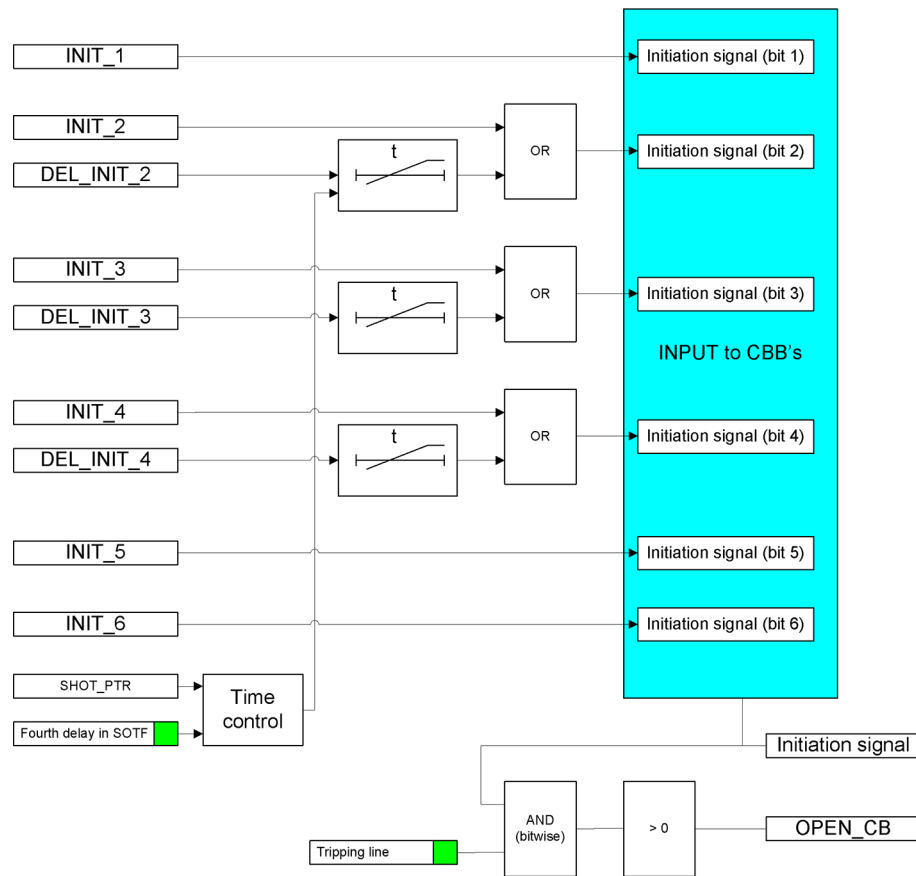


Figure 448: Schematic diagram of delayed initiation input signals

In total, the AR function contains six separate initiation lines used for the initiation or blocking of the autoreclosing shots. These lines are divided into two types of channels. In three of these channels, the signal to the AR function can be delayed, whereas the other three channels do not have any delaying capability.

Each channel that is capable of delaying a start signal has four time delays. The time delay is selected based on the shot pointer in the AR function. For the first reclose attempt, the first time delay is selected; for the second attempt, the second time delay and so on. For the fourth and fifth attempts, the time delays are the same.

Time delay settings for the DEL\_INIT\_2 signal

- Str 2 delay shot 1
- Str 2 delay shot 2
- Str 2 delay shot 3
- Str 2 delay shot 4

Time delay settings for the DEL\_INIT\_3 signal

- Str 3 delay shot 1
- Str 3 delay shot 2
- Str 3 delay shot 3
- Str 3 delay shot 4

Time delay settings for the DEL\_INIT\_4 signal

- Str 4 delay shot 1
- Str 4 delay shot 2

- Str 4 delay shot 3
- Str 4 delay shot 4

Normally, only two or three reclosing attempts are made. The third and fourth attempts are used to provide the so-called fast final trip to lockout.

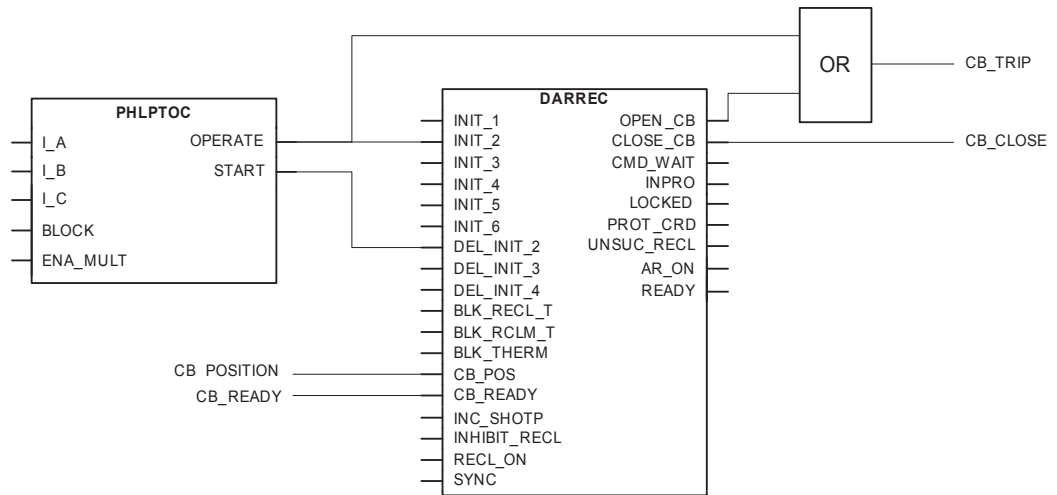


Figure 449: Autoreclosing configuration example

Delayed DEL\_INIT\_2 . . . 4 signals are used only when the autoreclosing shot is initiated with the start signal of a protection stage. After a start delay, the AR function opens the circuit breaker and an autoreclosing shot is initiated. When the shot is initiated with the trip signal of the protection, the protection function trips the circuit breaker and simultaneously initiates the autoreclosing shot.

If the circuit breaker is manually closed against the fault, that is, if SOTF is used, the fourth time delay can automatically be taken into use. This is controlled with the internal logic of the AR function and the *Fourth delay in SOTF* parameter.

A typical autoreclose situation is where one autoreclosing shot has been performed after the fault was detected. There are two types of such cases: operation initiated with protection start signal and operation initiated with protection trip signal. In both cases, the autoreclosing sequence is successful: the reclaim time elapses and no new sequence is started.

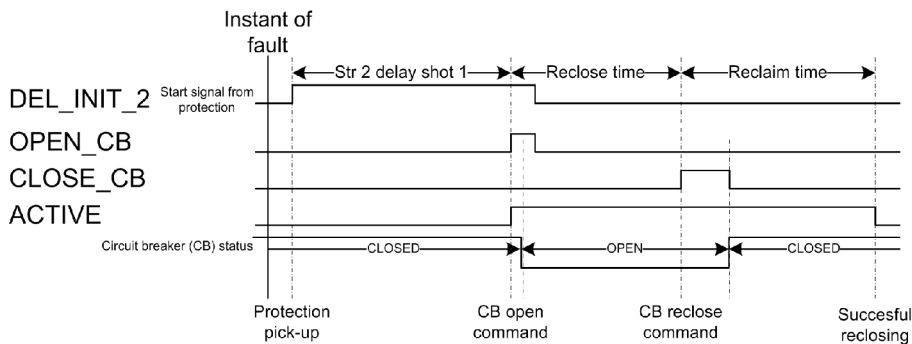
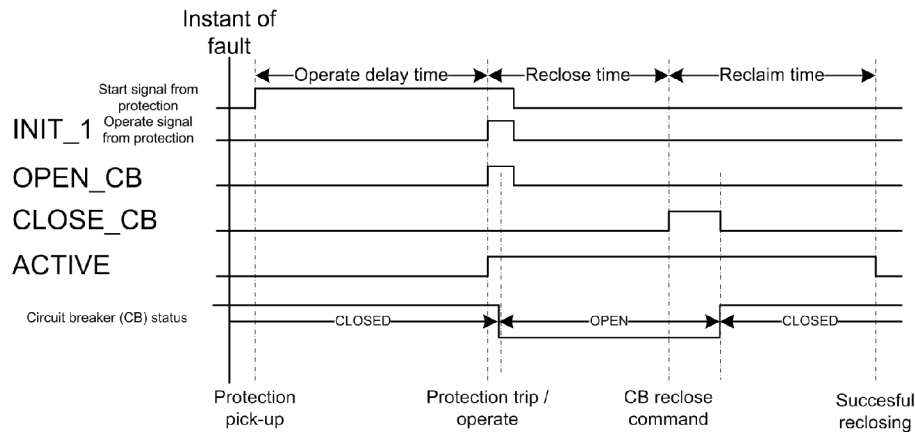


Figure 450: Signal scheme of autoreclosing operation initiated with protection start signal

The autoreclosing shot is initiated with a start signal of the protection function after the start delay time has elapsed. The autoreclosing starts when the *Str 2 delay shot 1* setting elapses.



*Figure 451: Signal scheme of autoreclosing operation initiated with protection operate signal*

The autoreclosing shot is initiated with a trip signal of the protection function. The autoreclosing starts when the protection operate delay time elapses.

Normally, all trip and start signals are used to initiate an autoreclosing shot and trip the circuit breaker. **ACTIVE** output indicates reclosing sequence in progress. If any of the input signals **INIT\_X** or **DEL\_INIT\_X** are used for blocking, the corresponding bit in the *Tripping line* setting must be **FALSE**. This is to ensure that the circuit breaker does not trip from that signal, that is, the signal does not activate the **OPEN\_CB** output. The default value for the setting is "63", which means that all initiation signals activate the **OPEN\_CB** output. The lowest bit in the *Tripping line* setting corresponds to the **INIT\_1** input, the highest bit to the **INIT\_6** line.

### 8.4.4.2 Shot initiation

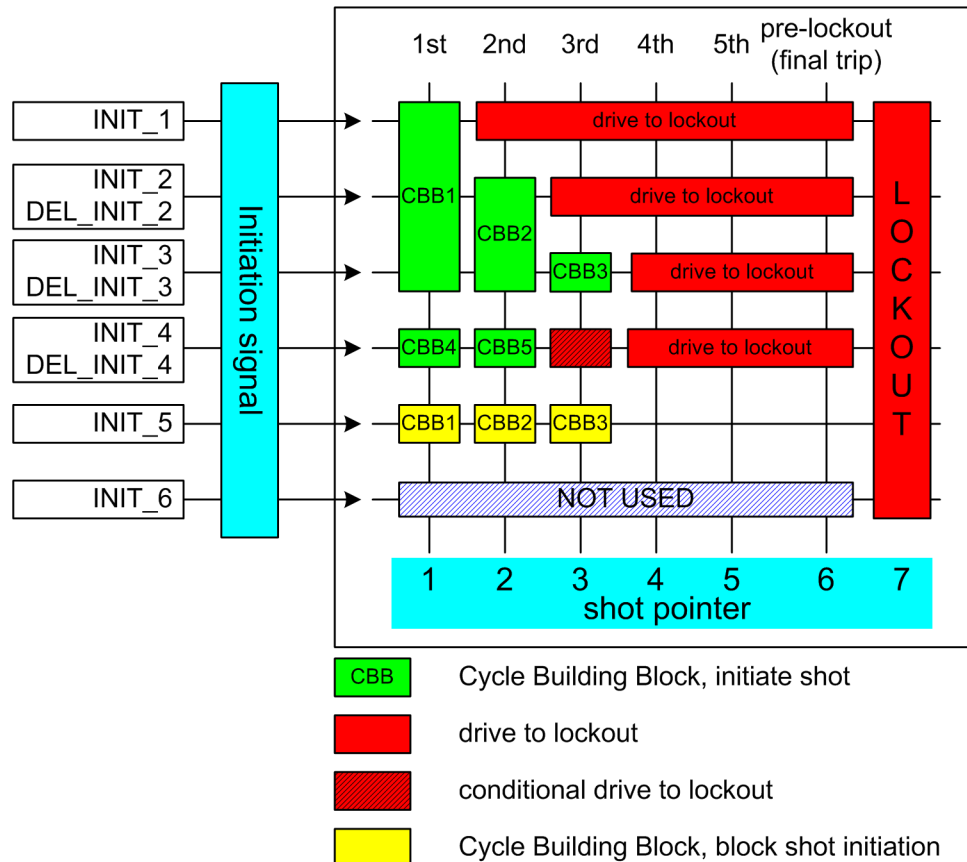


Figure 452: Example of an autoreclosing program with a reclose scheme matrix

In the AR function, each shot can be programmed to locate anywhere in the reclose scheme matrix. The shots are like building blocks used to design the reclose program. The building blocks are called CBBs. All blocks are alike and have settings which give the attempt number (columns in the matrix), the initiation or blocking signals (rows in the matrix) and the reclose time of the shot.

The settings related to CBB configuration are:

- *First...Seventh reclose time*
- *Init signals CBB1...CBB7*
- *Blk signals CBB1...CBB7*
- *Shot number CBB1...CBB7*

The reclose time defines the open and dead times, that is, the time between the OPEN\_CB and the CLOSE\_CB commands. The *Init signals CBBx* setting defines the initiation signals. The *Blk signals CBBx* setting defines the blocking signals that are related to the CBB (rows in the matrix). The *Shot number CBB1...CBB7* setting defines which shot is related to the CBB (columns in the matrix). For example, CBB1 settings are:

- *First reclose time* = 1.0s
- *Init signals CBB1* = 7 (three lowest bits: 111000 = 7)
- *Blk signals CBB1* = 16 (the fifth bit: 000010 = 16)
- *Shot number CBB1* = 1

CBB2 settings are:

- *Second reclose time* = 10s
- *Init signals CBB2* = 6 (the second and third bits: 011000 = 6)
- *Blk signals CBB2* = 16 (the fifth bit: 000010 = 16)
- *Shot number CBB2* = 2

CBB3 settings are:

- *Third reclose time* = 30s
- *Init signals CBB3* = 4 (the third bit: 001000 = 4)
- *Blk signals CBB3* = 16 (the fifth bit: 000010 = 16)
- *Shot number CBB3* = 3

CBB4 settings are:

- *Fourth reclose time* = 0.5s
- *Init signals CBB4* = 8 (the fourth bit: 000100 = 8)
- *Blk signals CBB4* = 0 (no blocking signals related to this CBB)
- *Shot number CBB4* = 1

If a shot is initiated from the `INIT_1` line, only one shot is allowed before lockout. If a shot is initiated from the `INIT_3` line, three shots are allowed before lockout.

A sequence initiation from the `INIT_4` line leads to a lockout after two shots. In a situation where the initiation is made from both the `INIT_3` and `INIT_4` lines, a third shot is allowed, that is, CBB3 is allowed to start. This is called conditional lockout. If the initiation is made from the `INIT_2` and `INIT_3` lines, an immediate lockout occurs.

The `INIT_5` line is used for blocking purposes. If the `INIT_5` line is active during a sequence start, the reclose attempt is blocked and the AR function goes to lockout.



If more than one CBBs are started with the shot pointer, the CBB with the smallest individual number is always selected. For example, if the `INIT_2` and `INIT_4` lines are active for the second shot, that is, the shot pointer is 2, CBB2 is started instead of CBB5.

Even if the initiation signals are not received from the protection functions, the AR function can be set to continue from the second to the fifth reclose shot. The AR function can, for example, be requested to automatically continue with the sequence when the circuit breaker fails to close when requested. In such a case, the AR function issues a `CLOSE_CB` command. When the wait close time elapses, that is, the closing of the circuit breaker fails, the next shot is automatically started. Another example is the embedded generation on the power line, which can make the synchronism check fail and prevent the reclosing. If the auto-reclose sequence is continued to the second shot, a successful synchronous reclosing is more likely than with the first shot, since the second shot lasts longer than the first one.

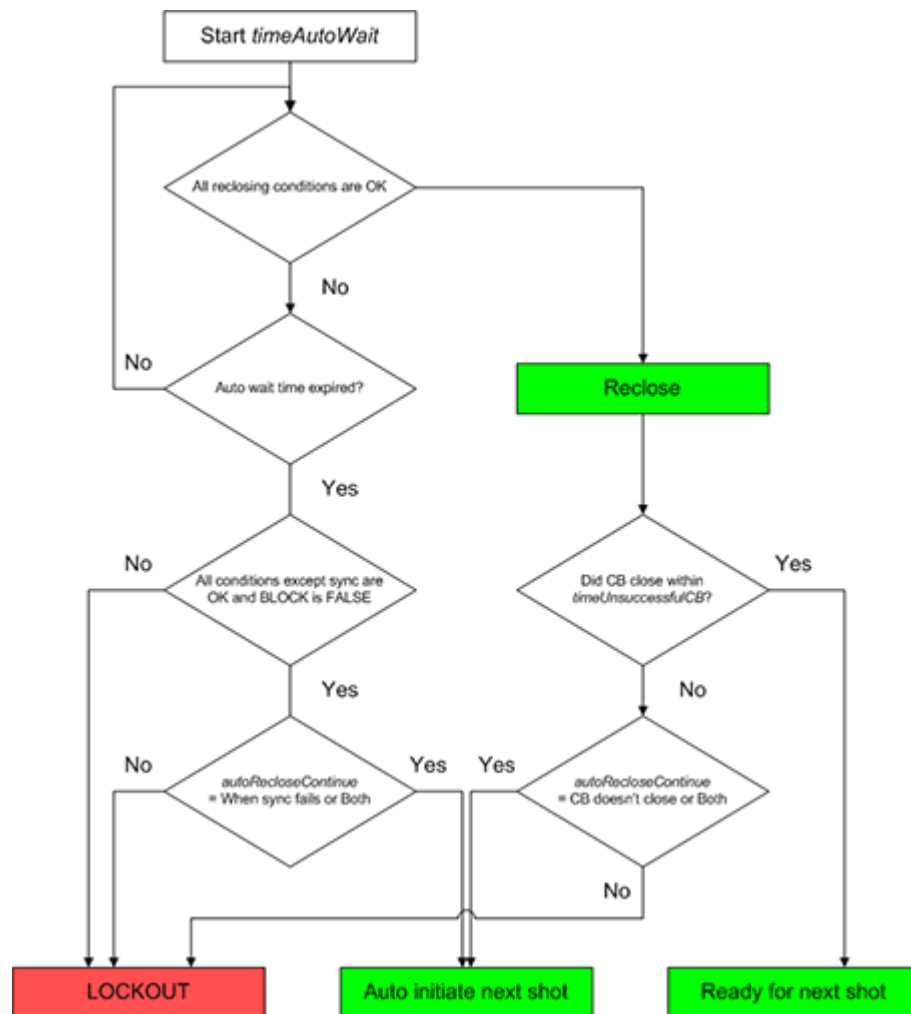


Figure 453: Logic diagram of auto-initiation sequence detection

Automatic initiation can be selected with the *Auto initiation Cnd* setting to be the following:

- Not allowed: no automatic initiation is allowed
- When the synchronization fails, the automatic initiation is carried out when the auto wait time elapses and the reclosing is prevented due to a failure during the synchronism check
- When the circuit breaker does not close, the automatic initiation is carried out if the circuit breaker does not close within the wait close time after issuing the reclose command
- Both: the automatic initiation is allowed when synchronization fails or the circuit breaker does not close.



The *Auto init* parameter defines which `INIT_X` lines are activated in the auto-initiation. The default value for this parameter is "0", which means that no auto-initiation is selected.

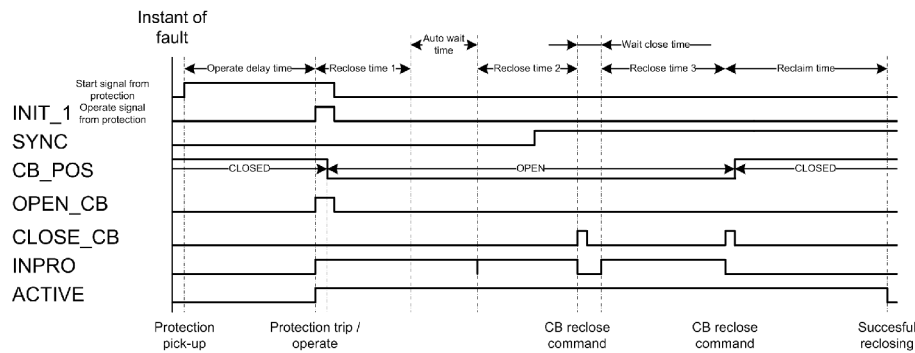


Figure 454: Example of an auto-initiation sequence with synchronization failure in the first shot and circuit breaker closing failure in the second shot

In the first shot, the synchronization condition is not fulfilled (SYNC is FALSE). When the auto wait timer elapses, the sequence continues to the second shot. During the second reclosing, the synchronization condition is fulfilled and the close command is given to the circuit breaker after the second reclose time has elapsed.

After the second shot, the circuit breaker fails to close when the wait close time has elapsed. The third shot is started and a new close command is given after the third reclose time has elapsed. The circuit breaker closes normally and the reclaim time starts. When the reclaim time has elapsed, the sequence is concluded successful.

### 8.4.4.3 Shot pointer controller

The execution of a reclose sequence is controlled by a shot pointer. It can be adjusted with the SHOT\_PTR monitored data.

The shot pointer starts from an initial value "1" and determines according to the settings whether or not a certain shot is allowed to be initiated. After every shot, the shot pointer value increases. This is carried out until a successful reclosing or lockout takes place after a complete shot sequence containing a total of five shots.

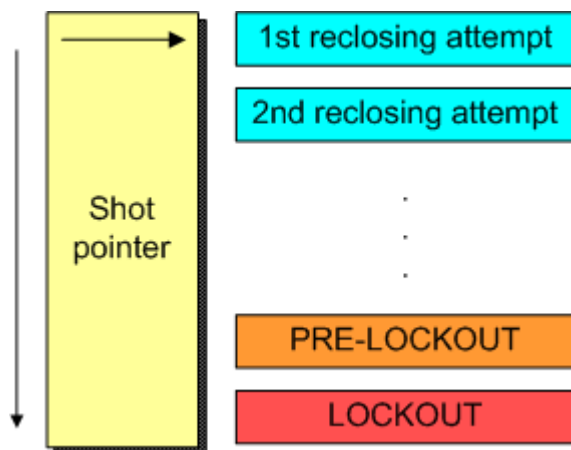


Figure 455: Shot pointer function

Every time the shot pointer increases, the reclaim time starts. When the reclaim time ends, the shot pointer sets to its initial value, unless no new shot is initiated. The shot pointer increases when the reclose time elapses or at the falling edge of the INC\_SHOTP signal.

When SHOT\_PTR has the value six, the AR function is in a so called pre-lockout state. If a new initiation occurs during the pre-lockout state, the AR function goes to lockout. Therefore, a new sequence initiation during the pre-lockout state is not possible.

The AR function goes to the pre-lockout state in the following cases:

- During SOTF
- When the AR function is active, it stays in a pre-lockout state for the time defined by the reclaim time
- When all five shots have been executed
- When the frequent operation counter limit is reached. A new sequence initiation forces the AR function to lockout.

### 8.4.4.4 Reclose controller

The reclose controller calculates the reclose, discrimination and reclaim times. The reclose time is started when the INPRO signal is activated, that is, when the sequence starts and the activated CBB defines the reclose time.

When the reclose time has elapsed, the CLOSE\_CB output is not activated until the following conditions are fulfilled:

- The SYNC input must be TRUE if the particular CBB requires information about the synchronism
- All AR initiation inputs that are defined protection lines (using the *Control line* setting) are inactive
- The circuit breaker is open
- The circuit breaker is ready for the close command, that is, the CB\_READY input is TRUE. This is indicated by active READY output.

If at least one of the conditions is not fulfilled within the time set with the *Auto wait time* parameter, the auto-reclose sequence is locked.

The synchronism requirement for the CBBs can be defined with the *Synchronisation set* setting, which is a bit mask. The lowest bit in the *Synchronisation set* setting is related to CBB1 and the highest bit to CBB7. For example, if the setting is set to "1", only CBB1 requires synchronism. If the setting is it set to "7", CBB1, CBB2 and CBB3 require the SYNC input to be TRUE before the reclosing command can be given.

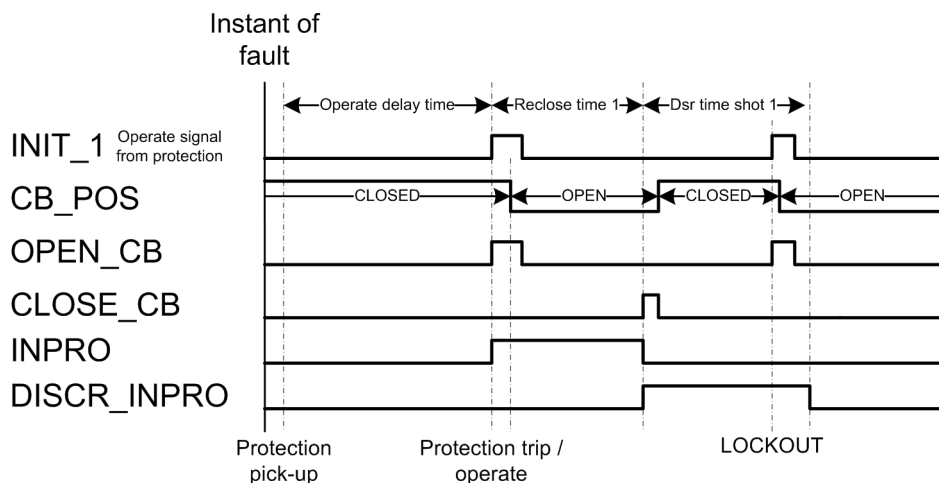


Figure 456: Initiation during discrimination time - AR function goes to lockout



The discrimination time starts when the close command `CLOSE_CB` has been given. If a start input is activated before the discrimination time has elapsed, the AR function goes to lockout. The default value for each discrimination time is zero. The discrimination time can be adjusted with the *Dsr time shot 1...4* parameter.

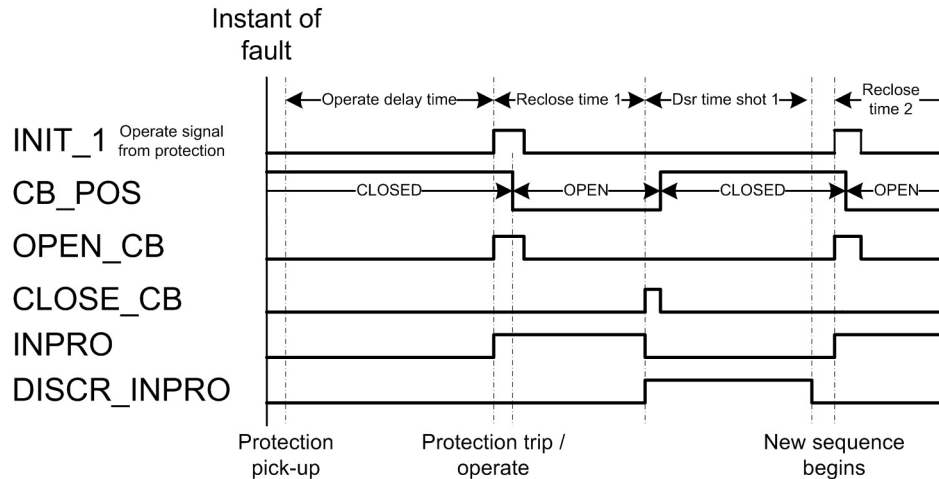


Figure 457: Initiation after elapsed discrimination time - new shot begins

#### 8.4.4.5

#### Sequence controller

When the `LOCKED` output is active, the AR function is in lockout. This means that new sequences cannot be initialized, because AR is insensitive to initiation commands. It can be released from the lockout state in the following ways.

- The function is reset through communication with the *RecRs* parameter. The same functionality can also be found in the Clear menu (DARREC1 reset).
- The lockout is automatically reset after the reclaim time, if the *Auto lockout reset* setting is in use.



If the *Auto lockout reset* setting is not in use, the lockout can be released only with the *RecRs* parameter.

The AR function can go to lockout for many reasons.

- The `INHIBIT_RECL` input is active.
- All shots have been executed and a new initiation is made (final trip).
- The time set with the *Auto wait time* parameter expires and the automatic sequence initiation is not allowed because of a synchronization failure.
- The time set with the *Wait close time* parameter expires, that is, the circuit breaker does not close or the automatic sequence initiation is not allowed due to a closing failure of the circuit breaker.
- A new shot is initiated during the discrimination time.
- The time set with the *Max wait time* parameter expires, that is, the master unit does not release the slave unit.
- The frequent operation counter limit is reached and new sequence is initiated. The lockout is released when the recovery timer elapses.
- The protection trip signal has been active longer than the time set with the *Max wait time* parameter since the shot initiation.

- The circuit breaker is closed manually during an autoreclosing sequence and the manual close mode is FALSE.

#### 8.4.4.6 Protection coordination controller

The `PROT_CRD` output is used for controlling the protection functions. In several applications, such as fuse-saving applications involving down-stream fuses, tripping and initiation of shot 1 should be fast (instantaneous or short-time delayed). The tripping and initiation of shots 2, 3 and definite tripping time should be delayed.

In this example, two overcurrent elements `PHLPTOC` and `PHIPTOC` are used. `PHIPTOC` is given an instantaneous characteristic and `PHLPTOC` is given a time delay.

The `PROT_CRD` output is activated, if the `SHOT_PTR` value is the same or higher than the value defined with the *Protection crd limit* setting and all initialization signals have been reset. The `PROT_CRD` output is reset under the following conditions:

- If the cut-out time elapses
- If the reclaim time elapses and the AR function is ready for a new sequence
- If the AR function is in lockout or disabled, that is, if the value of the *Protection crd mode* setting is "AR inoperative" or "AR inop, CB man".

The `PROT_CRD` output can also be controlled with the *Protection crd mode* setting. The setting has the following modes:

- "no condition": the `PROT_CRD` output is controlled only with the *Protection crd limit* setting
- "AR inoperative": the `PROT_CRD` output is active, if the AR function is disabled or in the lockout state, or if the `INHIBIT_RECL` input is active
- "CB close manual": the `PROT_CRD` output is active for the reclaim time if the circuit breaker has been manually closed, that is, the AR function has not issued a close command
- "AR inop, CB man": both the modes "AR inoperative" and "CB close manual" are effective
- "always": the `PROT_CRD` output is constantly active

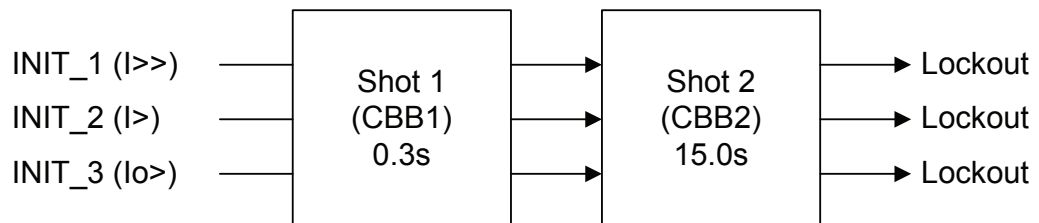


Figure 458: Configuration example of using the `PROT_CRD` output for protection blocking

If the *Protection crd limit* setting has the value "1", the instantaneous three-phase overcurrent protection function `PHIPTOC` is disabled or blocked after the first shot.

#### 8.4.4.7 Circuit breaker controller

Circuit breaker controller contains two features: SOTF and frequent-operation counter. SOTF protects the AR function in permanent faults.

The circuit breaker position information is controlled with the *CB closed Pos status* setting. The setting value "TRUE" means that when the circuit breaker is closed, the CB\_POS input is TRUE. When the setting value is "FALSE", the CB\_POS input is FALSE, provided that the circuit breaker is closed. The reclose command pulse time can be controlled with the *Close pulse time* setting: the CLOSE\_CB output is active for the time set with the *Close pulse time* setting. The CLOSE\_CB output is deactivated also when the circuit breaker is detected to be closed, that is, when the CB\_POS input changes from open state to closed state. The *Wait close time* setting defines the time after the CLOSE\_CB command activation, during which the circuit breaker should be closed. If the closing of circuit breaker does not happen during this time, the autoreclosing function is driven to lockout or, if allowed, an auto-initiation is activated.

The main motivation for autoreclosing to begin with is the assumption that the fault is temporary by nature, and that a momentary de-energizing of the power line and an automatic reclosing restores the power supply. However, when the power line is manually energized and an immediate protection trip is detected, it is very likely that the fault is of a permanent type. A permanent fault is, for example, energizing a power line into a forgotten earthing after a maintenance work along the power line. In such cases, SOTF is activated, but only for the reclaim time after energizing the power line and only when the circuit breaker is closed manually and not by the AR function.

SOTF disables any initiation of an autoreclosing shot. The energizing of the power line is detected from the CB\_POS information.

SOTF is activated when the AR function is enabled or when the AR function is started and the SOTF should remain active for the reclaim time.

When SOTF is detected, the parameter *SOTF* is active.



If the *Manual close mode* setting is set to FALSE and the circuit breaker has been manually closed during an autoreclosing shot, the AR unit goes to an immediate lockout.



If the *Manual close mode* setting is set to TRUE and the circuit breaker has been manually closed during an autoreclosing shot (the INPRO is active), the shot is considered as completed.



When SOTF starts, reclaim time is restarted, provided that it is running.

The frequent-operation counter is intended for blocking the autoreclosing function in cases where the fault causes repetitive autoreclosing sequences during a short period of time. For instance, if a tree causes a short circuit and, as a result, there are autoreclosing shots within a few minutes interval during a stormy night. These types of faults can easily damage the circuit breaker if the AR function is not locked by a frequent-operation counter.

The frequent-operation counter has three settings:

- *Frq Op counter limit*
- *Frq Op counter time*
- *Frq Op recovery time*

The *Frq Op counter limit* setting defines the number of reclose attempts that are allowed during the time defined with the *Frq Op counter time* setting. If the set value is reached within a pre-defined period defined with the *Frq Op counter time*

setting, the AR function goes to lockout when a new shot begins, provided that the counter is still above the set limit. The lockout is released after the recovery time has elapsed. The recovery time can be defined with the *Frq Op recovery time* setting .

If the circuit breaker is manually closed during the recovery time, the reclaim time is activated after the recovery timer has elapsed.

### 8.4.5 Counters

The AR function contains six counters. Their values are stored in a semi-retain memory. The counters are increased at the rising edge of the reclosing command. The counters count the following situations.

- COUNTER: counts every reclosing command activation
- CNT\_SHOT1: counts reclosing commands that are executed from shot 1
- CNT\_SHOT2: counts reclosing commands that are executed from shot 2
- CNT\_SHOT3: counts reclosing commands that are executed from shot 3
- CNT\_SHOT4: counts reclosing commands that are executed from shot 4
- CNT\_SHOT5: counts reclosing commands that are executed from shot 5

The counters are disabled through communication with the *DsaCnt* parameter. When the counters are disabled, the values are not updated.

The counters are reset through communication with the *CntRs* parameter. The same functionality can also be found in the clear menu (DARREC1 counters).

### 8.4.6 Application

Modern electric power systems can deliver energy to users very reliably. However, different kind of faults can occur. IEDs play an important role in detecting failures or abnormalities in the system. They detect faults and give commands for corresponding circuit breakers to isolate the defective element before excessive damage or a possible power system collapse occurs. A fast isolation also limits the disturbances caused for the healthy parts of the power system.

The faults can be transient, semi-transient or permanent. Permanent fault, for example in power cables, means that there is a physical damage in the fault location that must first be located and repaired before the network voltage can be restored.

In overhead lines, the insulating material between phase conductors is air. The majority of the faults are flash-over arcing faults caused by lightning, for example. Only a short interruption is needed for extinguishing the arc. These faults are transient by nature.

A semi-transient fault can be caused for example by a bird or a tree branch falling on the overhead line. The fault disappears on its own if the fault current burns the branch or the wind blows it away.

Transient and semi-transient faults can be cleared by momentarily de-energizing the power line. Using the auto-reclose function minimizes interruptions in the power system service and brings the power back on-line quickly and effortlessly.

The basic idea of the auto-reclose function is simple. In overhead lines, where the possibility of self-clearing faults is high, the auto-reclose function tries to restore the power by reclosing the breaker. This is a method to get the power system back into normal operation by removing the transient or semi-transient faults. Several

trials, that is, auto-reclose shots are allowed. If none of the trials is successful and the fault persists, definite final tripping follows.

The auto-reclose function can be used with every circuit breaker that has the ability for a reclosing sequence. In DARREC auto-reclose function the implementing method of auto-reclose sequences is patented by ABB

**Table 827: Important definitions related to auto-reclosing**

|                       |  |
|-----------------------|--|
| auto-reclose shot     | an operation where after a preset time the breaker is closed from the breaker tripping caused by protection  |
| auto-reclose sequence | a predefined method to do reclose attempts (shots) to restore the power system   |
| SOTF                  | If the protection detects a fault immediately after an open circuit breaker has been closed, it indicates that the fault was already there. It can be, for example, a forgotten earthing after maintenance work. Such closing of the circuit breaker is known as switch on to fault. Autoreclosing in such conditions is prohibited. |
| final trip            | Occurs in case of a permanent fault, when the circuit breaker is opened for the last time after all programmed auto-reclose operations. Since no auto-reclosing follows, the circuit breaker remains open. This is called final trip or definite trip.   |

8.4.6.1

Shot initiation

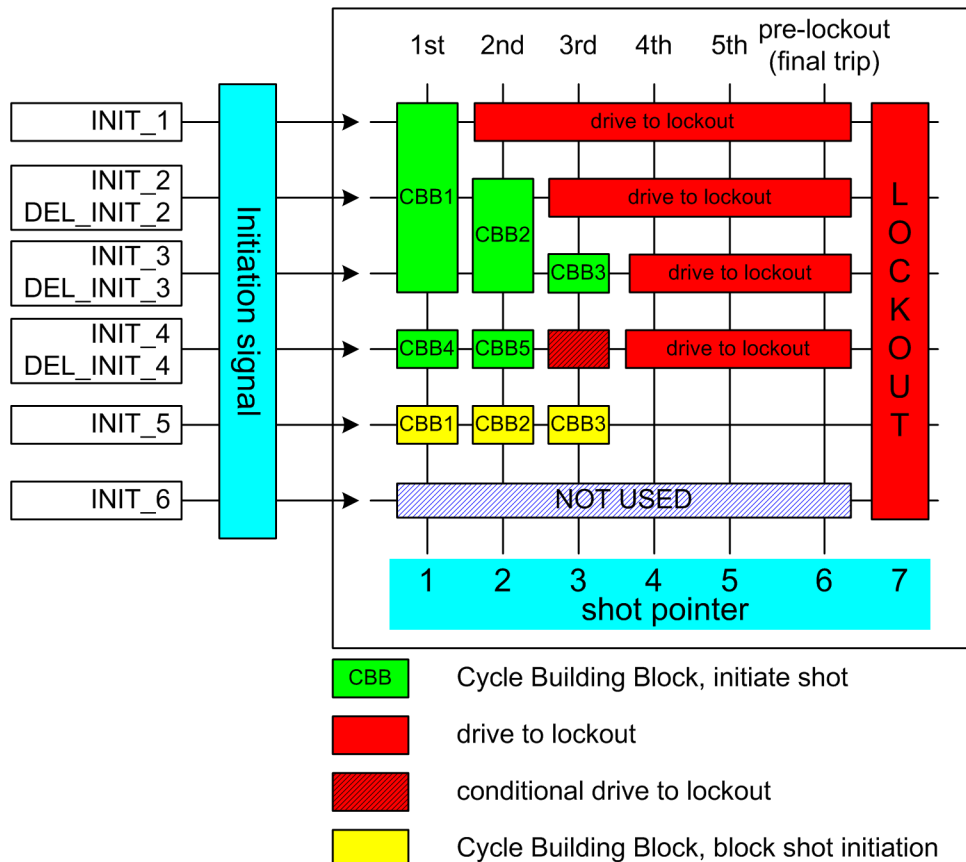


Figure 459: Example of an autoreclosing program with a reclose scheme matrix

In the AR function, each shot can be programmed to locate anywhere in the reclose scheme matrix. The shots are like building blocks used to design the reclose program. The building blocks are called CBBs. All blocks are alike and have settings which give the attempt number (columns in the matrix), the initiation or blocking signals (rows in the matrix) and the reclose time of the shot.

The settings related to CBB configuration are:

- *First...Seventh reclose time*
- *Init signals CBB1...CBB7*
- *Blk signals CBB1...CBB7*
- *Shot number CBB1...CBB7*

The reclose time defines the open and dead times, that is, the time between the `OPEN_CB` and the `CLOSE_CB` commands. The *Init signals CBBx* setting defines the initiation signals. The *Blk signals CBBx* setting defines the blocking signals that are related to the CBB (rows in the matrix). The *Shot number CBB1...CBB7* setting defines which shot is related to the CBB (columns in the matrix). For example, CBB1 settings are:

- *First reclose time* = 1.0s
- *Init signals CBB1* = 7 (three lowest bits: 111000 = 7)
- *Blk signals CBB1* = 16 (the fifth bit: 000010 = 16)
- *Shot number CBB1* = 1

CBB2 settings are:

- *Second reclose time* = 10s
- *Init signals CBB2* = 6 (the second and third bits: 011000 = 6)
- *Blk signals CBB2* = 16 (the fifth bit: 000010 = 16)
- *Shot number CBB2* = 2

CBB3 settings are:

- *Third reclose time* = 30s
- *Init signals CBB3* = 4 (the third bit: 001000 = 4)
- *Blk signals CBB3* = 16 (the fifth bit: 000010 = 16)
- *Shot number CBB3* = 3

CBB4 settings are:

- *Fourth reclose time* = 0.5s
- *Init signals CBB4* = 8 (the fourth bit: 000100 = 8)
- *Blk signals CBB4* = 0 (no blocking signals related to this CBB)
- *Shot number CBB4* = 1

If a shot is initiated from the `INIT_1` line, only one shot is allowed before lockout. If a shot is initiated from the `INIT_3` line, three shots are allowed before lockout.

A sequence initiation from the `INIT_4` line leads to a lockout after two shots. In a situation where the initiation is made from both the `INIT_3` and `INIT_4` lines, a third shot is allowed, that is, CBB3 is allowed to start. This is called conditional lockout. If the initiation is made from the `INIT_2` and `INIT_3` lines, an immediate lockout occurs.

The `INIT_5` line is used for blocking purposes. If the `INIT_5` line is active during a sequence start, the reclose attempt is blocked and the AR function goes to lockout.



If more than one CBBs are started with the shot pointer, the CBB with the smallest individual number is always selected. For example, if the `INIT_2` and `INIT_4` lines are active for the second shot, that is, the shot pointer is 2, CBB2 is started instead of CBB5.

Even if the initiation signals are not received from the protection functions, the AR function can be set to continue from the second to the fifth reclose shot. The AR function can, for example, be requested to automatically continue with the sequence when the circuit breaker fails to close when requested. In such a case, the AR function issues a `CLOSE_CB` command. When the wait close time elapses, that is, the closing of the circuit breaker fails, the next shot is automatically started. Another example is the embedded generation on the power line, which can make the synchronism check fail and prevent the reclosing. If the auto-reclose sequence is continued to the second shot, a successful synchronous reclosing is more likely than with the first shot, since the second shot lasts longer than the first one.

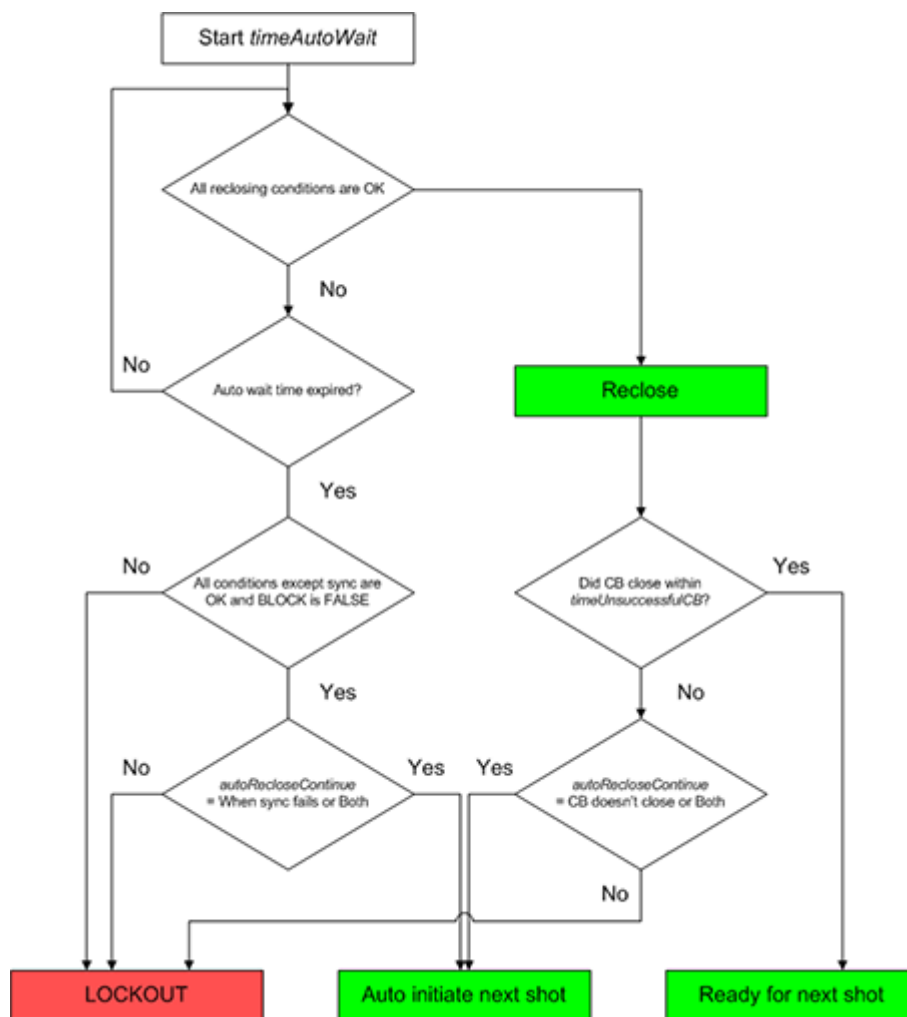


Figure 460: Logic diagram of auto-initiation sequence detection

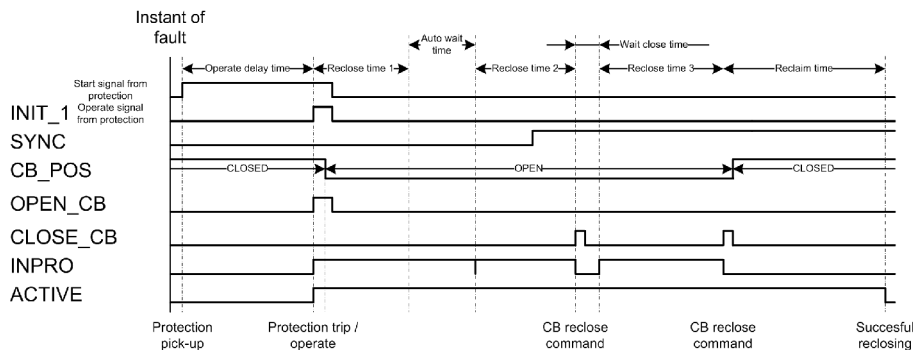
Automatic initiation can be selected with the *Auto initiation Cnd* setting to be the following:

- Not allowed: no automatic initiation is allowed

- When the synchronization fails, the automatic initiation is carried out when the auto wait time elapses and the reclosing is prevented due to a failure during the synchronism check
- When the circuit breaker does not close, the automatic initiation is carried out if the circuit breaker does not close within the wait close time after issuing the reclose command
- Both: the automatic initiation is allowed when synchronization fails or the circuit breaker does not close.



The *Auto init* parameter defines which `INIT_X` lines are activated in the auto-initiation. The default value for this parameter is "0", which means that no auto-initiation is selected.



*Figure 461: Example of an auto-initiation sequence with synchronization failure in the first shot and circuit breaker closing failure in the second shot*

In the first shot, the synchronization condition is not fulfilled (`SYNC` is `FALSE`). When the auto wait timer elapses, the sequence continues to the second shot. During the second reclosing, the synchronization condition is fulfilled and the close command is given to the circuit breaker after the second reclose time has elapsed.

After the second shot, the circuit breaker fails to close when the wait close time has elapsed. The third shot is started and a new close command is given after the third reclose time has elapsed. The circuit breaker closes normally and the reclaim time starts. When the reclaim time has elapsed, the sequence is concluded successful.

#### 8.4.6.2

#### Sequence

The auto reclose sequence is implemented by using CBBs. The highest possible amount of CBBs is seven. If the user wants to have, for example, a sequence of three shots, only the first three CBBs are needed. Using building blocks instead of fixed shots gives enhanced flexibility, allowing multiple and adaptive sequences.

Each CBB is identical. The *Shot number CBB\_* setting defines at which point in the auto-reclose sequence the CBB should be performed, that is, whether the particular CBB is going to be the first, second, third, fourth or fifth shot.

During the initiation of a CBB, the conditions of initiation and blocking are checked. This is done for all CBBs simultaneously. Each CBB that fulfils the initiation conditions requests an execution.

The function also keeps track of shots already performed, that is, at which point the auto-reclose sequence is from shot 1 to lockout. For example, if shots 1 and 2 have already been performed, only shots 3 to 5 are allowed.

Additionally, the *Enable shot jump* setting gives two possibilities:



- Only such CBBs that are set for the next shot in the sequence can be accepted for execution. For example, if the next shot in the sequence should be shot 2, a request from CBB set for shot 3 is rejected.
- Any CBB that is set for the next shot or any of the following shots can be accepted for execution. For example, if the next shot in the sequence should be shot 2, also CBBs that are set for shots 3, 4 and 5 are accepted. In other words, shot 2 can be ignored.

In case there are multiple CBBs allowed for execution, the CBB with the smallest number is chosen. For example, if CBB2 and CBB4 request an execution, CBB2 is allowed to execute the shot.

The auto-reclose function can perform up to five auto-reclose shots or cycles.

### 8.4.6.3 Configuration examples

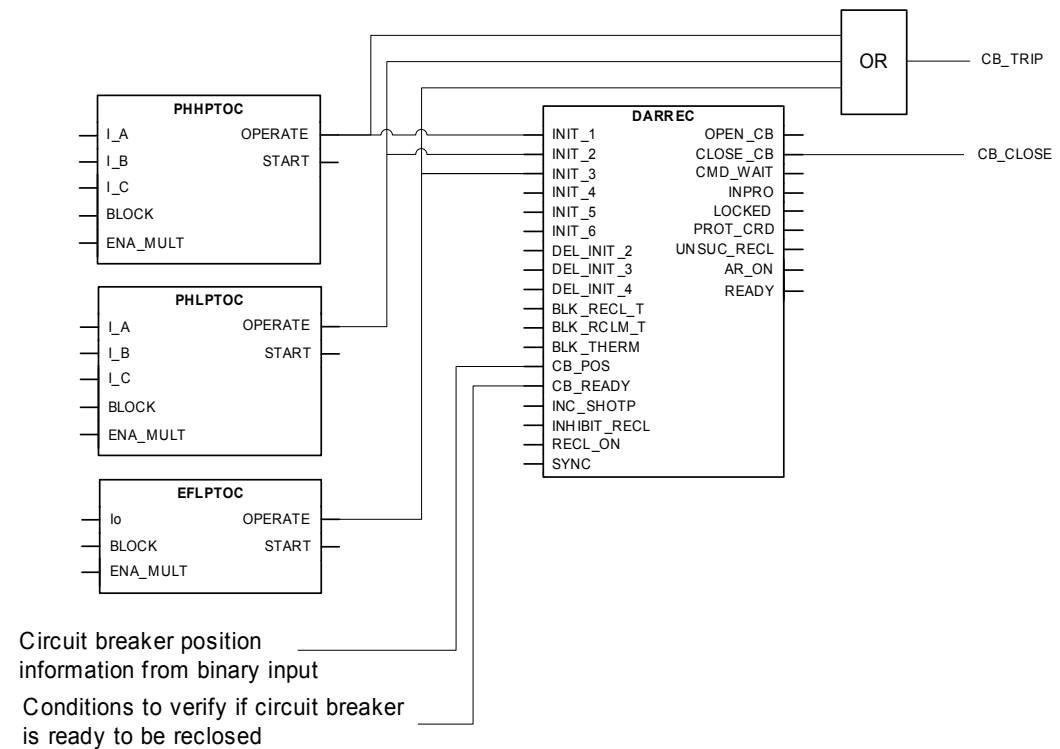


Figure 462: Example connection between protection and autoreclosing functions in IED configuration

It is possible to create several sequences for a configuration.

Autoreclose sequences for overcurrent and non-directional earth-fault protection applications where high speed and delayed autoreclosings are needed can be as follows:

#### Example 1.

The sequence is implemented by two shots which have the same reclosing time for all protection functions, namely I>>, I> and Io>. The initiation of the shots is done by activating the operating signals of the protection functions.

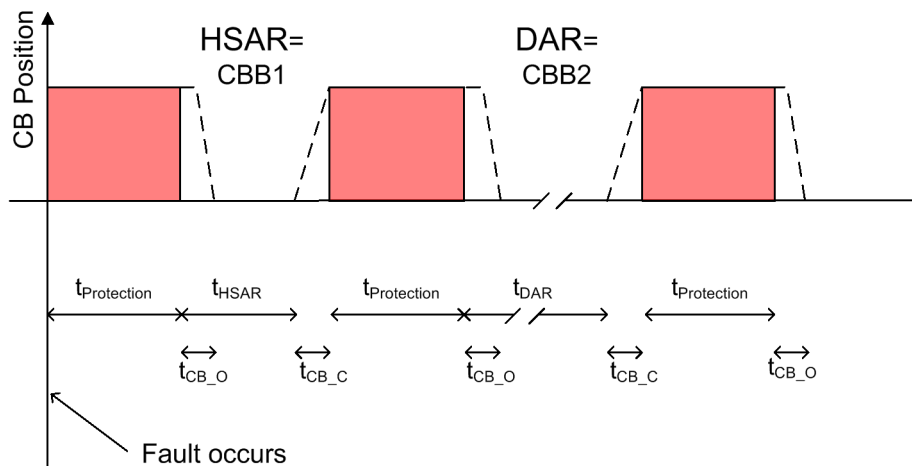


Figure 463: Autoreclosing sequence with two shots

- $t_{HSAR}$  Time delay of high-speed autoreclosing, here: *First reclose time*
- $t_{DAR}$  Time delay of delayed autoreclosing, here: *Second reclose time*
- $t_{Protection}$  Operating time for the protection stage to clear the fault
- $t_{CB\_O}$  Operating time for opening the circuit breaker
- $t_{CB\_C}$  Operating time for closing the circuit breaker

In this case, the sequence needs two CBBs. The reclosing times for shot 1 and shot 2 are different, but each protection function initiates the same sequence. The CBB sequence is described in [Figure 464](#) as follows:

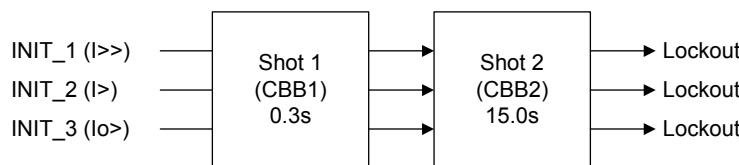


Figure 464: Two shots with three initiation lines

Table 828: Settings for configuration example 1

| Setting name        | Setting value                    |
|---------------------|----------------------------------|
| Shot number CBB1    | 1                                |
| Init signals CBB1   | 7 (lines 1, 2 and 3 = 1+2+4 = 7) |
| First reclose time  | 0.3s (an example)                |
| Shot number CBB2    | 2                                |
| Init signals CBB2   | 7 (lines 1, 2 and 3 = 1+2+4 = 7) |
| Second reclose time | 15.0s (an example)               |

### Example 2

There are two separate sequences implemented with three shots. Shot 1 is implemented by CBB1 and it is initiated with the high stage of the overcurrent protection ( $I_{>>}$ ). Shot 1 is set as a high-speed autoreclosing with a short time delay. Shot 2 is implemented with CBB2 and meant to be the first shot of the autoreclose sequence initiated by the low stage of the overcurrent protection ( $I_{>}$ ) and the low stage of the non-directional earth-fault protection ( $I_{o>}$ ). It has the same reclosing time in both situations. It is set as a high-speed autoreclosing for corresponding faults. The third shot, which is the second shot in the autoreclose sequence initiated by  $I_{>}$  or  $I_{o>}$ , is set as a delayed autoreclosing and executed after an unsuccessful high-speed autoreclosing of a corresponding sequence.

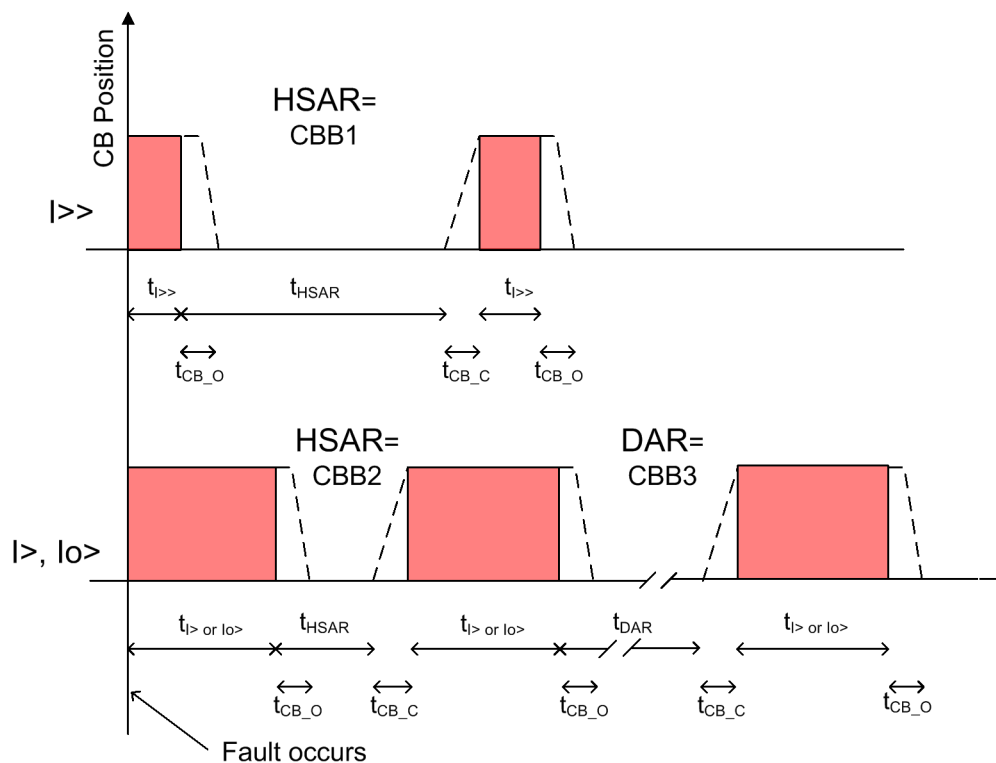


Figure 465: Autoreclosing sequence with two shots with different shot settings according to initiation signal

|                                |  |
|--------------------------------|--|
| $t_{HSAR}$                     | Time delay of high-speed autoreclosing, here: <i>First reclose time</i>        |
| $t_{DAR}$                      | Time delay of delayed autoreclosing, here: <i>Second reclose time</i>          |
| $t_{I_{>>}}$                   | Operating time for the $I_{>>}$ protection stage to clear the fault            |
| $t_{I_{>} \text{ or } I_{o>}}$ | Operating time for the $I_{>}$ or $I_{o>}$ protection stage to clear the fault |
| $t_{CB_O}$                     | Operating time for opening the circuit breaker                                 |
| $t_{CB_C}$                     | Operating time for closing the circuit breaker                                 |

In this case, the number of needed CBBs is three, that is, the first shot's reclosing time depends on the initiation signal.

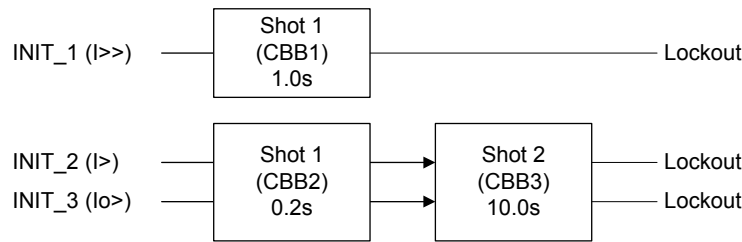


Figure 466: Three shots with three initiation lines

If the sequence is initiated from the `INIT_1` line, that is, the overcurrent protection high stage, the sequence is one shot long. If the sequence is initiated from the `INIT_2` or `INIT_3` lines, the sequence is two shots long.

Table 829: Settings for configuration example 2

| Setting name               | Setting value               |
|----------------------------|-----------------------------|
| <i>Shot number CBB1</i>    | 1                           |
| <i>Init signals CBB1</i>   | 1 (line 1)                  |
| <i>First reclose time</i>  | 0.0s (an example)           |
| <i>Shot number CBB2</i>    | 1                           |
| <i>Init signals CBB2</i>   | 6 (lines 2 and 3 = 2+4 = 6) |
| <i>Second reclose time</i> | 0.2s (an example)           |
| <i>Shot number CBB3</i>    | 2                           |
| <i>Init signals CBB3</i>   | 6 (lines 2 and 3 = 2+4 = 6) |
| <i>Third reclose time</i>  | 10.0s                       |

#### 8.4.6.4 Delayed initiation lines

The auto-reclose function consists of six individual auto-reclose initiation lines `INIT_1...INIT_6` and three delayed initiation lines:

- `DEL_INIT_2`
- `DEL_INIT_3`
- `DEL_INIT_4`

`DEL_INIT_2` and `INIT_2` are connected together with an OR-gate, as are inputs 3 and 4. Inputs 1, 5 and 6 do not have any delayed input. From the auto-reclosing point of view, it does not matter whether `INIT_x` or `DEL_INIT_x` line is used for shot initiation or blocking.

The auto-reclose function can also open the circuit breaker from any of the initiation lines. It is selected with the *Tripping line* setting. As a default, all initiation lines activate the `OPEN_CB` output.

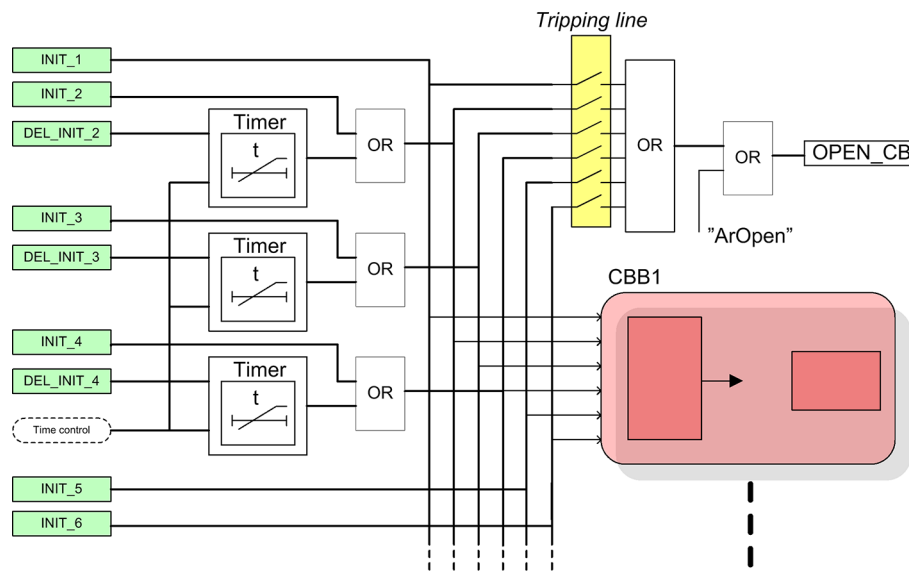


Figure 467: Simplified logic diagram of initiation lines

Each delayed initiation line has four different time settings:

Table 830: Settings for delayed initiation lines

| Setting name              | Description and purpose   |
|---------------------------|---|
| <i>Str x delay shot 1</i> | Time delay for the DEL_INIT_x line, where x is the number of the line 2, 3 or 4. Used for shot 1.   |
| <i>Str x delay shot 2</i> | Time delay for the DEL_INIT_x line, used for shot 2.  |
| <i>Str x delay shot 3</i> | Time delay for the DEL_INIT_x line, used for shot 3.  |
| <i>Str x delay shot 4</i> | Time delay for the DEL_INIT_x line, used for shots 4 and 5. Optionally, can also be used with SOTF. |

### 8.4.6.5 Shot initiation from protection start signal

In its simplest, all auto-reclose shots are initiated by protection trips. As a result, all trip times in the sequence are the same. This is why using protection trips may not be the optimal solution. Using protection start signals instead of protection trips for initiating shots shortens the trip times.

#### Example 1

When a two-shot-sequence is used, the start information from the protection function is routed to the DEL\_INIT\_2 input and the operate information to the INIT\_2 input. The following conditions have to apply:

- protection operate time = 0.5s
- *Str 2 delay shot 1* = 0.05s
- *Str 2 delay shot 2* = 60s
- *Str 2 delay shot 3* = 60s

Operation in a permanent fault:

1. Protection starts and activates the `DEL_INIT_2` input.
2. After 0.05 seconds, the first autoreclose shot is initiated. The function opens the circuit breaker: the `OPEN_CB` output activates. The total trip time is the protection start delay + 0.05 seconds + the time it takes to open the circuit breaker.
3. After the first shot, the circuit breaker is reclosed and the protection starts again.
4. Because the delay of the second shot is 60 seconds, the protection is faster and trips after the set operation time, activating the `INIT_2` input. The second shot is initiated.
5. After the second shot, the circuit breaker is reclosed and the protection starts again.
6. Because the delay of the second shot is 60 seconds, the protection is faster and trips after the set operation time. No further shots are programmed after the final trip. The function is in lockout and the sequence is considered unsuccessful.

### Example 2

The delays can be used also for fast final trip. The conditions are the same as in Example 1, with the exception of *Str 2 delay shot 3* = 0.10 seconds.

The operation in a permanent fault is the same as in Example 1, except that after the second shot when the protection starts again, *Str 2 delay shot 3* elapses before the protection operate time and the final trip follows. The total trip time is the protection start delay + 0.10 seconds + the time it takes to open the circuit breaker.

## 8.4.6.6 Fast trip in Switch on to fault

The *Str\_delay shot 4* parameter delays can also be used to achieve a fast and accelerated trip with SOTF. This is done by setting the *Fourth delay in SOTF* parameter to "1" and connecting the protection start information to the corresponding `DEL_INIT_` input.

When the function detects a closing of the circuit breaker, that is, any other closing except the reclosing done by the function itself, it always prohibits shot initiation for the time set with the *Reclaim time* parameter. Furthermore, if the *Fourth delay in SOTF* parameter is "1", the *Str\_delay shot 4* parameter delays are also activated.

### Example 1

The protection operation time is 0.5 seconds, the *Fourth delay in SOTF* parameter is set to "1" and the *Str 2 delay shot 4* parameter is 0.05 seconds. The protection start signal is connected to the `DEL_INIT_2` input.

If the protection starts after the circuit breaker closes, the fast trip follows after the set 0.05 seconds. The total trip time is the protection start delay + 0.05 seconds + the time it takes to open the circuit breaker.

## 8.4.7 Signals

### 8.4.7.1 DARREC Input signals

Table 831: DARREC Input signals

| Name         | Type    | Default | Description   |
|--------------|---------|---------|---|
| INIT_1       | BOOLEAN | 0=False | AR initialization / blocking signal 1                       |
| INIT_2       | BOOLEAN | 0=False | AR initialization / blocking signal 2                       |
| INIT_3       | BOOLEAN | 0=False | AR initialization / blocking signal 3                       |
| INIT_4       | BOOLEAN | 0=False | AR initialization / blocking signal 4                       |
| INIT_5       | BOOLEAN | 0=False | AR initialization / blocking signal 5                       |
| INIT_6       | BOOLEAN | 0=False | AR initialization / blocking signal 6                       |
| DEL_INIT_2   | BOOLEAN | 0=False | Delayed AR initialization / blocking signal 2               |
| DEL_INIT_3   | BOOLEAN | 0=False | Delayed AR initialization / blocking signal 3               |
| DEL_INIT_4   | BOOLEAN | 0=False | Delayed AR initialization / blocking signal 4               |
| BLK_RECL_T   | BOOLEAN | 0=False | Blocks and resets reclose time                              |
| BLK_RCLM_T   | BOOLEAN | 0=False | Blocks and resets reclaim time                              |
| BLK_THERM    | BOOLEAN | 0=False | Blocks and holds the reclose shot from the thermal overload |
| CB_POS       | BOOLEAN | 0=False | Circuit breaker position input                              |
| CB_READY     | BOOLEAN | 1=True  | Circuit breaker status signal                               |
| INC_SHOTP    | BOOLEAN | 0=False | A zone sequence coordination signal                         |
| INHIBIT_RECL | BOOLEAN | 0=False | Interrupts and inhibits reclosing sequence                  |
| RECL_ON      | BOOLEAN | 0=False | Level sensitive signal for allowing (high) /                |

Table continues on the next page

| Name | Type    | Default | Description                   |
|------|---------|---------|-------------------------------|
|      |         |         | not allowing (low) re-closing |
| SYNC | BOOLEAN | 0=False | Synchronizing check fulfilled |

### 8.4.7.2 DARREC Output signals

Table 832: DARREC Output signals

| Name       | Type    | Description  |
|------------|---------|--|
| OPEN_CB    | BOOLEAN | Open command for circuit breaker   |
| CLOSE_CB   | BOOLEAN | Close (reclose) command for circuit breaker  |
| CMD_WAIT   | BOOLEAN | Wait for master command  |
| INPRO      | BOOLEAN | Reclosing shot in progress, activated during dead time                                 |
| LOCKED     | BOOLEAN | Signal indicating that AR is locked out  |
| PROT_CRD   | BOOLEAN | A signal for coordination between the AR and the protection                            |
| UNSUC_RECL | BOOLEAN | Indicates an unsuccessful re-closing sequence  |
| AR_ON      | BOOLEAN | Autoreclosing allowed  |
| READY      | BOOLEAN | Indicates that the AR is ready for a new sequence, i.e. the CB_READY input equals TRUE |
| ACTIVE     | BOOLEAN | Reclosing sequence is in progress  |

## 8.4.8 Settings

### 8.4.8.1 DARREC Settings

Table 833: DARREC Non group settings (Basic)

| Parameter | Values (Range) | Unit | Step | Default | Description      |
|-----------|----------------|------|------|---------|------------------|
| Operation | 1=on           |      |      | 1=on    | Operation Off/On |

*Table continues on the next page*



| Parameter            | Values (Range)   | Unit | Step | Default           | Description   |
|----------------------|--|------|------|-------------------|---|
|                      | 5=off  |      |      |                   |   |
| Reclosing operation  | 1=Off<br>2=External Ctl<br>3=On                                    |      |      | 1=Off             | Reclosing operation (Off, External Ctl / On)                      |
| Close pulse time     | 10...10000   | ms   | 10   | 200               | CB close pulse time   |
| Reclaim time         | 100...1800000  | ms   | 100  | 10000             | Reclaim time  |
| Terminal priority    | 1=None<br>2=Low (follower)<br>3=High (master)                      |      |      | 1=None            | Terminal priority   |
| Synchronisation set  | 0...127  |      | 1    | 0                 | Selection for synchronizing requirement for reclosing             |
| Auto initiation cnd  | 1=Not allowed<br>2=When sync fails<br>3=CB doesn't close<br>4=Both |      |      | 2=When sync fails | Auto initiation condition   |
| Tripping line        | 0...63   |      | 1    | 0                 | Tripping line, defines INIT inputs which cause OPEN_CB activation |
| Fourth delay in SOTF | 0=False<br>1=True  |      |      | 0=False           | Sets 4th delay into use for all DEL_INIT signals during SOTF      |
| First reclose time   | 0...300000   | ms   | 10   | 5000              | Dead time for CBB1  |
| Second reclose time  | 0...300000   | ms   | 10   | 5000              | Dead time for CBB2  |
| Third reclose time   | 0...300000   | ms   | 10   | 5000              | Dead time for CBB3  |
| Fourth reclose time  | 0...300000   | ms   | 10   | 5000              | Dead time for CBB4  |

Table continues on the next page

| Parameter            | Values (Range) | Unit | Step | Default | Description                              |
|----------------------|----------------|------|------|---------|--|
| Fifth reclose time   | 0...300000     | ms   | 10   | 5000    | Dead time for CBB5                       |
| Sixth reclose time   | 0...300000     | ms   | 10   | 5000    | Dead time for CBB6                       |
| Seventh reclose time | 0...300000     | ms   | 10   | 5000    | Dead time for CBB7                       |
| Init signals CBB1    | 0...63         |      | 1    | 0       | Initiation lines for CBB1                |
| Init signals CBB2    | 0...63         |      | 1    | 0       | Initiation lines for CBB2                |
| Init signals CBB3    | 0...63         |      | 1    | 0       | Initiation lines for CBB3                |
| Init signals CBB4    | 0...63         |      | 1    | 0       | Initiation lines for CBB4                |
| Init signals CBB5    | 0...63         |      | 1    | 0       | Initiation lines for CBB5                |
| Init signals CBB6    | 0...63         |      | 1    | 0       | Initiation lines for CBB6                |
| Init signals CBB7    | 0...63         |      | 1    | 0       | Initiation lines for CBB7                |
| Shot number CBB1     | 0...5          |      | 1    | 0       | Shot number for CBB1                     |
| Shot number CBB2     | 0...5          |      | 1    | 0       | Shot number for CBB2                     |
| Shot number CBB3     | 0...5          |      | 1    | 0       | Shot number for CBB3                     |
| Shot number CBB4     | 0...5          |      | 1    | 0       | Shot number for CBB4                     |
| Shot number CBB5     | 0...5          |      | 1    | 0       | Shot number for CBB5                     |
| Shot number CBB6     | 0...5          |      | 1    | 0       | Shot number for CBB6                     |
| Shot number CBB7     | 0...5          |      | 1    | 0       | Shot number for CBB7                     |
| Frq Op counter limit | 0...250        |      | 1    | 0       | Frequent operation counter lockout limit |
| Frq Op counter time  | 1...250        | min  | 1    | 1       | Frequent operation counter time          |
| Frq Op recovery time | 1...250        | min  | 1    | 1       | Frequent operation counter               |

*Table continues on the next page*

| Parameter | Values (Range) | Unit | Step | Default | Description  |
|-----------|----------------|------|------|---------|--|
|           |                |      |      |         | ter recovery time  |
| Auto init | 0...63         |      | 1    | 0       | Defines INIT lines that are activated at auto initiation |

**Table 834: DARREC Non group settings (Advanced)**

| Parameter          | Values (Range)    | Unit | Step | Default | Description  |
|--------------------|-------------------|------|------|---------|--|
| Manual close mode  | 0=False<br>1=True |      |      | 0=False | Manual close mode  |
| Wait close time    | 50...10000        | ms   | 50   | 250     | Allowed CB closing time after reclose command              |
| Max wait time      | 100...1800000     | ms   | 100  | 10000   | Maximum wait time for BLK_RECL_T release                   |
| Max trip time      | 100...10000       | ms   | 100  | 10000   | Maximum wait time for deactivation of protection signals   |
| Max Thm block time | 100...1800000     | ms   | 100  | 10000   | Maximum wait time for thermal blocking signal deactivation |
| Cut-out time       | 0...1800000       | ms   | 100  | 10000   | Cutout time for protection coordination                    |
| Dsr time shot 1    | 0...10000         | ms   | 100  | 0       | Discrimination time for first reclosing                    |
| Dsr time shot 2    | 0...10000         | ms   | 100  | 0       | Discrimination time for second reclosing                   |
| Dsr time shot 3    | 0...10000         | ms   | 100  | 0       | Discrimination time for third reclosing                    |

*Table continues on the next page*

| Parameter            | Values (Range)   | Unit | Step | Default           | Description  |
|----------------------|--|------|------|-------------------|--|
| Dsr time shot 4      | 0...10000  | ms   | 100  | 0                 | Discrimination time for fourth reclosing                       |
| Auto wait time       | 0...60000  | ms   | 10   | 2000              | Wait time for reclosing condition fullfilling                  |
| Auto lockout reset   | 0=False<br>1=True  |      |      | 1=True            | Automatic lockout reset  |
| Protection crd limit | 1...5  |      | 1    | 1                 | Protection coordination shot limit                             |
| Protection crd mode  | 1=No condition<br>2=AR inoperative<br>3=CB close manual<br>4=AR inop, CB man<br>5=Always |      |      | 4=AR inop, CB man | Protection coordination mode                                   |
| Control line         | 0...63   |      | 1    | 63                | Control line, defines INIT inputs which are protection signals |
| Enable shot jump     | 0=False<br>1=True  |      |      | 1=True            | Enable shot jumping  |
| CB closed Pos status | 0=False<br>1=True  |      |      | 0=False           | Circuit breaker closed position status                         |
| Blk signals CBB1     | 0...63   |      | 1    | 0                 | Blocking lines for CBB1  |
| Blk signals CBB2     | 0...63   |      | 1    | 0                 | Blocking lines for CBB2  |
| Blk signals CBB3     | 0...63   |      | 1    | 0                 | Blocking lines for CBB3  |
| Blk signals CBB4     | 0...63   |      | 1    | 0                 | Blocking lines for CBB4  |
| Blk signals CBB5     | 0...63   |      | 1    | 0                 | Blocking lines for CBB5  |

Table continues on the next page

| Parameter          | Values (Range) | Unit | Step | Default | Description                         |
|--------------------|----------------|------|------|---------|-------------------------------------|
| Blk signals CBB6   | 0...63         |      | 1    | 0       | Blocking lines for CBB6             |
| Blk signals CBB7   | 0...63         |      | 1    | 0       | Blocking lines for CBB7             |
| Str 2 delay shot 1 | 0...300000     | ms   | 10   | 0       | Delay time for start2, 1st re-close |
| Str 2 delay shot 2 | 0...300000     | ms   | 10   | 0       | Delay time for start2 2nd re-close  |
| Str 2 delay shot 3 | 0...300000     | ms   | 10   | 0       | Delay time for start2 3rd re-close  |
| Str 2 delay shot 4 | 0...300000     | ms   | 10   | 0       | Delay time for start2, 4th re-close |
| Str 3 delay shot 1 | 0...300000     | ms   | 10   | 0       | Delay time for start3, 1st re-close |
| Str 3 delay shot 2 | 0...300000     | ms   | 10   | 0       | Delay time for start3 2nd re-close  |
| Str 3 delay shot 3 | 0...300000     | ms   | 10   | 0       | Delay time for start3 3rd re-close  |
| Str 3 delay shot 4 | 0...300000     | ms   | 10   | 0       | Delay time for start3, 4th re-close |
| Str 4 delay shot 1 | 0...300000     | ms   | 10   | 0       | Delay time for start4, 1st re-close |
| Str 4 delay shot 2 | 0...300000     | ms   | 10   | 0       | Delay time for start4 2nd re-close  |
| Str 4 delay shot 3 | 0...300000     | ms   | 10   | 0       | Delay time for start4 3rd re-close  |
| Str 4 delay shot 4 | 0...300000     | ms   | 10   | 0       | Delay time for start4, 4th re-close |

### 8.4.9 Monitored data

### 8.4.9.1 DARREC Monitored data

Table 835: DARREC Monitored data

| Name        | Type    | Values (Range)   | Unit | Description                        |
|-------------|---------|--|------|------------------------------------|
| DISA_COUNT  | BOOLEAN | 0=False<br>1=True  |      | Signal for counter disabling       |
| FRQ_OPR_CNT | INT32   | 0...2147483647   |      | Frequent operation counter         |
| FRQ_OPR_AL  | BOOLEAN | 0=False<br>1=True  |      | Frequent operation counter alarm   |
| STATUS      | Enum    | -1=Not defined<br>1=Ready<br>2=InProgress<br>3=Successful<br>4=WaitingFor-Trip<br>5=TripFromProtection<br>6=FaultDisappeared<br>7=WaitToComplete<br>8=CBclosed<br>9=CycleUnsuccessful<br>10=Unsuccessful<br>11=Aborted |      | AR status signal for IEC61850      |
| INPRO_1     | BOOLEAN | 0=False<br>1=True  |      | Reclosing shot in progress, shot 1 |
| INPRO_2     | BOOLEAN | 0=False<br>1=True  |      | Reclosing shot in progress, shot 2 |
| INPRO_3     | BOOLEAN | 0=False<br>1=True  |      | Reclosing shot in progress, shot 3 |
| INPRO_4     | BOOLEAN | 0=False<br>1=True  |      | Reclosing shot in progress, shot 4 |
| INPRO_5     | BOOLEAN | 0=False<br>1=True  |      | Reclosing shot in progress, shot 5 |

Table continues on the next page

| Name         | Type    | Values (Range)   | Unit | Description   |
|--------------|---------|--|------|---|
| DISCR_INPRO  | BOOLEAN | 0=False<br>1=True                                      |      | Signal indicating that discrimination time is in progress |
| CUTOUT_INPRO | BOOLEAN | 0=False<br>1=True                                      |      | Signal indicating that cut-out time is in progress        |
| SUC_RECL     | BOOLEAN | 0=False<br>1=True                                      |      | Indicates a successful reclosing sequence                 |
| UNsuc_CB     | BOOLEAN | 0=False<br>1=True                                      |      | Indicates an unsuccessful CB closing                      |
| CNT_SHOT1    | INT32   | 0...2147483647   |      | Resetable operation counter, shot 1                       |
| CNT_SHOT2    | INT32   | 0...2147483647   |      | Resetable operation counter, shot 2                       |
| CNT_SHOT3    | INT32   | 0...2147483647   |      | Resetable operation counter, shot 3                       |
| CNT_SHOT4    | INT32   | 0...2147483647   |      | Resetable operation counter, shot 4                       |
| CNT_SHOT5    | INT32   | 0...2147483647   |      | Resetable operation counter, shot 5                       |
| COUNTER      | INT32   | 0...2147483647   |      | Resetable operation counter, all shots                    |
| SHOT_PTR     | INT32   | 1...7  |      | Shot pointer value  |
| MAN_CB_CL    | BOOLEAN | 0=False<br>1=True                                      |      | Indicates CB manual closing during reclosing sequence     |
| SOTF         | BOOLEAN | 0=False<br>1=True                                      |      | Switch-onto-fault   |
| DARREC       | Enum    | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status  |

## 8.4.10 Technical data

Table 836: DARREC Technical data

| Characteristic        | Value                            |
|-----------------------|----------------------------------|
| Operate time accuracy | ±1.0% of the set value or ±20 ms |

## 8.4.11 Technical revision history

Table 837: Technical revision history

| Technical revision | Change  |
|--------------------|---|
| B                  | The <code>PROT_DISA</code> output removed and re-removed the related settings               |
| C                  | The default value of the <i>CB closed Pos status</i> setting changed from "True" to "False" |
| D                  | SHOT_PTR output range 0..7 (earlier 0..6).  |
| E                  | Monitored data ACTIVE transferred to be ACT visible output. SHOT_PTR output range 1..7.     |
| F                  | Internal improvement.   |

## 8.5 Tap changer control with voltage regulator OLATCC

### 8.5.1 Identification

| Function description                       | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|--|--------------------------|--------------------------|-------------------------------|
| Tap changer control with voltage regulator | OLATCC                   | COLTC                    | 90V                           |



## 8.5.2 Function block

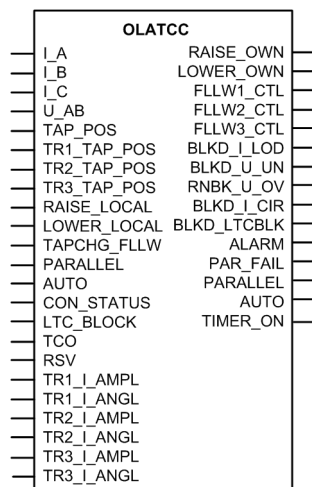


Figure 468: Function block

## 8.5.3 Functionality

The tap changer control with voltage regulator function OLATCC (on-load tap changer controller) is designed for regulating the voltage of power transformers with on-load tap changers in distribution substations. OLATCC provides a manual or automatic voltage control of the power transformer by using the raising or lowering signals to the on-load tap changer.

The automatic voltage regulation can be used in single or parallel transformer applications. Parallel operation can be based on Master/Follower (M/F), Negative Reactance Principle (NRP) or Minimizing Circulating Current (MCC).

OLATCC includes the line drop compensation (LDC) functionality, and the load decrease is possible with a dynamic voltage reduction.

Either definite time characteristic (DT) or inverse time characteristic (IDMT) is selectable for delays between the raising and lowering operations.

The function contains a blocking functionality. It is possible to block the voltage control operations with an external signal or with the supervision functionality of the function.

## 8.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of OLATCC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

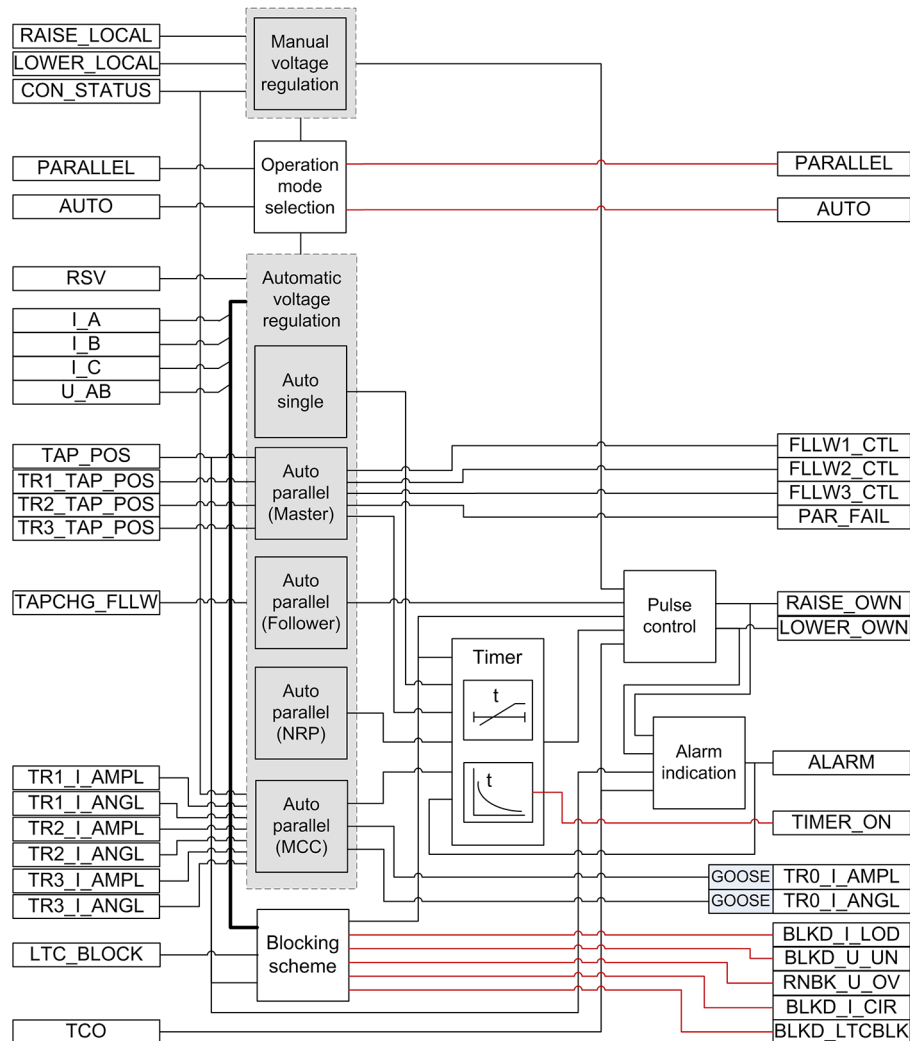


Figure 469: Functional module diagram

### 8.5.4.1 Voltage and current measurements

The measured voltage must be a phase-to-phase voltage from the regulated side. Typically, it is the phase-to-phase voltage  $U_{AB}$  from the secondary side of the power transformer. If the phase voltages are measured, the voltage  $U_{AB}$  is calculated internally in the IED.

Currents from the secondary side of the power transformer ( $I_A - I_C$ ) have several uses.

- The highest phase current value is used for overcurrent blocking.
- The currents from the secondary side of the power transformer are used for line drop compensation (average of the connected inputs).
- The currents from the secondary side of the power transformer are used for calculating the circulating current in the Negative Reactance Principle (NRP) and Minimizing Circulating Current (MCC) operation modes.

Both voltage  $U_{AB}$  and the phase currents from the secondary side ( $I_x$ , where  $x$  is A, B or C) are always measured using the value of the filtered fundamental frequency

component (DFT). Hence, the harmonics are always suppressed. Moreover, the measured voltage value is continuously average-filtered with the eight-value-long sliding window where the resulting filtering delay is not compensated. The phase-compensated voltage  $U_A$  is always used in calculations, although it is not connected.  $U_m$  is the averaged value used for control and its magnitude can be read from the monitored data  $U\_MEAS$ .

Similarly, the magnitude of the phase current of the own transformer,  $I_x$ , and the phase angle difference between the internally phase-compensated voltage  $U_A$  and phase current  $I_x$  are also average-filtered by the same length-fixed window. The phase angle value can be read from the monitored data  $ANGL\_UA\_IA$ . These currents and phase angle differences are used solely on circulating current calculations.



The angle difference is used in [Equation 64](#), [Equation 65](#) and [Equation 68](#).

There are minimum limits for the voltage and current magnitudes, resulting in the magnitude and phase angle difference values diverging from zero. The voltage magnitude must exceed three percent of  $U_n$  and the current  $I_A$  must exceed two percent of  $I_n$ .

#### 8.5.4.2 Tap changer position inputs

The position value of the tap changer can be brought to OLATCC as a resistance value, a mA signal or as a binary-coded signal. More information on how the resistance value, the mA signal or a binary-coded interface are implemented can be found in TPOSYLTC in the technical manual of the IED.

The indicated tap changer position of the own transformer is internally connected to the  $TAP\_POS$  input, and the tap changer positions of the parallel transformers are fed to the other  $TR_x\_TAP\_POS$  inputs. This also defines the connection identity so that follower 1 is connected to  $TR1\_TAP\_POS$ , follower 2 is connected to  $TR2\_TAP\_POS$  and follower 3 is connected to  $TR3\_TAP\_POS$ . The own transformer position can be read from the monitored data  $TAP\_POS$ . The follower tap changer positions can also be read from the input data  $TR_x\_TAP\_POS$ , where x is a value between 1 and 3.

The tap changer position value is given in parentheses. For example, (0) indicates that there is no tap changer position connected or the tap changer position value quality is bad. Typically, if no tap changer position is connected, all the TPOSYLTC binary inputs are FALSE by default and the value shown is (0). A value other than zero indicates bad quality. A bad-quality tap changer position is dealt by OLATCC like unconnected tap position information.

#### 8.5.4.3 Operation mode selection

OLATCC has the *Operation mode* and *Auto parallel mode* settings for selecting the desired operation mode. The *Operation mode* setting can have any of the following values: "Manual", "Auto single", "Auto parallel", "Input control" and "Command". If the *Operation mode* setting is set to "Input control", the acting operation mode is determined by the inputs  $PARALLEL$  and  $AUTO$ . When the *Operation mode* setting is set to "Command", the acting operation mode is determined by the IEC 61850 command data points Auto and ParOp. The  $PARALLEL$  input and ParOp define if the transformer (voltage regulator) is in the parallel or single mode. The  $AUTO$  input defines the operation status in the single mode.  $PARALLEL$  and  $AUTO$  Monitored

data represent acting "Parallel or single operation" and "Auto/Manual indication" respectively.

**Table 838: Acting operation mode determined by the operation mode inputs and command signals**

| PARALLEL | AUTO   | Operation Mode |
|----------|--------|----------------|
| 0        | 0      | Manual         |
| 0        | 1      | Auto single    |
| 1        | 0 or 1 | Auto parallel  |

Furthermore, if *Operation mode* has been set to "Auto parallel", the second setting parameter *Auto parallel mode* defines the parallel mode and the alternatives are "Auto master", "Auto follower", "MCC" or "NRP".

The acting operation mode can be read from the monitored data OPR\_MODE\_STS.

#### Command Exclusion

An acting operation mode change using two inputs ( PARALLEL and AUTO) and setting group change (either with the input or via menu) is needed when the acting operation mode must be changed automatically, that is, there is a logic which drives these two inputs and setting group change based on the status information from the circuit breakers.

The common Local/Remote (L/R) exclusion concerns the manual raising and lowering commands of OLATCC, that is, it internally proves the exclusion mechanism to prevent the remote commands (from SCADA) when the IED is in local mode.

### 8.5.4.4 Manual voltage regulation

The manual raising and lowering commands can be given either via the configuration inputs LOWER\_LOCAL and RAISE\_LOCAL, via the HMI of the IED or via remote commands. The acting operation mode of OLATCC must be set to "Manual" and the Local/Remote control LR state monitored data of the IED has to be "Local" to execute the control commands manually from HMI or via configuration inputs. Although OLATCC is set to "Manual" but the LR state is set to "OFF" or "Remote", no manual control commands can be given.

For remote commands, the acting operation mode of the OLATCC function must also be set to "Manual" and the LR state monitored data has to be "Remote".

The manual raising or lowering commands can be given locally either via the *Manual control* parameter ("Cancel"/"Lower"/"Raise") located in the HMI menu **Control > OLATCC1** or via the configuration inputs LOWER\_LOCAL or RAISE\_LOCAL.

A raising command is given by selecting the enumeration value "Raise" and the lowering command is given by selecting the enumeration value "Lower". An accepted manual raising/lowering command activates the corresponding output RAISE\_OWN or LOWER\_OWN to control the voltage of the own transformer.

#### Voltage control vs. tap changer moving direction

OLATCC has the control settings *Lower block tap* and *Raise block tap*. The *Lower block tap* and *Raise block tap* settings should give the tap changer position that results in the lowest and highest controlled voltage value (usually at the LV side of

the transformer). The setting of both *Raise block tap* value higher than *Lower block tap* value and *Lower block tap* value higher than *Raise block tap* value is allowed.

When the value of *Raise block tap* exceeds the *Lower block tap* value, the raise control activates the `RAISE_OWN` output. This results in raising the tap changer position, and the measured voltage rises. Furthermore, the `RAISE_OWN` output value is TRUE. If the own tap changer position is connected (that is, the own tap changer's quality is good), the tap changer alarm is activated if the tap changer does not move upwards in the *Cmd error delay time* setting after the pulse activation, resulting that `ALARM_REAS` in the monitored data contains a command error value. The *Cmd error delay time* setting default value is 20 seconds.

The lowering control works in a similar way, as shown in [Figure 470](#). In the output data, the `LOWER_OWN` output value is TRUE. An alarm is generated if the tap changer does not move upwards in *Cmd error delay time* after the pulse activation, assuming that the own tap changer position is connected.

In the second case, the parameters are set so that the value of *Lower block tap* exceeds the value of *Raise block tap*. The raising control activates the `RAISE_OWN` output. The result should be that the tap changer lowers its position and the measured voltage rises. Furthermore, the `RAISE_OWN` output value is TRUE in the output data. If the own tap changer position is connected, the tap changer alarm is activated if the tap changer does not move downwards in *Cmd error delay time* after the pulse activation, resulting that `ALARM_REAS` in the monitored data contains a command error value.

#### 8.5.4.5 Automatic voltage regulation of single transformer

OLATCC is intended to control the power transformers with a motor-driven on-load tap changer. The function is designed to regulate the voltage at the secondary side of the power transformer. The control method is based on a step-by-step principle, which means that one control pulse at a time is issued to the tap changer mechanism to move it exactly one position upwards or downwards. However, when intermediate steps are not indicated for the tap changer, it does not cause alarm if more than one step change is met.

The purpose of the regulator is to maintain a stable secondary voltage of the power transformer. The basis for this operation is the *Band center voltage* setting. By increasing or decreasing various compensation factors, the regulator calculates a control voltage from the band center voltage as shown in [Equation 62](#). Hence, the control voltage is the desired transformer secondary voltage to be maintained by the regulator. The control voltage is compared to the measured voltage and the difference between the two forms the regulating process error.

Since the tap changer changes the voltage in steps, a certain error has to be allowed. The error, called *Band width voltage*, is also set by the user. A recommended setting for *Band width voltage* should be close to twice the step voltage of the transformer  $\Delta U_{\text{step}}$  and never below it as a minimum. For example, *Band width voltage* is twice the value of  $\Delta U_{\text{step}}$  in [Figure 470](#).

If the measured voltage fluctuates within the control voltage  $\pm$  half the *Band width voltage* setting, the regulator is inactive. If the measured voltage is outside the half-bandwidth voltage limits, an adjustable delay T1 (*Control delay time 1*) starts, as shown in [Figure 470](#), where the lowering function is an example. The delay T1 remains active as long as the measured voltage is outside the hysteresis limits of half the value of *Band width voltage*. The factory setting for the hysteresis is 10 percent of the set *Band width voltage*.

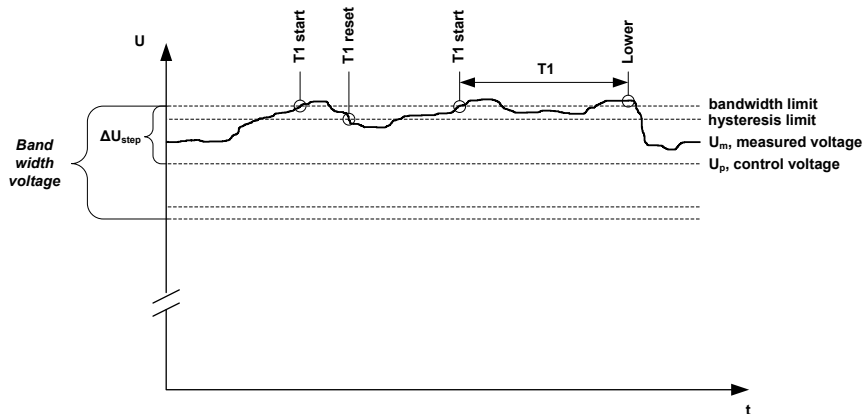


Figure 470: Voltage-regulating function. A control pulse to lower the voltage is issued after the elapsed  $T1$ .

If the measured voltage is outside the hysteresis when the delay counter  $T1$  reaches its setting value, the raising or lowering output relay is activated. This activates either output pulse `RAISE_OWN` or `LOWER_OWN`, and the motor drive of the tap changer operates. The status of these outputs can be read from the output data `RAISE_OWN` or `LOWER_OWN`.

If the measured voltage falls or rises within the hysteresis limits during the operating time, the delay counter is reset.

The pulse length can be defined with the *LTC pulse time* setting. The default value is 1.5 seconds.

A short delay same as the typical tap changer operating time is active before the start of the next operating timer is possible. For OLATCC, the delay is set to 6 seconds. If one tap changer operation is not enough to regulate the transformer voltage within the hysteresis limits, a second adjustable delay  $T2$  (*Control delay time 2*), usually with a shorter time setting than  $T1$ , starts. This delay is used for the control commands within the same sequence until the recovery of voltage occurs. The delays  $T1$  and  $T2$  can be selected either with definite or inverse time characteristics. In the inverse time mode operation, the operating time depends on the difference between the control voltage and the measured voltage as shown in [Equation 69](#). The bigger the difference in the voltage, the shorter the operating time. More information on the inverse time operation can be found in [Chapter 8.5.4.7 Timer characteristics](#).

### Regulation equation

The simple regulating principle is often complemented by additional features to take the voltage drop of lines into account (line drop compensation), coordinate the regulation of parallel transformers and change the voltage level according to the loading state of the network. The control voltage  $U_p$  is calculated according to the equation

$$U_p = U_s + U_z + U_{ci} - U_{rsv}$$

(Equation 62)

|           |  |
|-----------|--|
| $U_p$     | Control voltage                              |
| $U_s$     | Set voltage level <i>Band center voltage</i> |
| $U_z$     | Line drop compensation term                  |
| $U_{ci}$  | Circulating current compensation term        |
| $U_{rsv}$ | Voltage reduction parameter                  |

$U_p$  can be directly read in the monitored data  $U\_CTL$ .

The circulating current compensation term is calculated only in the parallel acting operation modes "NRP" and "MCC".

### Line Drop Compensation (LDC)

The line drop compensation feature is used to compensate the voltage drop along a line or network fed by the transformer. The compensation setting parameters can be calculated theoretically if the resistance and reactance of the line are known or measured practically from the line drop.

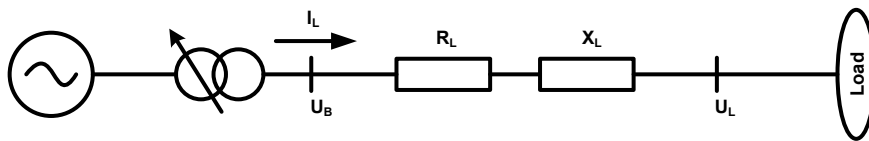


Figure 471: Equivalent electrical circuit for calculating the LDC term

The compensation parameters *Line drop V Ris* ( $U_r$ ) and *Line drop V React* ( $U_x$ ), are percentage values of  $U_n$  according to the equations.

$$\text{Line drop V Ris} = U_r [\%] = \frac{\sqrt{3} \cdot I_{CT\_n1} \cdot R}{U_{VT\_n1}} \cdot 100 \quad [\%U_n]$$

$$\text{Line drop V React} = U_x [\%] = \frac{\sqrt{3} \cdot I_{CT\_n1} \cdot X}{U_{VT\_n1}} \cdot 100 \quad [\%U_n]$$

(Equation 63)

|              |  |
|--------------|--|
| $I_{CT\_n1}$ | Nominal primary current of the CT                          |
| $U_{VT\_n1}$ | Nominal primary voltage of the VT (phase-to-phase voltage) |
| R            | Resistance of the line, $\Omega$ /phase                    |
| X            | Reactance of the line, $\Omega$ /phase                     |

The general LDC equation can be calculated.

$$U_z = \frac{I_{injected}}{I_n} \cdot \frac{(U_r [\%] \cos \phi + U_x [\%] \sin \phi)}{100} \quad [xU_n]$$

(Equation 64)

|                |  |
|----------------|--|
| $I_{injected}$ | Average of the currents I_A, I_B and I_C                       |
| $U_r$          | Setting <i>Line drop V Ris</i>                                 |
| $U_x$          | Setting <i>Line drop V React</i>                               |
| $\phi$         | Phase angle between U_A and I_A (ANGL_UA_IA in monitored data) |

By default, the line drop compensation (LDC) is not active. LDC is activated by setting *LDC enable* to "True". To keep the LDC term within acceptable limits in all situations, OLATCC has a setting parameter *LDC limit*, which has a default value of 0.10 xU<sub>n</sub>. As a result, this gives the maximum value for U<sub>z</sub> in [Equation 62](#).

If more than one line is connected to the LV busbar, the equivalent impedance is calculated and given as a parameter setting as shown in [Figure 471](#) for the equivalent electrical circuit for calculating LDC. For example, if there are N number of identical lines with identical loads in the substation, the R- and X-values needed for the settings *Line drop V React* and *Line drop V Ris* are obtained by dividing the resistance and the reactance of one line by N. Because the voltage drop is different in lines with different impedances and load currents, it is necessary to make a compromise when setting the *Line drop V React* and *Line drop V Ris* settings. Raising the voltage in the point of lowest voltage must not lead to overvoltage elsewhere.

By default, the line drop compensation is effective only on the normal active power flow direction. If the active power flow in the transformer turns opposite, that is, from the regulated side towards the system in the upper level, the LDC term is ignored, that is, set to zero. In such a case, it is assumed that the feeding units at the regulated side of the transformers maintain proper voltage levels. This can cause a conflict if the transformer tries to reduce the voltage at the substation. Additionally, it is difficult to predict the actual voltage levels in the feeder lines in such a case, and lowering the voltage at the substation can have harmful effects in the far end of the network. However, the *Rv Pwr flow allowed* setting allows also negative LDC terms to be taken into equation.

The topology changes in the network can cause changes to the equivalent impedance value of the network. If the change is substantial, the setting groups can be used to switch between different setting values for *Line drop V React* and *Line drop V Ris*. In practice this means that the boolean-type information from the topology change is connected to the active setting group change.

The use of the LDC equation in the case of parallel transformers is described in [Chapter 8.5.4.6 Automatic voltage regulation of parallel transformers](#).

### Reduce Set Voltage (RSV) input

The system frequency decreases when the active power production in the network is smaller than its consumption. Either the power supply has to be increased or some loads have to be shed to restore the power balance.

The simplest way to decrease the load is to reduce the voltage level by giving a lower band center voltage value to the regulators. For this purpose, OLATCC has the setting group parameter *Band reduction*. The RSV input activation results in



reduction. If this input is set to TRUE, a set target voltage value is decreased by *Band reduction*. If more than one  $RSV$  reduction steps are desired, the setting group change has to be used where different *Band reduction* values are supported. The decreased value is kept as a target value as long as the  $RSV$  input is TRUE.

Because the decrease of frequency indicates a need to reduce the load, it is practical to connect the start signal of an underfrequency function block to the  $RSV$  digital input.

It depends on the load characteristics how much the load is reduced as the voltage drops. For instance, purely resistive loads are proportional to the square of the voltage, whereas motor drives based on frequency controllers may draw constant power despite small voltage changes.

The status of the  $RSV$  input can be read from the  $RSV$  input data.

#### 8.5.4.6 Automatic voltage regulation of parallel transformers

It is likely that a circulating current between transformers occurs if two or more transformers with slightly different ratios are energized in parallel. This is due to the unbalanced short circuit impedances of the parallel transformers. To avoid such currents, the tap changers of the transformers should be adjusted to achieve equilibrium. If the transformers are assumed identical, the tap (voltage) steps and tap positions should also match. In this case, the Master/Follower principle can be used. However, unequally rated transformers with different tap steps can be connected in parallel and these configurations can also be managed by the tap changer control function. For these configurations, the Minimizing Circulating Current (MCC) or Negative Reactance Principle (NRP) should be used. The MCC and NRP principles are also suitable for identical transformers.

The circulating current, which is almost purely inductive, is defined as negative if it flows towards the transformer.  $U_{ci}$  in [Equation 62](#) is positive and the control voltage  $U_p$  rises as a result to the  $RAISE\_OWN$  output signal activation if the circulating current level is sufficient ([Equation 65](#) and [Equation 67](#)) and the other parameters remain the same. As a result, the voltage rise should diminish the circulating current.

##### LDC equation and parallel connection

The additional challenge in the parallel connection regarding the line drop compensation is to know the total current which flows through the parallel transformers.

In the Master/Follower mode, it is easier to know the total current than in other parallel modes since the transformers are assumed to have identical ratings, that is, the total current ( $I_{injected}$  in [Equation 63](#)) is obtained by multiplying the measured load current (the average of the secondary currents  $I_A$ ,  $I_B$  and  $I_C$  of the connected own transformer) with the number of parallel transformers. OLATCC can internally conclude the number of parallel transformers from the connected tap changer position inputs. However, if there is no connected position information from the other parallel transformers, the correct number of the parallel transformers, excluding the own transformer, needs to be set with the *Parallel trafos* setting.

In the MCC mode, the application configuration with multiple instances of OLATCC transfers the information from the measured load currents between the regulators so that the total current needed in the line drop compensation can be summed accurately. Here,  $I_{injected}$  is defined to be the phasor sum of all the parallel power

transformer secondary-side currents. The currents from other transformers must be fed via the `TRx_I_AMPL` and `TRx_I_ANGL` inputs.

In the NRP mode, the parallel transformers have different ratings and there is no communication between the regulators. Therefore, when setting *Line drop V React* and *Line drop V Ris*, the  $I_{CT,n1}$  used in the equation should be the sum of the rated currents of all the transformers operating in parallel. Here,  $I_{injected}$  is also defined as the average of the connected secondary currents ( $I_A$ ,  $I_B$  and  $I_C$ ). The calculated line drop compensation value can be read from the monitored data LDC.

### Master/Follower principle M/F

The Master/Follower (M/F) operation principle is suitable for power transformers with identical ratings and step voltages. One voltage regulator (master) measures and controls and the other regulators (followers) follow the master, that is, all the tap changers connected in parallel are synchronized. This parallel operation is obtained by connecting the `FLLWx_CTL` output of the master to the corresponding input `TAPCHG_FLLW` of the followers in the ACT worksheet.

The values for the `FLLWx_CTL` command are 1=Lower follower x and 2=Raise follower x. Consequently, the values for the `TAPCHG_FLLW` command are 1=Lower and 2=Raise.

If several regulators are to act as masters (one at a time), their outputs also have to be routed to the inputs of other regulators. To start the parallel operation, the master regulator is set to the "Auto master" mode and the followers to the "Auto follower" mode. To implement this setting, a group changing has to be planned.

To keep all the tap changers in the same position, the master needs to know the tap positions of the followers. This way, the circulating current is kept at its minimum. The position values of the followers can be brought to the master via `TPOSYLTC`.

If it is not possible to use horizontal communication between the IEDs and the position information cannot be wired from the parallel transformers, the M/F principle can still be used to regulate two or an unlimited number of transformers in parallel. Since the master cannot detect the tap positions of parallel transformers, it just activates the lowering and raising outputs for all the followers when it controls its own tap changer. This is called blind control. In this case, a number of parallel transformers are regulated as one unit. The tap position inputs 1...3 (`TR1_TAP_POS.. TR3_TAP_POS`) must be left unconnected for the master to know that the tap positions of the followers are unknown. The time delay between successive commands can be set by the *Follower delay time* setting. The default value is six seconds.

When a disconnected transformer is taken into use and the tap position is unknown, the follower should be manually controlled to the same position as the master. This can also take place in the master/follower mode. First, the master gives a control command to its own transformer, that is, it is echoed to the followers (the follower tap positions have to be connected). Thereafter, successive control commands to the followers take place until the master and followers have the same tap positions.

### Out-of-step function

The out-of-step function is usually used in the M/F modes only. The out-of-step function means that the master is able to detect the position values of the followers and control them to the same position as the master is. In this case, the master assumes that the followers also have either *Raise block tap* higher than *Lower block tap* or *Lower block tap* higher than *Raise block tap* because this defines what is the given command pulse for a follower. If the master has *Raise block tap* higher

than *Lower block tap* and the follower has *Lower block tap* higher than *Raise block tap*, the corresponding `TAPCHG_FLLW` included control signals should be connected crosswise. This requires an extra logic where dual-point command bits have to be converted, that is,  $0 \Rightarrow 0$ ,  $[01]=1 \Rightarrow [10]=2$  and  $[10]=2 \Rightarrow [01]=1$ .

M/F is the only parallel mode which has an out-of-step functionality. In the MCC and NRP operation modes, the circulating current is minimized, which most probably means different tap positions in the parallel transformers. Moreover, these modes allow different ratings and step voltages for the parallel transformers. Therefore, it is reasonable to apply the out-of-step function only to the M/F operation mode.

The out-of-step function is triggered when the master detects a difference of at least one step between the tap changer positions in the follower and in the master. The master then sends special raising or lowering commands to the diverged follower. If two consecutive commands fail to change the position of the follower to the right direction, the master activates the `PAR_FAIL` output, that is, `PAR_FAIL` is set to TRUE, and stops the special recovery efforts. However, every time the master controls its own tap changer later, it always sends a controlling pulse to the diverged follower too. Furthermore, if the master notices a correct position change after a sent pulse, it restarts the attempt to drive the follower to the same position and deactivates the `PAR_FAIL` output, that is, `PAR_FAIL` is set to FALSE. However, if there still are diverged followers, the reset is not indicated. It is indicated only when no diverged followers exist. Monitoring, and hence the indication of a paralleling failure, is not possible in blind control. The followers with a parallel failure can be read from the monitored data `FAIL_FLLW`. For example, if only follower 3 is in the parallel failure state, `FAIL_FLLW` has the value "Follower 3". If both followers 1 and 2 are in the parallel failure state, `FAIL_FLLW` has the value "Followers 1+2". By default, when no failed followers exist, the value is "No failed followers".

### Negative Reactance Principle NRP

This parallel control scheme is suitable for power transformers with different ratings and step voltages. Since no communication between the regulators is needed, this principle can be applied even when the parallel transformers are located at different substations. To start the parallel operation, the acting operation mode has to be set to "NRP" for all the regulators of the connection. The acting operation mode can be changed via function block inputs or by setting either locally or remotely.

When applying this principle, each regulator has a phase angle setting  $\phi_{\text{Load}}$  (setting parameter *Load phase angle*) towards which it tries to regulate the current. The setting value is chosen according to the expected power factor of the load (positive setting value equals inductive load). When the actual phase angle of the load current is the same as the setting and the transformers and their tap changer positions are identical, the currents of the two or more transformers are in the same phase as the total load current. If the tap changer positions are different, the circulating current flows and the currents of different transformers either lag or lead the load current. [Figure 472](#) shows that the circulating current is the reactive component which separates the measured current vector from the expected angle value.

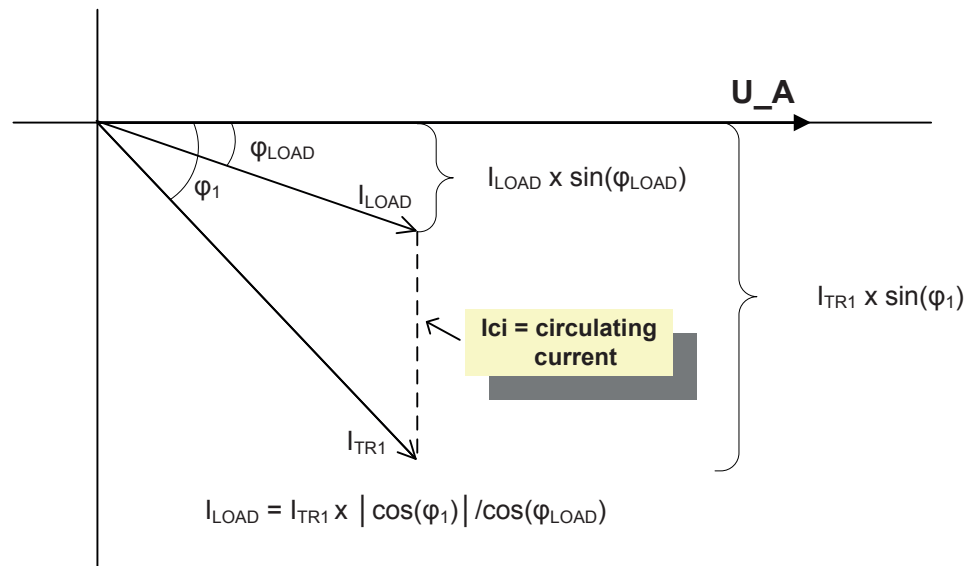


Figure 472: The expected phase angle of the load supplied by the transformers operating in parallel is entered as a setting value  $\phi_{Load}$

The regulators calculate the circulating current with the equation

$$I_{ci} = (\sin \phi_1 - \tan \phi_{Load} \cdot |\cos \phi_1|) \cdot I_{TR1}$$

(Equation 65)

|               |   |
|---------------|---|
| $I_{TR1}$     | Average of the currents $I_A$ , $I_B$ and $I_C$ |
| $\phi_1$      | Phase angle between $U_A$ and $I_A$             |
| $\phi_{Load}$ | The set Load phase angle of the load current    |

In the negative reactance method, the circulating current is minimized by changing the control voltage according to the measured circulating current. The regulator calculates the circulating current compensation term  $U_{ci}$  using the equation

$$U_{ci} = \frac{-I_{ci}}{I_n} \cdot \frac{Stability}{100} \cdot U_n$$

(Equation 66)

|                  |   |
|------------------|---|
| $I_{ci}$         | Circulating current   |
| <i>Stability</i> | Stability setting (the recommended value depends on the loop impedance) |

If the transformers operating in parallel have different rated currents, the value of the *Stability factor* setting of the regulator should be proportional to the rated currents, that is, the higher the rated current, the higher the *Stability factor* setting value.

By comparing the reactive components of the currents measured by the different regulators it is possible to find out if the circulating current has been minimized. The circulating current is minimized when the reactive components are equal.

The negative reactance method gives satisfactory results only if the phase angle of the load current is known relatively accurately. If the actual phase angle deviates from the phase angle setting, a regulating error occurs. However, for the cases where there is an occasional stepwise change in the phase angle of the load, the regulating error can be suppressed with the logic. This kind of stepwise change can occur, for example, when a capacitor bank is switched on to compensate a reactive power flow.

Another possibility is to use an automatic setting group change between setting groups in different loading situations. The setting groups then have different set values for the load phase angle.

### Minimizing Circulating Current principle MCC

The MCC principle is an optimal solution for controlling the parallel transformers of different ratings or step voltages in substations with varying reactive loads. Since this control scheme allows the exchange of data between regulators, the circulating current can be calculated more accurately than with other schemes. However, a maximum of four regulators can be connected in parallel. To start the parallel operation, the acting operation mode parameter has to be set to "MCC" for all the regulators of the connection. Furthermore, the signal `CON_STATUS` must indicate that the transformers are connected to the network. A unit that is minimizing the circulating current must have the acting operation mode set to "MCC". However, units that have the acting operation mode set to "Manual" do not perform any circulating current minimization operations themselves.

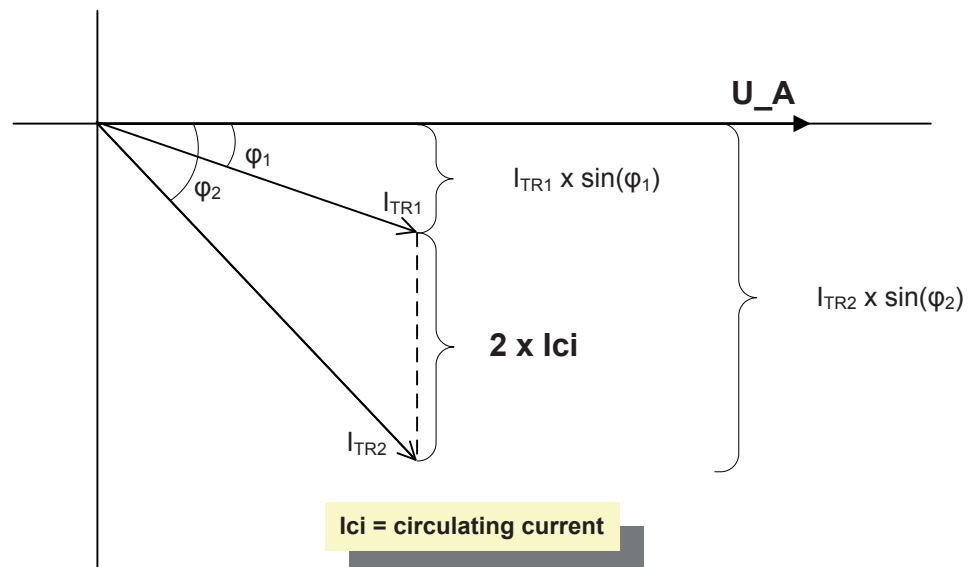


Figure 473: The circulating current between two parallel transformers

In this case, the circulating current can be calculated with the equation

$$I_{ci} = \frac{(\sin \phi_1 \cdot I_{TR1} - \sin \phi_2 \cdot I_{TR2})}{2}$$

(Equation 67)

|           |  |
|-----------|--|
| $I_{TR1}$ | Average primary value of the currents I_A, I_B and I_C measured by regulator 1 |
| $I_{TR2}$ | Average primary value of the currents I_A, I_B and I_C measured by regulator 2 |
| $\phi_1$  | Phase angle between U_A and I_A in regulator 1                                 |
| $\phi_2$  | Phase angle between U_A and I_A in regulator 2                                 |

The circulation current can be read from the monitored data I\_CIR.

Using the circulating current, the compensation term  $U_{ci}$  can be calculated with the equation

$$U_{ci} = \frac{-I_{ci}}{I_{CT\_n1}} \cdot \frac{\text{Stability}}{100} \cdot U_n$$

(Equation 68)

|                         |   |
|-------------------------|---|
| $I_{ci}$                | Circulating current, primary value                                      |
| $I_{CT\_n1}$            | Nominal primary current of the CT                                       |
| <i>Stability factor</i> | Stability setting (the recommended value depends on the loop impedance) |

Using the circulating current, a compensation term  $U_{ci}$  can be calculated using [Equation 66](#). The value of  $U_{ci}$ , which can be positive or negative, is considered by adding it to the *Band center voltage*  $U_s$  ([Equation 62](#)). According to [Figure 473](#) and [Equation 65](#), the phasor information from the other IEDs is needed.

#### Parallel unit detection and the MCC mode

The network connection status information is essential for the MCC operation mode. The status FALSE needs to be connected to the CON\_STATUS input to ensure a proper operation of the MCC calculation if the transformer is disconnected but OLATCC remains in the MCC mode. This way the disconnected transformer is excluded from the circulating current calculations.

The CON\_STATUS input is used to identify if a certain transformer controller is able to send the current information to other transformer controllers for circulating current minimization purposes. As a result, this input has effect only in the MCC or Manual acting operation modes. In these modes, if CON\_STATUS is TRUE, the information transmission is started. The circulating current information receiving is allowed only in the MCC acting operation mode when CON\_STATUS is TRUE. PAR\_UNIT\_MCC can be seen in the monitored data view.

### Communication and the MCC mode

The phasor information from the other parallel IEDs is needed for the circular current calculation. Therefore, multiple instances of the function are needed in the application (no GOOSE communication).

The transferred current phasor contains the primary value of the measured current. The received current phasor information can be read from the input data `TRx_I_AMPL` and `TRx_I_ANGL` for the magnitude and angle respectively. The value "x" gives the connected parallel transformer number, a value between 1 and 3.

The sent phasor information always represents the difference between the voltage phasor  $U_A$  and  $L_A$ . This information regarding the current phasor can be read from the output data `TR0_I_AMPL` and `TR0_I_ANGL`. The allowed acting operation modes for sending data are MCC or Manual, both with the input `CON_STATUS` activated. The communication can be seen to be active when the sent and received phasor magnitude is not clamped to zero. The communication phasor magnitude found to be zero results either from a rejected acting operation mode or too low signal magnitudes (see [Chapter 8.5.4.1 Voltage and current measurements](#)). Active `CON_STATUS` indicates that the corresponding transformer is connected to network and its current affects the circular current of other transformers even when it is itself in the manual operating mode.

## 8.5.4.7

### Timer characteristics

#### Operation timer functionality

The delay times can be set to follow either the definite time characteristic or the inverse time characteristic with the *Delay characteristic* setting. By default, the "Definite time" type is selected. The timer mode cannot be changed between cycles T1 and T2, only either before T1 has started or after T2 has elapsed.

**Table 839: Different timer mode delays**

| Timer mode | Setting                     | Description  |
|------------|-----------------------------|--|
| T1         | <i>Control delay time 1</i> | First delay when the measured voltage exceeds or falls below the limit value.              |
| T2         | <i>Control delay time 2</i> | Second delay when the first control did not bring the measured voltage to a desired level. |

The delay after the command pulse activation and the restart of the timer is six seconds. The delay is assumed to be the tap changer operating delay. The timer status can also be read from the monitoring data `TIMER_STS`, where T1 active gives a value "Lower timer1 on" or "Raise timer1 on" while T2 active gives a value "Lower timer2 on" or "Raise timer2 on". Furthermore, the "Fast lower T on" value indicates that the fast lowering control functionality is active ([Chapter 8.5.4.9 Blocking scheme](#)).

Activation of operation timer also activates the `TIMER_ON` output.

#### IDMT type operation

The IDMT timer can be selected by setting *Delay characteristic* to "Inverse time". The minimum time at the inverse time characteristic is limited to 1.0 second. However,

the minimum recommended setting of the control delay times T1 and T2 is 10 seconds when the definite time delay is used and 25 seconds when the inverse time delay is used.

The inverse time function is defined by the equations:

$$B = \frac{U_d}{(U_{BW} / 2)}$$

(Equation 69)

$U_d$   $|U_m - U_p|$ , differential voltage

$U_{BW}$  Setting parameter *Band width voltage*

$$t = \frac{T}{2^{(B-1)}}$$

(Equation 70)

T T1 or T2

The monitored data UD\_CTL shows the differential voltage value  $U_m - U_p$ . If the value exceeds half of the *Band width voltage* setting and has a negative sign, a raising pulse is issued. The UD\_CTL monitored data can also be seen in the DT timer mode.

The hysteresis approach is presented in [Figure 470](#).

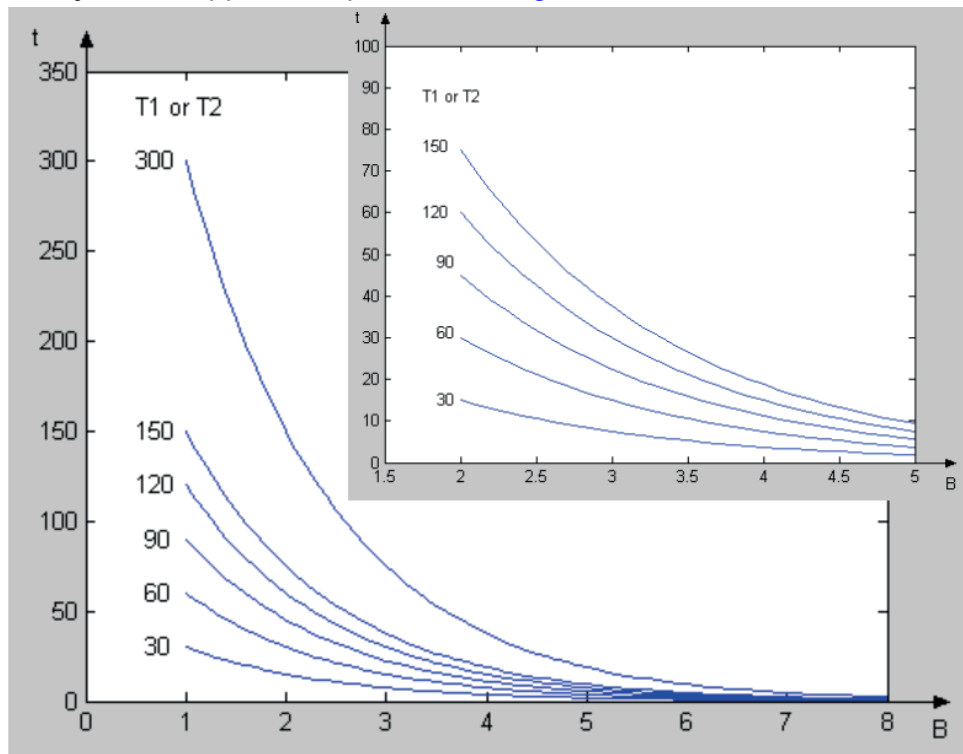


Figure 474: Inverse time characteristic for different values on T1 or T2 (The smaller figure is a zoom-in of the larger one)



### 8.5.4.8 Pulse control

The tap changer generates an active operating signal when the tap-changing process is active. This signal is to be connected to the TCO input. The signal is used for alarming purposes. If the signal is active (=TRUE) for more than 15 seconds after the control pulse has been deactivated, an alarm is generated ([Chapter 8.5.4.10 Alarm indication](#)). If the TCO input is not connected, no alarm is generated.

The control operation is disabled when the TCO input signal is active, unless no tap changer stuck is detected ([Chapter 8.5.4.10 Alarm indication](#)). Thus, it is not possible for the controller to send new pulses to the tap changer when it is already operating. This is because the tap changers are typically immune to new pulses when they are operating. Furthermore, because the pulses are omitted, the tap changer pulse counter of the controller is not incremented either.

The commands are not tolerated during an active pulse. Therefore the command pulse length (setting *LTC pulse time*) has to be carefully selected, although an active TCO input is used internally to prevent new commands from reaching the tap changer.

To be more certain that no new pulses are to be sent when the tap changer is in operation, the tap changer operating signal can also be connected to the LTC\_BLOCK input. In this case, the external blocking is achieved when an automatic pulse is sent to the operating tap changer. The external LTC\_BLOCK has by default no effect when the acting operation mode is set to "Manual".

The status of the TCO input can be read from the TCO input data.

### 8.5.4.9 Blocking scheme

The operation of the voltage regulator can be blocked for several reasons. The purpose of blocking is to prevent the tap changer from operating under conditions that can damage the tap changer or exceed other power system-related limits. The BLK\_STATUS monitored data does not imply actual blocking but reveals if the coming command pulse is issued or not. The blocking itself happens when the corresponding bit in the signal BLK\_STATUS is active and the command pulse is started due to a timer elapse or a local command. This is to avoid unnecessary event sending.

The BLK\_STATUS monitored data is also packed. It contains information about the blocking status as bit-coded output. The block status output does not indicate the actual blocking but indicates if the coming command is successful. The actual blocking is indicated by studying the corresponding monitored data (BLK\_I\_LOD, BLK\_U\_UN, RNBK\_U\_OV, BLK\_LTCBLOCK, BLK\_I\_CIR, BLK\_RAISE and BLK\_LOWER) values. [Table 840](#) illustrates the meaning of different monitored data values. For example, the block status value 9 indicates that there are conditional circulating current and load current blockings (8 + 1 = 9) indicated. By default, the status is "0".

| Bit     | Active value | Blocking reason          |
|---------|--------------|--------------------------|
| 6 (msb) | 64           | Lowest position reached  |
| 5       | 32           | Highest position reached |
| 4       | 16           | External LTC_BLOCK       |
| 3       | 8            | High circuit current     |

*Table continues on the next page*

| Bit     | Active value | Blocking reason                     |
|---------|--------------|-------------------------------------|
| 2       | 4            | Overtoltage - Runback raise voltage |
| 1       | 2            | Undervoltage - Block lower voltage  |
| 0 (lsb) | 1            | Overcurrent - Load current          |

The cross (X) in the table defines when the operation is blocked (if the corresponding bit is active in BLK\_STATUS). For example, an overvoltage (runback raising voltage) results in blocking only when the acting operation mode is "Manual" and the manual raising command is given.

**Table 840: Default blocking schema in OLATCC**

| Acting operation mode              | Command | Load current | Block lowering voltage | Runback raising voltage | High circulating current | External Block | Extreme positions |
|------------------------------------|---------|--------------|------------------------|-------------------------|--------------------------|----------------|-------------------|
| Manual                             | Raise   | X            |                        | X                       |                          |                | X                 |
|                                    | Lower   | X            |                        |                         |                          |                | X                 |
| Auto follower                      | Raise   | X            | X                      |                         |                          | X              | X                 |
|                                    | Lower   | X            | X                      |                         |                          | X              | X                 |
| Auto single, Auto master, NRP, MCC | Raise   | X            | X                      |                         | X                        | X              | X                 |
|                                    | Lower   | X            | X                      |                         | X <sup>1)</sup>          | X              | X <sup>2)</sup>   |

In addition to the default blocking, the *Custom Man blocking* setting has been added due to different operation practices considering the manual command blocking. The setting can be used to adapt blockings considering the manual overcurrent, undervoltage or external blocking. (The blockings are in the table in columns Load current, Block lowering voltage and External block for the manual operating mode.) The default value for the parameter is "OC". This means that default blocking schema explained in the table operates as such. However, there are also other alternatives that cause different operation when compared to that table.

**Table 841: Customized manual blocking schema**

| Manual blocking type | Enumeration     | Description  |
|----------------------|-----------------|--|
| 1                    | Custom disabled | No load current, blocking of lower (under) voltage or external blocking have effect in the manual. |
| 2                    | OC              | Load current blocking has an effect in the manual operation mode                                   |

*Table continues on the next page*

<sup>107</sup> Because the circulating current is only calculated in the NRP and MCC modes, it can have a blocking effect only in these modes.

<sup>108</sup> In these cases pure automatic operation notices that the extreme position has already been reached and there is no need to activate the signal for data set event sending. The automatic follower case can here be compared to a manual case and an event can be sent, that is, the corresponding output is activated.

| Manual blocking type | Enumeration | Description  |
|----------------------|-------------|--|
| 3                    | UV          | Block lowering (under) voltage blocking has an effect in the manual operation mode   |
| 4                    | OC, UV      | Conditions 2 and 3 together: Load current and block lowering (under) voltage blocking have effect in the manual operation mode                     |
| 5                    | EXT         | External blocking has an effect in the manual operation mode   |
| 6                    | OC, EXT     | Conditions 2 and 5 together: Load current and external blocking have effect in the manual operation mode   |
| 7                    | UV, EXT     | Conditions 3 and 5 together: Block lowering (under) voltage and external blocking have effect in the manual operation mode                         |
| 8                    | OC, UV, EXT | All conditions 2, 3 and 5 together: Load current and block lowering (under) voltage and external blocking have effect in the manual operation mode |

If the *Custom Man blocking* setting is "Custom disabled", the blocking schema regarding the acting operation mode "Manual" is as given in [Table 841](#). Other operation modes follow the default schema.

**Table 842: Blocking schema for selection "Custom disabled"**

| Acting operation mode | Command | Load current | Block lowering voltage | Runback raising voltage | High circulating current | External Block | Extreme positions |
|-----------------------|---------|--------------|------------------------|-------------------------|--------------------------|----------------|-------------------|
| Manual                | Raise   |              |                        | X                       |                          |                | X                 |
|                       | Lower   |              |                        |                         |                          |                | X                 |

**Table 843: Blocking schema for selection "OC, UV, EXT"**

| Acting operation mode | Command | Load current | Block lowering voltage | Runback raising voltage | High circulating current | External Block | Extreme positions |
|-----------------------|---------|--------------|------------------------|-------------------------|--------------------------|----------------|-------------------|
| Manual                | Raise   | X            | X                      | X                       |                          | X              | X                 |
|                       | Lower   | X            | X                      |                         |                          | X              | X                 |

**Table 844: Blocking schema for selection "UV, EXT"**

| Acting operation mode | Command | Load current | Block lowering voltage | Runback raising voltage | High circulating current | External Block | Extreme positions |
|-----------------------|---------|--------------|------------------------|-------------------------|--------------------------|----------------|-------------------|
| Manual                | Raise   |              | X                      | X                       |                          | X              | X                 |
|                       | Lower   |              | X                      |                         |                          | X              | X                 |

### Load current

The load current blocking is mainly used for preventing the tap changer from operating in an overcurrent situation. For example, if the current is not high enough to activate the protective IED of the substation, it can still be fatal for the diverter switch of the tap changer. This operation can be adjusted with the setting parameter *Load current limit*. The maximum of measurements from the

secondary-side current phases is used for blocking. By default, both the automatic operation and the manual operation are blocked ( [Table 840](#)) when the set limit is exceeded.

The blocking status can be read from the monitored data BLKD\_I\_LOD.

### Block lowering voltage

The block lowering voltage feature blocks both raising and lowering voltage commands if the measured voltage is too low to be corrected by operating the tap changer. Such a situation can occur due to a faulty measuring circuit, an earth fault or an overcurrent situation. By default, only the automatic (also automatic follower) operation is blocked when the undervoltage condition is met ( [Table 840](#)). This operation can be adjusted with the setting parameter *Block lower voltage*.

The blocking status can be read from the monitored data BLKD\_U\_UN.

However, there is no minimum limit for the undervoltage blocking. The blocking is allowed even if the measured voltage is not connected or it has temporarily a very low value. There is a minimum limit for the phase angle calculation based on the voltage phasor magnitude.

### Runback raising voltage

The manual raising command is blocked if the overvoltage limit is exceeded ( [Table 840](#)). However, in the automatic operation mode, the overvoltage situation triggers the fast lowering feature. More information can be found in [Chapter 8.5.4.4 Manual voltage regulation](#). This operation can be adjusted with the setting parameter *Runback raise V*.

The blocking status can be read from the monitored data RNBK\_U\_OV.

### High Circulating Current

The circulating current value is calculated in the operation modes Negative Reactance Principle (NRP) and Minimizing Circulating Current (MCC). Only the automatic operation in these modes is blocked when the high circulating current is measured ( [Chapter 8.5.4.9 Blocking scheme](#)). This operation can be adjusted with the setting parameter *Cir current limit*.

The blocking status can be read from the monitored data BLKD\_I\_CIR.

### LTC\_BLOCK – external block input

With the PCM600 tool configuration possibilities, a desired blocking condition can be built by connecting an outcome to this input. The blocking status can be read from the monitored data BLKD\_LTCBLK. When activated, this input blocks only the automatic operation of the regulator by default ( [Table 840](#)). For the fully automatic modes, the signal activation resets the timer, and the monitored data BLKD\_LTCBLK is not activated.

### Extreme positions

This blocking function supervises the extreme positions of the tap changer. These extreme positions can be adjusted with the setting parameters *Raise block tap* and *Lower block tap*. When the tap changer reaches one of these two positions, the commands in the corresponding direction are blocked ( [Table 840](#)). It depends on the comparison between the *Raise block tap* and *Lower block tap* settings, which

direction is blocked ( *AAVoltage control vs. tap changer moving direction*). This blocking affects both the automatic and manual operation modes.

However, as shown in *Table 840*, no blocking indication is to be generated in the fully automatic modes. Here "Auto follower" is not a fully automatic mode. The unconnected position information does not cause the total block of OLATCC, only the extreme position blocking is not working.

The blocking status can be seen in the generated events.

### Fast lowering control

OLATCC provides the fast lowering control in the automatic operation modes. When the set *Runback raise V* is exceeded, the regulator gives fast lowering control pulses until the voltage drops below the specified limit. This fast lowering control can be seen with the monitoring data `TIMER_STS`, where the value "Fast lower T on" indicates this functionality to be active.



To allow the fast lowering operation, *Runback raise V* has to be set always to a value higher than the control voltage (`U_CTL`) plus half of *Band width voltage*.

Typically, the blockings are reset when the corresponding limit with the hysteresis is undershoot or exceeded. Although blocking is reset after undershooting the above-mentioned limit, the fast lowering control operation continues until the measured voltage signal difference undershoots half the *Band width voltage* hysteresis limit ( *Figure 470*). As a result, normal automatic mode operation is not possible before this happens.

Fast lowering control causes successive `LOWER_OWN` pulses to be activated. The time between consecutive pulse starts is the pulse length plus 1.5 seconds.

- There is no tap changer operating delay (otherwise six seconds) taken into account in this cycle (meaning that some command pulses are ineffective due to tap changer operation, as described in *Chapter 8.5.4.8 Pulse control*)
- Timer mode set by *Delay characteristic* has no effect here (always the DT timer-type operation). Because the minimum pulse length (the *LTC pulse time* setting) is 0.5 seconds, the shortest interval between successive pulses can be two seconds.

In the automatic follower mode, the fast lowering is not triggered. In this way, the awkward dispersion of position values in different units can be avoided. The master always decides on the fast lowering on behalf of the follower units. Moreover, master and follower should measure an equal voltage level and have similar setting values for the overvoltage blocking limit.

## 8.5.4.10 Alarm indication

### Tap Changer Monitoring

OLATCC supervises the operation of the tap changer and alarms if the alarm condition is detected. An alarm activation means that the `ALARM` output is activated and the alarm reason can be read from the monitored data `ALARM_REAS`. Alarms are in use by default but they can be set not to be in use by setting *Alarms enabled* to "False". Three different alarm conditions and their combinations can be detected by OLATCC.

### Command error

OLATCC supervises the tap changer position information of the own transformer when a control pulse is given. If the correct position change (direction depends on the comparison of the settings *Raise block tap* and *Lower block tap*) is not seen by OLATCC in *Cmd error delay time* after the pulse start, the alarm is issued.

If the position information is not connected, no alarm is generated. The alarm is reset when the correct change in position value is detected after a given pulse or if a new command pulse is given.

The monitored data ALARM\_REAS is set during an alarm. This means that if the alarm reason is active, ALARM\_REAS has the value "Cmd error".

### TCO signal fails

If the tap changer operating signal TCO stays active for more than 15 seconds after the output pulse deactivation, OLATCC concludes this as an abnormal condition and assumes that the tap changer is stuck. The alarm is reset when the TCO input signal deactivates. The monitored data ALARM\_REAS is set during the alarm. This means that only if alarm reason is active, ALARM\_REAS has the value "TCO error".

If the TCO input signal is not connected (indicated by bad quality), this type of alarm is not possible.

### Regulator pumping

It is possible that faulty settings cause the regulator to give control pulses too frequently. For example, too low a setting for the *Band width voltage* ([Figure 470](#)) can result in a pumping condition where the regulator has problems to bring the regulated voltage to a desired level. To detect this, OLATCC has a setting *Max operations in 1h*, which defines the allowed number of lowering and raising commands during a one-hour sliding time window. The detection is active both in the manual and automatic operation modes. The alarm is reset after the counted number of the operations during the one-hour time window is less than the set value. The number of executed operations per last one hour can be read from the monitored data OP\_TM\_NUM\_H. However, this parameter is updated only in three-minute intervals. Again, the monitored data ALARM\_REAS is set during an alarm. This means that only if alarm reason is active, ALARM\_REAS has the value "Pump error".

The operation of OLATCC is not blocked during an alarm situation, but all the alarms mentioned above cause the automatic operation to be delayed. In practice, this means that the set delay times T1 and T2 are doubled.

In addition to the alarm detections, OLATCC provides a nonvolatile operation counter parameter (monitored data OPR\_CNT) for determining the service intervals of the tap changer. The counter gives the total number of raising and lowering commands given in the manual and automatic modes. All commands, even those that are omitted by the tap changer due to its operation sequence, are calculated in a cumulative counter. This data parameter can be reset via the clear menu parameter *OLATCC counter*.

## 8.5.5 Application

OLATCC is used to control the voltage on the load side of the power transformer. Based on the measured voltage and current, the function block determines whether

the voltage needs to be increased or decreased. The voltage is regulated by the raising or lowering commands sent to the tap changer.

The basic principle for voltage regulation is that no regulation takes place as long as the voltage stays within the bandwidth setting. The measured voltage is always compared to the calculated control voltage  $U_p$ . Once the measured voltage deviates from the bandwidth, the delay time  $T1$  starts. When the set delay time has elapsed, a raising or lowering control pulse is sent to the tap changer. Should the measured voltage still be outside the bandwidth after one tap change, the delay time  $T2$  starts.  $T2$  is normally shorter than  $T1$ .

Under certain circumstances, the automatic voltage regulator needs to be enhanced with additional functions such as Line Drop Compensation (LDC) and Reduce Set Voltage (RSV). Also, various parallel operation modes are available to fit applications where two or more power transformers are connected to the same busbar at the same time. The parallel operation modes of OLATCC are Master/Follower (M/F), Minimizing Circulating Current (MCC) and Negative Reactance Principle (NRP).

#### Configuration example for the Manual and Auto single modes

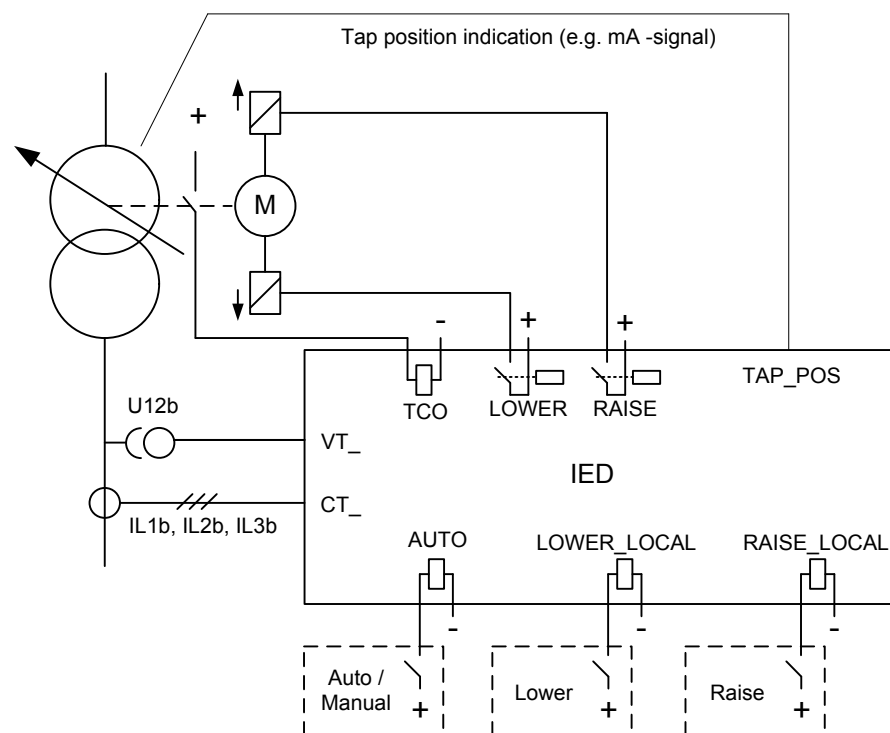


Figure 475: Basic connection diagram for the voltage regulator

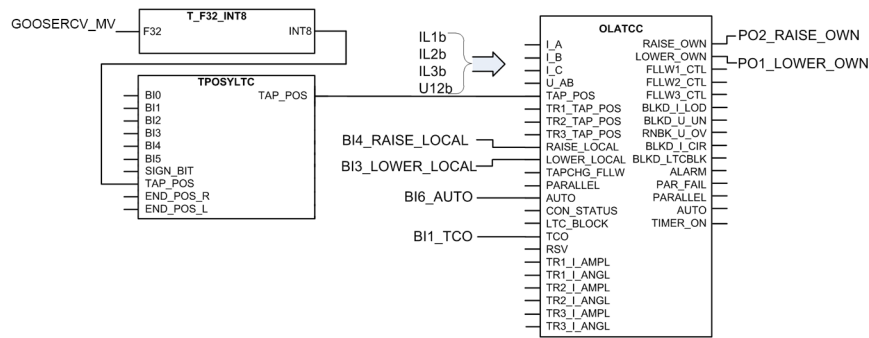


Figure 476: Configuration example for the Manual and Auto single modes

The configuration example uses an mA signal to indicate the current tap position of the local transformer. To take that position information to OLATCC, the measured mA signal is received via GOOSE message from the bay level merging unit or relay. The value is then converted to integer value with T\_F32\_INT8 function. That integer value is connected to the TAP\_POS input of the TPOSYLTC function. The tap position value is automatically transferred from TPOSYLTC to OLATCC without a configuration connection.

**Configuration example for the Auto parallel (Master/Follower) mode**

The configuration example for Master/Follower describes how the tap position information is transferred from follower to master. The status information from circuit breakers and an extra logic can be used to change the operation mode via inputs of the master and the follower (*Operation mode* = "Input control").



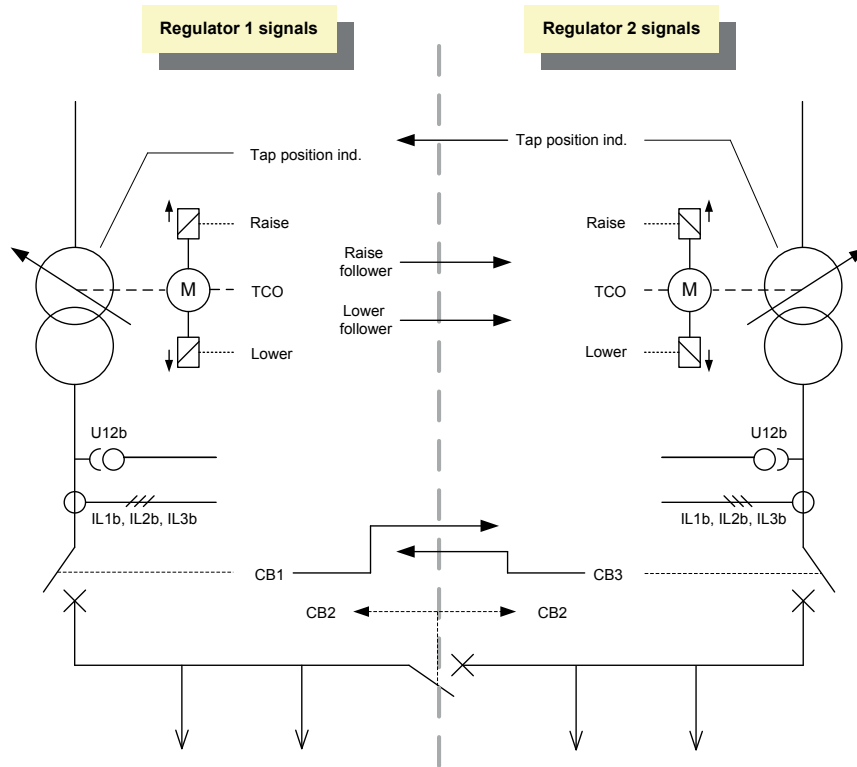


Figure 477: An example of the configuration for the Auto parallel (Master/Follower) mode (the position of the follower known by the master)

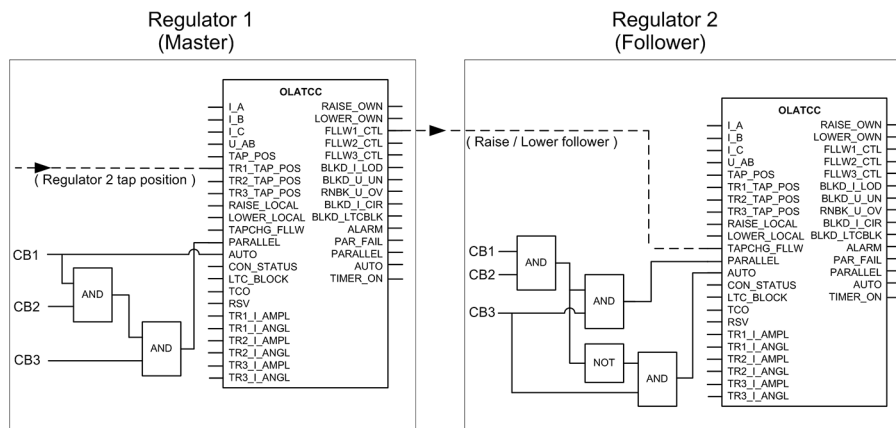


Figure 478: Simplified regulator 1&2 configurations of the Master/Follower example

Table 845: The automatic selection of operation modes for regulators in the Master/Follower example

| CB1  | CB2    | CB3    | Regulator 1 | Regulator 2 |
|------|--------|--------|-------------|-------------|
| Open | Open   | Open   | Manual      | Manual      |
| Open | Open   | Closed | Manual      | Auto single |
| Open | Closed | Open   | Manual      | Manual      |

Table continues on the next page

| CB1    | CB2    | CB3    | Regulator 1   | Regulator 2   |
|--------|--------|--------|---|---|
| Open   | Closed | Closed | Manual  | Auto single   |
| Closed | Open   | Open   | Auto single   | Manual  |
| Closed | Open   | Closed | Auto single   | Auto single   |
| Closed | Closed | Open   | Auto single   | Manual  |
| Closed | Closed | Closed | Auto parallel (Master)<br><i>Auto parallel mode = "Auto master"</i> | Auto parallel (Follower)<br><i>Auto parallel mode = "Auto follower"</i> |

**Configuration example for the Auto parallel (MCC) mode**

The purpose of the Auto parallel (MCC) mode is to minimize the circulating current between the parallel transformers.

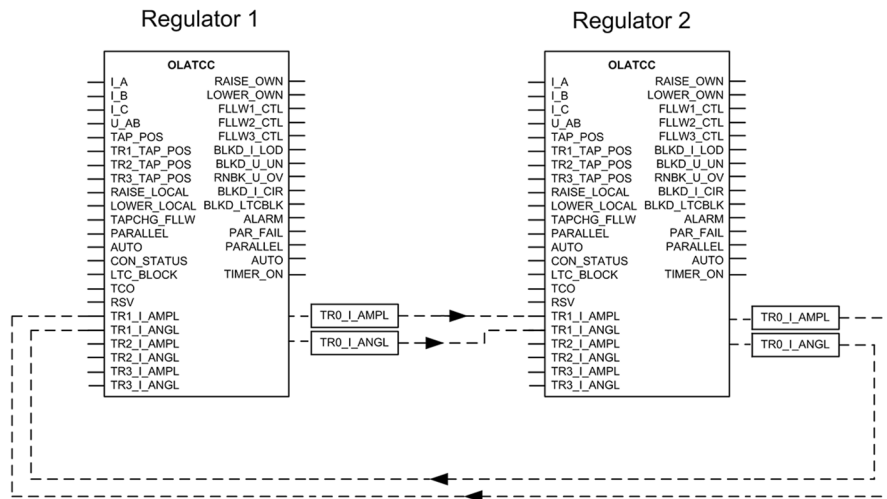


Figure 479: Two parallel transformers and the horizontal connection to transfer current and the phase angle information when the MCC principle is used

**Configuration example for the Auto parallel (NRP) mode**

The advantage of the Negative Reactance Principle (NRP) operation mode is that no wiring or communication is needed between the IEDs. The voltage regulators operate independently. However, for the cases where there is an occasional stepwise change in the phase angle of the load, the regulating error can be suppressed by an automatic setting group change or by changing the operation mode with the logic.

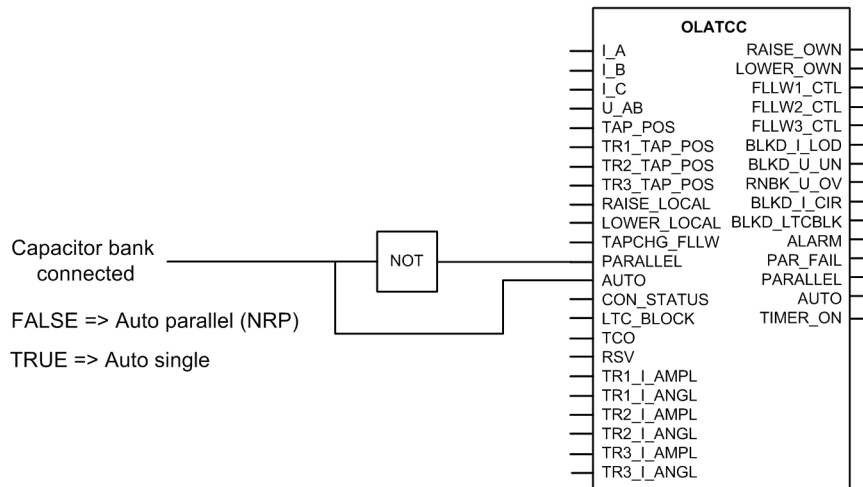


Figure 480: Changing the operation mode of OLATCC automatically when the capacitor bank is connected

**Comparison summary between parallel operation modes**

The parallel operation modes are needed because if the parallel regulators operated independently, at some point the transformers would become out of step with each other.

The circulating current would increase and the line drop compensation would thus increase for the transformer giving the highest voltage. Correspondingly, the increasing circulating current would cause the transformer giving the lowest voltage to decrease the voltage due to a decreased line drop compensation effect. In other words, the two transformers would run apart.

However, it is case-specific which parallel operation mode is the most suitable.

**Table 846: Different parallel operation modes**

| Parallel operation modes                                 | Description   |
|--|---|
| Master/Follower (follower positions not known by master) | <p>Requires power transformers with identical ratings and step voltages</p> <ul style="list-style-type: none"> <li>- Extra wiring work: raising/lowering commands (input TAPCHG_FLLW connected from output FLLWx_CTL) from the master to the follower</li> <li>- Manual control needed in the beginning of operation</li> <li>- Blind control: follower positions after control cannot be supervised. It must be relied on that the followers are following the commands.</li> </ul> <p>+ Parallel transformers are regulated as one unit</p> |

Table continues on the next page

| Parallel operation modes                   | Description   |
|--|---|
|  | <ul style="list-style-type: none"> <li>+ Supports an unlimited number of transformers in parallel</li> </ul>  |
| Master/Follower (follower positions known) | <p>Requires power transformers with identical ratings and step voltages.</p> <ul style="list-style-type: none"> <li>- Extra wiring work:               <ul style="list-style-type: none"> <li>raising/lowering commands (the TAPCHG_FLLW input connected from the FLLWx_CTL output) from the master to the follower</li> <li>TAP_POS connections from the followers to the master</li> </ul> </li> <li>- Supports not more than four transformers in parallel.</li> </ul>   |
| Negative reactance principle               | <p>The actual phase angle setting results in a regulating error. When the line drop compensation is used, the setting should be changed when the number of transformers in parallel operation is changed.</p> <ul style="list-style-type: none"> <li>+ The step voltages and short circuit impedances of the transformers do not need to be identical.</li> <li>+ No communication or wiring between regulators is needed, meaning that the principle can be applied even when the parallel transformers are located at different substations.</li> <li>+ Supports an unlimited number of transformers in parallel</li> </ul> |
| Minimizing circulating current             | <ul style="list-style-type: none"> <li>- Requires extra configuration efforts since this principle utilizes a horizontal communication between the regulators (the inputs TRx_I connected from parallel transformer controller's outputs TR0_I).</li> <li>+ The step voltages and short circuit impedances of the transformers do not need to be identical.</li> <li>+ The phase angle of the load current may vary without any impact on the regulation accuracy.</li> <li>+ Automatic adjustment for the number of transformers (for an accurate calculation of line drop compensation term)</li> </ul>                     |

## 8.5.6 Signals

### 8.5.6.1 OLATCC Input signals

Table 847: OLATCC Input signals

| Name        | Type    | Default | Description  |
|-------------|---------|---------|--|
| I_A         | SIGNAL  | 0       | Phase A current  |
| I_B         | SIGNAL  | 0       | Phase B current  |
| I_C         | SIGNAL  | 0       | Phase C current  |
| U_AB        | SIGNAL  | 0       | Phase-to-phase voltage AB  |
| TAP_POS     | INT8    | 0       | Integer value representing tap changer position of own transformer |
| TR1_TAP_POS | INT32   | 0       | Integer value representing tap changer position of transformer 1   |
| TR2_TAP_POS | INT32   | 0       | Integer value representing tap changer position of transformer 2   |
| TR3_TAP_POS | INT32   | 0       | Integer value representing tap changer position of transformer 3   |
| RAISE_LOCAL | BOOLEAN | 0=False | Raise command input from configuration                             |
| LOWER_LOCAL | BOOLEAN | 0=False | Lower command input from configuration                             |
| TAPCHG_FLLW | Enum    | 0=False | Change follower tap position (stop, lower, higher)                 |
| PARALLEL    | BOOLEAN | 0=False | Parallel or single operation                                       |
| AUTO        | BOOLEAN | 0=False | Auto/Manual indication   |
| CON_STATUS  | BOOLEAN | 0=False | Network connection status of the (own) transformer                 |
| LTC_BLOCK   | BOOLEAN | 0=False | External signal for blocking                                       |

Table continues on the next page

| Name       | Type    | Default | Description                                   |
|------------|---------|---------|---|
| TCO        | BOOLEAN | 0=False | Tap changer operating input                   |
| RSV        | BOOLEAN | 0=False | Reduce set voltage active                     |
| TR1_I_AMPL | FLOAT32 | 0.00    | Received current magnitude from transformer 1 |
| TR1_I_ANGL | FLOAT32 | 0.00    | Received current angle from transformer 1     |
| TR2_I_AMPL | FLOAT32 | 0.00    | Received current magnitude from transformer 2 |
| TR2_I_ANGL | FLOAT32 | 0.00    | Received current angle from transformer 2     |
| TR3_I_AMPL | FLOAT32 | 0.00    | Received current magnitude from transformer 3 |
| TR3_I_ANGL | FLOAT32 | 0.00    | Received current angle from transformer 3     |

### 8.5.6.2

## OLATCC Output signals

Table 848: OLATCC Output signals

| Name      | Type    | Description  |
|-----------|---------|--|
| RAISE_OWN | BOOLEAN | Raise command for own transformer  |
| LOWER_OWN | BOOLEAN | Lower command for own transformer  |
| FLLW1_CTL | INT32   | Lower/Raise command for follower transformer 1 in the Master/Follower operation mode |
| FLLW2_CTL | INT32   | Lower/Raise command for follower transformer 2 in the Master/Follower operation mode |
| FLLW3_CTL | INT32   | Lower/Raise command for follower transformer 3 in the Master/Follower operation mode |
| ALARM     | BOOLEAN | Alarm status   |
| PAR_FAIL  | BOOLEAN | Parallel failure detected  |

*Table continues on the next page*

| Name        | Type    | Description                                     |
|-------------|---------|---|
| PARALLEL    | BOOLEAN | Parallel or single operation                    |
| AUTO        | BOOLEAN | Auto/Manual indication                          |
| BLKD_I_LOD  | BOOLEAN | Indication of over current blocking             |
| BLKD_U_UN   | BOOLEAN | Indication of under voltage blocking            |
| RNBK_U_OV   | BOOLEAN | Indication of raise voltage runback             |
| BLKD_I_CIR  | BOOLEAN | Indication of high circulating current blocking |
| BLKD_LTCBLK | BOOLEAN | Indication of external blocking                 |

## 8.5.7 Settings

### 8.5.7.1 OLATCC Settings

Table 849: OLATCC Group settings (Basic)

| Parameter           | Values (Range)                                     | Unit | Step  | Default       | Description                             |
|---------------------|--|------|-------|---------------|---|
| Auto parallel mode  | 2=Auto master<br>3=Auto follower<br>5=NRP<br>7=MCC |      |       | 2=Auto master | Parallel mode selection                 |
| Band center voltage | 0.000...2.000                                      | xUn  | 0.001 | 1.000         | Band center voltage Us                  |
| Line drop V Ris     | 0.0...25.0   | %    | 0.1   | 0.0           | Resistive line-drop compensation factor |
| Line drop V React   | 0.0...25.0   | %    | 0.1   | 0.0           | Reactive line-drop compensation factor  |
| Band reduction      | 0.00...9.00  | %Un  | 0.01  | 0.00          | Step size for reduce set voltage (RSV)  |
| Stability factor    | 0.0...70.0   | %    | 0.1   | 0.0           | Stability factor in parallel operation  |

*Table continues on the next page*

| Parameter            | Values (Range) | Unit | Step | Default | Description   |
|----------------------|----------------|------|------|---------|---|
| Load phase angle     | -89...89       | deg  | 1    | 0       | Load phase-shift, used only with the negative reactance principle |
| Control delay time 1 | 1000...300000  | ms   | 100  | 60000   | Control delay time for the first control pulse                    |
| Control delay time 2 | 1000...300000  | ms   | 100  | 30000   | Control delay time for the following control pulses               |

Table 850: OLATCC Non group settings (Basic)

| Parameter           | Values (Range)  | Unit | Step | Default   | Description                            |
|---------------------|---|------|------|-----------|--|
| Operation           | 1=on<br>5=off   |      |      | 1=on      | Operation Off / On                     |
| Operation mode      | 1=Manual<br>2=Auto single<br>3=Auto parallel<br>4=Input control<br>5=Command                      |      |      | 5=Command | The operation mode                     |
| Custom Man blocking | 1=Custom disabled<br>2=OC<br>3=UV<br>4=OC, UV<br>5=EXT<br>6=OC, EXT<br>7=UV, EXT<br>8=OC, UV, EXT |      |      | 2=OC      | Customized manual blocking             |
| Parallel trafos     | 0...10  |      | 1    | 0         | Number of parallel transformers in ad- |

*Table continues on the next page*



| Parameter            | Values (Range)                    | Unit | Step | Default         | Description  |
|----------------------|-----------------------------------|------|------|-----------------|--|
|                      |                                   |      |      |                 | dition to own transformer  |
| Delay characteristic | 0=Inverse time<br>1=Definite time |      |      | 1=Definite time | Selection of delay characteristic  |
| Band width voltage   | 1.20...18.00                      | %Un  | 0.01 | 3.00            | Allowed deviation of the control voltage                                     |
| Load current limit   | 0.10...5.00                       | xIn  | 0.01 | 2.00            | Load current blocking limit  |
| Block lower voltage  | 0.10...1.20                       | xUn  | 0.01 | 0.70            | Voltage limit, where further voltage lowering commands are blocked           |
| Runback raise V      | 0.80...2.40                       | xUn  | 0.01 | 1.25            | Voltage limit, where fast lower commands takes place                         |
| Cir current limit    | 0.10...5.00                       | xIn  | 0.01 | 0.15            | Blocking limit for high circulating current                                  |
| LDC limit            | 0.00...2.00                       | xUn  | 0.01 | 0.10            | Maximum limit for line drop compensation term                                |
| Lower block tap      | -36...36                          |      | 1    | 0               | Tap changer limit position which gives lowest voltage on the regulated side  |
| Raise block tap      | -36...36                          |      | 1    | 17              | Tap changer limit position which gives highest voltage on the regulated side |
| LTC pulse time       | 500...10000                       | ms   | 100  | 1500            | Output pulse duration, common for  |

*Table continues on the next page*

| Parameter  | Values (Range)    | Unit | Step | Default | Description                          |
|------------|-------------------|------|------|---------|--------------------------------------|
|            |                   |      |      |         | raise and lower pulses               |
| LDC enable | 0=False<br>1=True |      |      | 1=True  | Selection for line drop compensation |

Table 851: OLATCC Non group settings (Advanced)

| Parameter            | Values (Range)    | Unit | Step | Default | Description   |
|----------------------|-------------------|------|------|---------|---|
| Max operations in 1h | 0...10000         |      | 1    | 100     | Allowed number of controls per one hour sliding window      |
| Cmd error delay time | 10...50           | s    | 1    | 20      | Time delay before command error will be activated           |
| Follower delay time  | 6...20            | s    | 1    | 6       | Time delay between successive follower commands by a master |
| Alarms enabled       | 0=False<br>1=True |      |      | 1=True  | Alarm selection   |
| Rv Pwr flow allowed  | 0=False<br>1=True |      |      | 0=False | Reverse power flow allowed                                  |

## 8.5.8 Monitored data

### 8.5.8.1 OLATCC Monitored data

Table 852: OLATCC Monitored data

| Name       | Type    | Values (Range)   | Unit | Description                   |
|------------|---------|------------------|------|-------------------------------|
| TR0_I_AMPL | FLOAT32 | 0.00...15000.00  | A    | Transmitted current magnitude |
| TR0_I_ANGL | FLOAT32 | -180.00...180.00 | deg  | Transmitted current angle     |

*Table continues on the next page*

| Name         | Type    | Values (Range)   | Unit | Description  |
|--------------|---------|--|------|--|
| U_MEAS       | FLOAT32 | 0.00...5.00  | xUn  | Phase-to-phase voltage, average filtered                                   |
| ANGL_UA_IA   | FLOAT32 | -180...180   | deg  | Measured angle value between phase A voltage and current                   |
| TIMER_STS    | Enum    | 0=Timer off<br>1=Lower timer1 on<br>2=Raise timer1 on<br>3=Lower timer2 on<br>4=Raise timer2 on<br>5=Fast lower T on |      | Timer T1, T2 or fast lower timer active                                    |
| OPR_MODE_STS | Enum    | 0=Not in use<br>1=Manual<br>2=Auto single<br>3=Auto master<br>4=Auto follower<br>5=MCC<br>6=NRP                      |      | The acting operation mode of the function block                            |
| U_CTL        | FLOAT32 | 0.000...3.000  | xUn  | Control voltage, Up, target voltage level                                  |
| UD_CTL       | FLOAT32 | -2.000...2.000   | xUn  | Voltage difference between Measured voltage - Control Voltage: $U_m - U_p$ |
| I_CIR        | FLOAT32 | -10.00...10.00   | xIn  | Calculated circulating current - calculated in operation modes NRP and MCC |
| LDC          | FLOAT32 | -2.00...2.00   | xUn  | Calculated line drop compensation  |
| BLK_STATUS   | INT32   | 0...127  |      | Bit-coded output showing the   |

*Table continues on the next page*

| Name         | Type  | Values (Range)  | Unit | Description   |
|--------------|-------|---|------|---|
|              |       |   |      | blocking status for the next operation                  |
| ALARM_REAS   | Enum  | 0=No alarm<br>1=Cmd error<br>2=TCO error<br>3=Cmd + TCO err<br>4=Pump error<br>5=Pump + cmd err<br>6=Pump + TCO err<br>7=Pmp+TCO+cmd err            |      | Status and reason for alarm                             |
| OP_TM_NUM_H  | INT32 | 0...2147483647  |      | Number of controls for own tap changer during last hour |
| FAIL_FLLW    | Enum  | 0=No failed followers<br>1=Follower 1<br>2=Follower 2<br>3=Followers 1+2<br>4=Follower 3<br>5=Followers 1+3<br>6=Followers 2+3<br>7=Followers 1+2+3 |      | Failed followers  |
| PAR_UNIT_MCC | Enum  | 0=No parall units<br>1=Trafo 1<br>2=Trafo 2<br>3=Trafos 1 and 2<br>4=Trafo 3<br>5=Trafos 1 and 3<br>6=Trafos 2 and 3<br>7=Trafos 1+2+3              |      | Parallel units included in MCC calculation              |
| OPR_CNT      | INT32 | 0...2147483647  |      | Total number of raise and lower commands given          |

*Table continues on the next page*

| Name   | Type | Values (Range)   | Unit | Description                       |
|--------|------|--|------|-----------------------------------|
|        |      |  |      | in the manual and automatic modes |
| OLATCC | Enum | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status                            |

## 8.5.9 Technical data

Table 853: OLATCC Technical data

| Characteristic   | Value  |
|--|--|
| Operation accuracy <sup>109</sup>  | Depending on the frequency of the measured current: $f_n \pm 2$ Hz   |
| Differential voltage $U_d = \pm 0.5\%$ of the measured value or $\pm 0.005 \times U_n$ (in measured voltages $< 2.0 \times U_n$ )<br>Operation value = $\pm 1.5\%$ of the $U_d$ for $U_s = 1.0 \times U_n$ | +4.0%/-0% of the set value   |
| Operate time accuracy in definite time mode  |  |
| Operate time accuracy in inverse time mode <sup>1)</sup>   | +8.5%/-0% of the set value<br>(at theoretical B in range of 1.1...5.0)<br>Also note fixed minimum operate time (IDMT) 1 s. |
| Reset ratio for control operation  | Typically 0.80 (1.20)  |
| Reset ratio for analogue based blockings (except run back raise voltage blocking)  | Typically 0.96 (1.04)  |

## 8.5.10 Technical revision history

Table 854: OLATTC Technical revision history

| Technical revision | Change  |
|--------------------|---|
| B                  | Added new output <code>TIMER_ON</code> (new 61850 data for that). ACT interface changes by interchanging already existing data between monitored data and |

*Table continues on the next page*

<sup>109</sup> Default setting values used

<sup>110</sup> Voltage before deviation = set *Band center voltage*

| Technical revision | Change   |
|--------------------|--|
|                    | output interface. <i>Operation mode</i> default to be changed to 4=Input control (previously it was Manual). |
| C                  | Internal improvement.  |
| D                  | Added input TAP_POS. Added command mode for <i>Operation mode</i> setting.                                   |

## 9 Power quality measurement functions

### 9.1 Current total demand distortion CMHAI

#### 9.1.1 Identification

| Function description            | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|---------------------------------|--------------------------|--------------------------|-------------------------------|
| Current total demand distortion | CMHAI                    | PQM3I                    | PQM3I                         |

#### 9.1.2 Function block

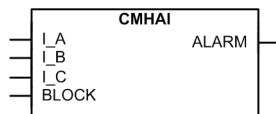


Figure 481: Function block

#### 9.1.3 Functionality

The current total demand distortion function CMHAI is used for monitoring the current total demand distortion TDD.

#### 9.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of CMHAI can be described with a module diagram. All the modules in the diagram are explained in the next sections.

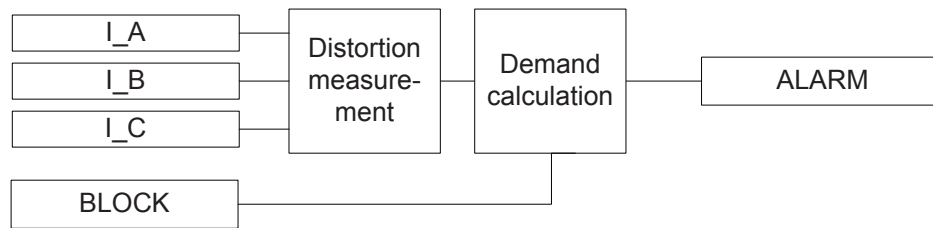


Figure 482: Functional module diagram

### Distortion measurement

The distortion measurement module measures harmonics up to the 11th harmonic. The total demand distortion TDD is calculated from the measured harmonic components with the formula

$$TDD = \frac{\sqrt{\sum_{k=2}^N I_k^2}}{I_{max\_demand}}$$

$I_k$

$k^{\text{th}}$  harmonic component

$I_{max\_demand}$

The maximum demand current defined by the setting Initial Dmd current

### Demand calculation

The demand value for TDD is calculated separately for each phase. If any of the calculated total demand distortion values is above the set alarm limit *TDD alarm limit*, the ALARM output is activated.

The demand calculation window is set with the *Demand interval* setting. It has seven window lengths from "1 minute" to "180 minutes". The window type can be set with the *Demand window* setting. The available options are "Sliding" and "Non-sliding".

The activation of the BLOCK input blocks the ALARM output.

## 9.1.5 Application

In standards, the power quality is defined through the characteristics of the supply voltage. Transients, short-duration and long-duration voltage variations, unbalance and waveform distortions are the key characteristics describing power quality. Power quality is, however, a customer-driven issue. It could be said that any power problem concerning voltage or current that results in a failure or misoperation of customer equipment is a power quality problem.

Harmonic distortion in a power system is caused by nonlinear devices. Electronic power converter loads constitute the most important class of nonlinear loads in a power system. The switch mode power supplies in a number of single-phase electronic equipment, such as personal computers, printers and copiers, have a very high third-harmonic content in the current. Three-phase electronic power converters, that is, dc/ac drives, however, do not generate third-harmonic currents. Still, they can be significant sources of harmonics.



Power quality monitoring is an essential service that utilities can provide for their industrial and key customers. Not only can a monitoring system provide information about system disturbances and their possible causes, it can also detect problem conditions throughout the system before they cause customer complaints, equipment malfunctions and even equipment damage or failure. Power quality problems are not limited to the utility side of the system. In fact, the majority of power quality problems are localized within customer facilities. Thus, power quality monitoring is not only an effective customer service strategy but also a way to protect a utility's reputation for quality power and service.

CMHAI provides a method for monitoring the power quality by means of the current waveform distortion. CMHAI provides a short-term 3-second average and a long-term demand for TDD.

## 9.1.6 Signals

### 9.1.6.1 CMHAI Input signals

Table 855: CMHAI Input signals

| Name  | Type    | Default | Description                         |
|-------|---------|---------|-------------------------------------|
| I_A   | Signal  | 0       | Phase A current                     |
| I_B   | Signal  | 0       | Phase B current                     |
| I_C   | Signal  | 0       | Phase C current                     |
| BLOCK | BOOLEAN | 0=False | Block signal for all binary outputs |

### 9.1.6.2 CMHAI Output signals

Table 856: CMHAI Output signals

| Name  | Type    | Description          |
|-------|---------|----------------------|
| ALARM | BOOLEAN | Alarm signal for TDD |

## 9.1.7 Settings

### 9.1.7.1 CMHAI Settings

Table 857: CMHAI Non group settings (Basic)

| Parameter | Values (Range) | Unit | Step | Default | Description        |
|-----------|----------------|------|------|---------|--------------------|
| Operation | 1=on           |      |      | 1=on    | Operation Off / On |

*Table continues on the next page*

| Parameter       | Values (Range)   | Unit | Step | Default      | Description                          |
|-----------------|--|------|------|--------------|--------------------------------------|
|                 | 5=off  |      |      |              |                                      |
| Demand interval | 0=1 minute<br>1=5 minutes<br>2=10 minutes<br>3=15 minutes<br>4=30 minutes<br>5=60 minutes<br>6=180 minutes |      |      | 2=10 minutes | Time interval for demand calculation |
| Demand window   | 1=Sliding<br>2=Non-sliding   |      |      | 1=Sliding    | Demand calculation window type       |
| TDD alarm limit | 1.0...100.0  | %    | 0.1  | 50.0         | TDD alarm limit                      |

**Table 858: CMHAI Non group settings (Advanced)**

| Parameter           | Values (Range) | Unit | Step | Default | Description            |
|---------------------|----------------|------|------|---------|------------------------|
| Initial Dmd current | 0.10...1.00    | xIn  | 0.01 | 1.00    | Initial demand current |

## 9.1.8 Monitored data

### 9.1.8.1 CMHAI Monitored data

**Table 859: CMHAI Monitored data**

| Name                 | Type      | Values (Range) | Unit | Description                        |
|----------------------|-----------|----------------|------|------------------------------------|
| Max demand TDD IL1   | FLOAT32   | 0.00...500.00  | %    | Maximum demand TDD for phase A     |
| Max demand TDD IL2   | FLOAT32   | 0.00...500.00  | %    | Maximum demand TDD for phase B     |
| Max demand TDD IL3   | FLOAT32   | 0.00...500.00  | %    | Maximum demand TDD for phase C     |
| Time max dmd TDD IL1 | Timestamp |                |      | Time of maximum demand TDD phase A |

*Table continues on the next page*

| Name                 | Type      | Values (Range) | Unit | Description                            |
|----------------------|-----------|----------------|------|--|
| Time max dmd TDD IL2 | Timestamp |                |      | Time of maximum demand TDD phase B     |
| Time max dmd TDD IL3 | Timestamp |                |      | Time of maximum demand TDD phase C     |
| 3SMHTDD_A            | FLOAT32   | 0.00...500.00  | %    | 3 second mean value of TDD for phase A |
| DMD_TDD_A            | FLOAT32   | 0.00...500.00  | %    | Demand value for TDD for phase A       |
| 3SMHTDD_B            | FLOAT32   | 0.00...500.00  | %    | 3 second mean value of TDD for phase B |
| DMD_TDD_B            | FLOAT32   | 0.00...500.00  | %    | Demand value for TDD for phase B       |
| 3SMHTDD_C            | FLOAT32   | 0.00...500.00  | %    | 3 second mean value of TDD for phase C |
| DMD_TDD_C            | FLOAT32   | 0.00...500.00  | %    | Demand value for TDD for phase C       |

## 9.1.9 Technical revision history

Table 860: CMHAI Technical revision history

| Technical revision | Change                |
|--------------------|-----------------------|
| B                  | Internal improvement. |
| C                  | Internal improvement. |
| D                  | Internal improvement. |

## 9.2 Voltage total harmonic distortion VMHAI

### 9.2.1 Identification

| Function description              | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|-----------------------------------|--------------------------|--------------------------|-------------------------------|
| Voltage total harmonic distortion | VMHAI                    | PQM3U                    | PQM3V                         |

### 9.2.2 Function block

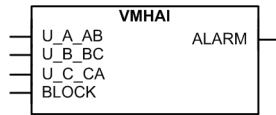


Figure 483: Function block

### 9.2.3 Functionality

The voltage total harmonic distortion function VMHAI is used for monitoring the voltage total harmonic distortion THD.

### 9.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of VMHAI can be described with a module diagram. All the modules in the diagram are explained in the next sections.

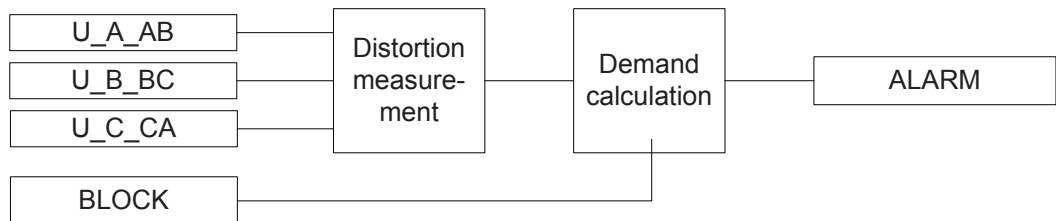


Figure 484: Functional module diagram

#### Distortion measurement

The distortion measurement module measures harmonics up to the 11th harmonic. The total harmonic distortion THD for voltage is calculated from the measured harmonic components with the formula

$$THD = \frac{\sqrt{\sum_{k=2}^N U_k^2}}{U_1}$$

$U_k$

$k^{th}$  harmonic component

$U_1$

the voltage fundamental component amplitude

### Demand calculation

The demand value for THD is calculated separately for each phase. If any of the calculated demand THD values is above the set alarm limit *THD alarm limit*, the `ALARM` output is activated.

The demand calculation window is set with the *Demand interval* setting. It has seven window lengths from "1 minute" to "180 minutes". The window type can be set with the *Demand window* setting. The available options are "Sliding" and "Non-sliding".

The activation of the `BLOCK` input blocks the `ALARM` output.

## 9.2.5 Application

VMHAI provides a method for monitoring the power quality by means of the voltage waveform distortion. VMHAI provides a short-term three-second average and long-term demand for THD.

## 9.2.6 Signals

### 9.2.6.1 VMHAI Input signals

Table 861: VMHAI Input signals

| Name   | Type    | Default | Description   |
|--------|---------|---------|---|
| U_A_AB | SIGNAL  | 0       | Phase-to-earth voltage A or phase-to-phase voltage AB |
| U_B_BC | SIGNAL  | 0       | Phase-to-earth voltage B or phase-to-phase voltage BC |
| U_C_CA | SIGNAL  | 0       | Phase-to-earth voltage C or phase-to-phase voltage CA |
| BLOCK  | BOOLEAN | 0=False | Block signal for all binary outputs                   |

### 9.2.6.2 VMHAI Output signals

Table 862: VMHAI Output signals

| Name  | Type    | Description          |
|-------|---------|----------------------|
| ALARM | BOOLEAN | Alarm signal for THD |

## 9.2.7 Settings

### 9.2.7.1 VMHAI Settings

Table 863: VMHAI Non group settings (Basic)

| Parameter       | Values (Range)   | Unit | Step | Default      | Description                          |
|-----------------|--|------|------|--------------|--------------------------------------|
| Operation       | 1=on<br>5=off  |      |      | 1=on         | Operation Off / On                   |
| Demand interval | 0=1 minute<br>1=5 minutes<br>2=10 minutes<br>3=15 minutes<br>4=30 minutes<br>5=60 minutes<br>6=180 minutes |      |      | 2=10 minutes | Time interval for demand calculation |
| Demand window   | 1=Sliding<br>2=Non-sliding   |      |      | 1=Sliding    | Demand calculation window type       |
| THD alarm limit | 1.0...100.0  | %    | 0.1  | 50.0         | THD alarm limit                      |

## 9.2.8 Monitored data

### 9.2.8.1 VMHAI Monitored data

Table 864: VMHAI Monitored data

| Name               | Type    | Values (Range) | Unit | Description                    |
|--------------------|---------|----------------|------|--------------------------------|
| Max demand THD UL1 | FLOAT32 | 0.00...500.00  | %    | Maximum demand THD for phase A |
| Max demand THD UL2 | FLOAT32 | 0.00...500.00  | %    | Maximum demand THD for phase B |
| Max demand THD UL3 | FLOAT32 | 0.00...500.00  | %    | Maximum demand THD for phase C |

*Table continues on the next page*

| Name                 | Type      | Values (Range) | Unit | Description                            |
|----------------------|-----------|----------------|------|--|
| Time max dmd THD UL1 | Timestamp |                |      | Time of maximum demand THD phase A     |
| Time max dmd THD UL2 | Timestamp |                |      | Time of maximum demand THD phase B     |
| Time max dmd THD UL3 | Timestamp |                |      | Time of maximum demand THD phase C     |
| 3SMHTHD_A            | FLOAT32   | 0.00...500.00  | %    | 3 second mean value of THD for phase A |
| DMD_THD_A            | FLOAT32   | 0.00...500.00  | %    | Demand value for THD for phase A       |
| 3SMHTHD_B            | FLOAT32   | 0.00...500.00  | %    | 3 second mean value of THD for phase B |
| DMD_THD_B            | FLOAT32   | 0.00...500.00  | %    | Demand value for THD for phase B       |
| 3SMHTHD_C            | FLOAT32   | 0.00...500.00  | %    | 3 second mean value of THD for phase C |
| DMD_THD_C            | FLOAT32   | 0.00...500.00  | %    | Demand value for THD for phase C       |

## 9.2.9 Technical revision history

Table 865: VMHAI Technical revision history

| Technical revision | Change                |
|--------------------|-----------------------|
| B                  | Internal improvement. |
| C                  | Internal improvement. |

## 9.3 Voltage variation PHQVVR

### 9.3.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|----------------------|--------------------------|--------------------------|-------------------------------|
| Voltage variation    | PHQVVR                   | PQMU                     | PQMV                          |

### 9.3.2 Function block

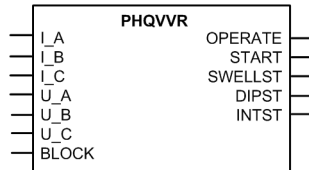


Figure 485: Function block

### 9.3.3 Functionality

The voltage variation function PHQVVR is used for measuring the short-duration voltage variations in distribution networks.

Power quality in the voltage waveform is evaluated by measuring voltage swells, dips and interruptions. PHQVVR includes single-phase and three-phase voltage variation modes.

Typically, short-duration voltage variations are defined to last more than half of the nominal frequency period and less than one minute. The maximum magnitude (in the case of a voltage swell) or depth (in the case of a voltage dip or interruption) and the duration of the variation can be obtained by measuring the RMS value of the voltage for each phase. International standard 61000-4-30 defines the voltage variation to be implemented using the RMS value of the voltage. IEEE standard 1159-1995 provides recommendations for monitoring the electric power quality of the single-phase and polyphase ac power systems.

PHQVVR contains a blocking functionality. It is possible to block a set of function outputs or the function itself, if desired.

### 9.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PHQVVR can be described with a module diagram. All the modules in the diagram are explained in the next sections.



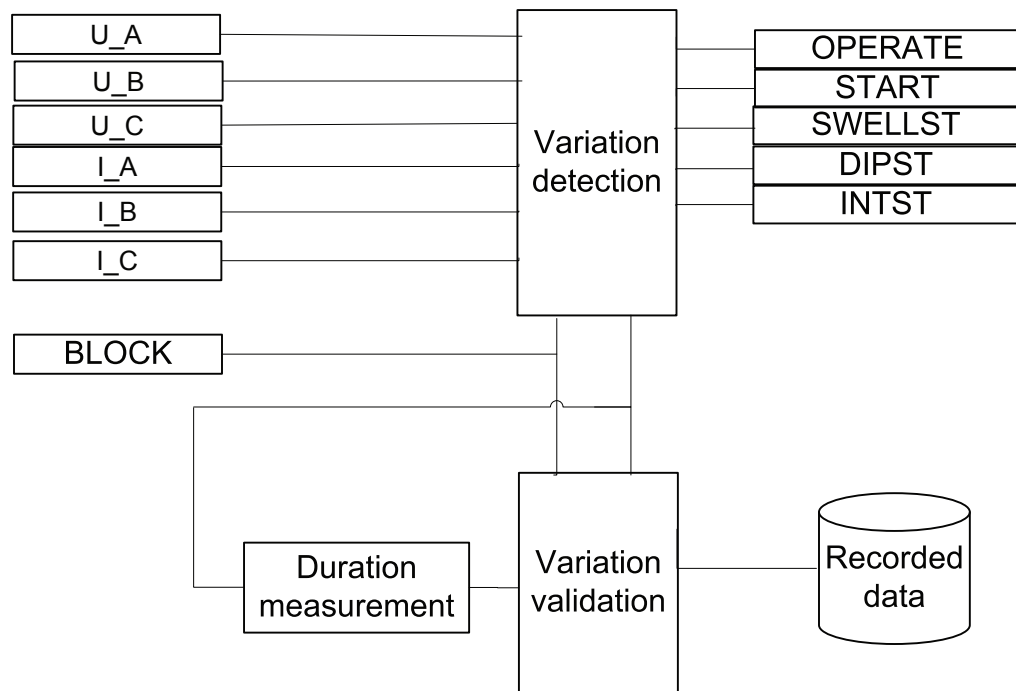


Figure 486: Functional module diagram

### 9.3.4.1 Phase mode setting

PHQVVR is designed for both single-phase and polyphase ac power systems, and selection can be made with the *Phase mode* setting, which can be set either to the "Single Phase" or "Three Phase" mode. The default setting is "Single Phase".

The basic difference between these alternatives depends on how many phases are needed to have the voltage variation activated. When the *Phase mode* setting is "Single Phase", the activation is straightforward. There is no dependence between the phases for variation start. The `START` output and the corresponding phase start are activated when the limit is exceeded or undershot. The corresponding phase start deactivation takes place when the limit (includes small hysteresis) is undershot or exceeded. The `START` output is deactivated when there are no more active phases.

However, when *Phase mode* is "Three Phase", all the monitored phase signal magnitudes, defined with *Phase supervision*, have to fall below or rise above the limit setting to activate the `START` output and the corresponding phase output, that is, all the monitored phases have to be activated. Accordingly, the deactivation occurs when the activation requirement is not fulfilled, that is, one or more monitored phase signal magnitudes return beyond their limits. Phases do not need to be activated by the same variation type to activate the `START` output. Another consequence is that if only one or two phases are monitored, it is sufficient that these monitored phases activate the `START` output.

### 9.3.4.2 Variation detection

The module compares the measured voltage against the limit settings. If there is a permanent undervoltage or overvoltage, the *Reference voltage* setting can be set to this voltage level to avoid the undesired voltage dip or swell indications. This is

accomplished by converting the variation limits with the *Reference voltage* setting in the variation detection module, that is, when there is a voltage different from the nominal voltage, the *Reference voltage* setting is set to this voltage.

The *Variation enable* setting is used for enabling or disabling the variation types. By default, the setting value is "Swell+dip+Int" and all the alternative variation types are indicated. For example, for setting "Swell+dip", the interruption detection is not active and only swell or dip events are indicated.

In a case where *Phase mode* is "Single Phase" and the dip functionality is available, the output `DIPST` is activated when the measured TRMS value drops below the *Voltage dip set 3* setting in one phase and also remains above the *Voltage Int set* setting. If the voltage drops below the *Voltage Int set* setting, the output `INTST` is activated. `INTST` is deactivated when the voltage value rises above the setting *Voltage Int set*. When the same measured TRMS magnitude rises above the setting *Voltage swell set 3*, the `SWELLST` output is activated.

There are three setting value limits for dip (*Voltage dip set 1..3*) and swell activation (*Voltage swell set 1..3*) and one setting value limit for interruption.



If *Phase mode* is "Three Phase", the `DIPST` and `INTST` outputs are activated when the voltage levels of all monitored phases, defined with the parameter *Phase supervision*, drop below the *Voltage Int set* setting value. An example for the detection principle of voltage interruption for "Three Phase" when *Phase supervision* is "Ph A + B + C", and also the corresponding start signals when *Phase mode* is "Single Phase", are as shown in the example for the detection of a three-phase interruption.

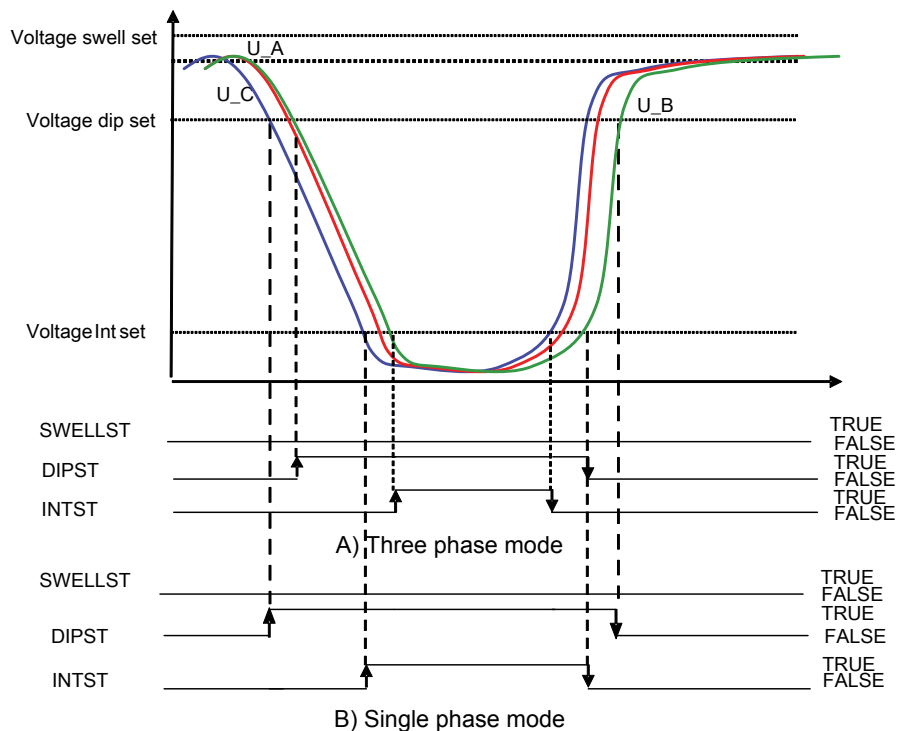


Figure 487: Detection of three-phase voltage interruption

The module measures voltage variation magnitude on each phase separately, that is, there are phase-segregated outputs `ST_A`, `ST_B` and `ST_C` for voltage variation indication. The configuration parameter *Phase supervision* defines which voltage

phase or phases are monitored. If a voltage phase is selected to be monitored, the function assumes it to be connected to a voltage measurement channel. In other words, if an unconnected phase is monitored, the function falsely detects a voltage interruption in that phase.

The maximum magnitude and depth are defined as percentage values calculated from the difference between the reference and the measured voltage. For example, a dip to 70 percent means that the minimum voltage dip magnitude variation is 70 percent of the reference voltage amplitude.

The activation of the `BLOCK` input resets the function and outputs.

### 9.3.4.3 Variation validation

The validation criterion for voltage variation is that the measured total variation duration is between the set minimum and maximum durations (Either one of *VVa dip time 1*, *VVa swell time 1* or *VVa Int time 1*, depending on the variation type, and *VVa Dur Max*). The maximum variation duration setting is the same for all variation types.

*Figure 488* shows voltage dip operational regions. In *Figure 487*, only one voltage dip/swell/Int set is drawn, whereas in this figure there are three sub-limits for the dip operation. When *Voltage dip set 3* is undershot, the corresponding `ST_x` and also the `DIPST` outputs are activated. When the TRMS voltage magnitude remains between *Voltage dip set 2* and *Voltage dip set 1* for a period longer than *VVa dip time 2* (shorter time than *VVa dip time 3*), a momentary dip event is detected. Furthermore, if the signal magnitude stays between the limits longer than *VVa dip time 3* (shorter time than *VVa Dur max*), a temporary dip event is detected. If the voltage remains below *Voltage dip set 1* for a period longer than *VVa dip time 1* but a shorter time than *VVa dip time 2*, an instantaneous dip event is detected.

For an event detection, the `OPERATE` output is always activated for one task cycle. The corresponding counter and only one of them (`INSTDIPCNT`, `MOMDIPCNT` or `TEMPDIPCNT`) is increased by one. If the dip limit undershooting duration is shorter than *VVa dip time 1*, *VVa swell time 1* or *VVa Int time 1*, the event is not detected at all, and if the duration is longer than *VVa Dur Max*, `MAXDURDIPCNT` is increased by one but no event detection resulting in the activation of the `OPERATE` output and recording data update takes place. These counters are available through the monitored data view on the WHMI or through tools via communications. There are no phase-segregated counters but all the variation detections are registered to a common time/magnitude-classified counter type. Consequently, a simultaneous multiphase event, that is, the variation-type event detection time moment is exactly the same for two or more phases, is counted only once also for single-phase power systems.

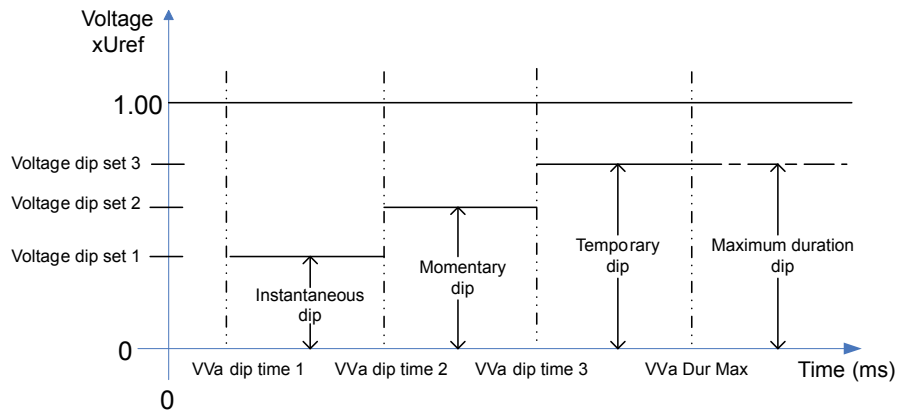


Figure 488: Voltage dip operational regions

In [Figure 489](#), the corresponding limits regarding the swell operation are provided with the inherent magnitude limit order difference. The swell functionality principle is the same as for dips, but the different limits for the signal magnitude and times and the inherent operating zone change (here, *Voltage swell set x* > 1.0 xUn) are applied.

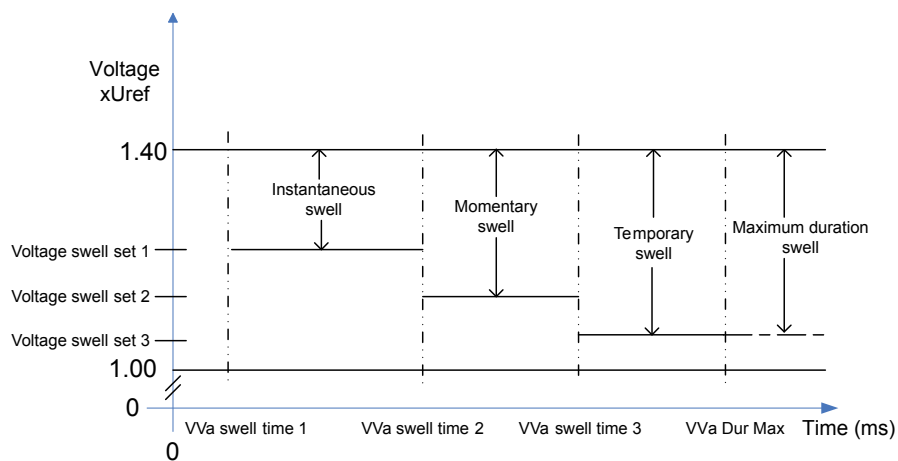


Figure 489: Voltage swell operational regions

For interruption, as shown in [Figure 490](#), there is only one magnitude limit but four duration limits for interruption classification. Now the event and counter type depends only on variation duration time.

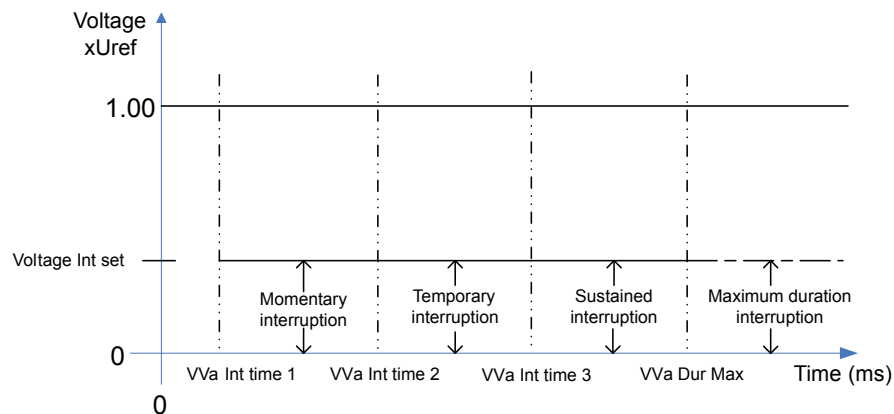


Figure 490: Interruption operating regions

Generally, no event detection is done if both the magnitude and duration requirements are not fulfilled. For example, the dip event does not indicate if the TRMS voltage magnitude remains between *Voltage dip set 3* and *Voltage dip set 2* for a period shorter than *VVa dip time 3* before rising back above *Voltage dip set 3*.

The event indication ends and possible detection is done when the TRMS voltage returns above (for dip and interruption) or below (for swell) the activation-starting limit. For example, after an instantaneous dip, the event indication when the voltage magnitude exceeds *Voltage dip set 1* is not detected (and recorded) immediately but only if no longer dip indication for the same dip variation takes place and maximum duration time for dip variation does not exceed before the signal magnitude rises above *Voltage dip set 3*. There is a small hysteresis for all these limits to avoid the oscillation of the output activation. No drop-off approach is applied here due to the hysteresis.

Consequently, only one event detection and recording of the same variation type can take place for one voltage variation, so the longest indicated variation of each variation type is detected. Furthermore, it is possible that another instantaneous dip event replaces the one already indicated if the magnitude again undershoots *Voltage dip set 1* for the set time after the first detection and the signal magnitude or time requirement is again fulfilled. Another possibility is that if the time condition is not fulfilled for an instantaneous dip detection but the signal rises above *Voltage dip set 1*, the already elapsed time is included in the momentary dip timer. Especially the interruption time is included in the dip time. If the signal does not exceed *Voltage dip set 2* before the timer *VVa dip time 2* has elapsed when the momentary dip timer is also started after the magnitude undershooting *Voltage dip set 2*, the momentary dip event instead is detected. Consequently, the same dip occurrence with a changing variation depth can result in several dip event indications but only one detection. For example, if the magnitude has undershot *Voltage dip set 1* but remained above *Voltage Intr set* for a shorter time than the value of *VVa dip time 1* but the signal rises between *Voltage dip set 1* and *Voltage dip set 2* so that the total duration of the dip activation is longer than *VVa dip time 2* and the maximum time is not overshoot, this is detected as a momentary dip even though a short instantaneous dip period has been included. In text, the terms "deeper" and "higher" are used for referring to dip or interruption.

Although examples are given for dip events, the same rules can be applied to the swell and interruption functionality too. For swell indication, "deeper" means that the signal rises even more and "higher" means that the signal magnitude becomes lower respectively.

The adjustable voltage thresholds adhere to the relationships:

$$V_{Va} \text{ dip time } 1 \leq V_{Va} \text{ dip time } 2 \leq V_{Va} \text{ dip time } 3.$$

$$V_{Va} \text{ swell time } 1 \leq V_{Va} \text{ swell time } 2 \leq V_{Va} \text{ swell time } 3.$$

$$V_{Va} \text{ Int time } 1 \leq V_{Va} \text{ Int time } 2 \leq V_{Va} \text{ Int time } 3.$$

There is a validation functionality built-in function that checks the relationship adherence so that if  $V_{Va} \times \text{time } 1$  is set higher than  $V_{Va} \times \text{time } 2$  or  $V_{Va} \times \text{time } 3$ ,  $V_{Va} \times \text{time } 2$  and  $V_{Va} \times \text{time } 3$  are set equal to the new  $V_{Va} \times \text{time } 1$ . If  $V_{Va} \times \text{time } 2$  is set higher than  $V_{Va} \times \text{time } 3$ ,  $V_{Va} \times \text{time } 3$  is set to the new  $V_{Va} \times \text{time } 2$ . If  $V_{Va} \times \text{time } 2$  is set lower than  $V_{Va} \times \text{time } 1$ , the entered  $V_{Va} \times \text{time } 2$  is rejected. If  $V_{Va} \times \text{time } 3$  is set lower than  $V_{Va} \times \text{time } 2$ , the entered  $V_{Va} \times \text{time } 3$  is rejected.

#### 9.3.4.4 Duration measurement

The duration of each voltage phase corresponds to the period during which the measured TRMS values remain above (swell) or below (dip, interruption) the corresponding limit.

Besides the three limit settings for the variation types dip and swell, there is also a specific duration setting for each limit setting. For interruption, there is only one limit setting common for the three duration settings. The maximum duration setting is common for all variation types.

The duration measurement module measures the voltage variation duration of each phase voltage separately when the *Phase mode* setting is "Single Phase". The phase variation durations are independent. However, when the *Phase mode* setting is "Three Phase", voltage variation may start only when all the monitored phases are active. An example of variation duration when *Phase mode* is "Single Phase" can be seen in [Figure 491](#). The voltage variation in the example is detected as an interruption for the phase B and a dip for the phase A, and also the variation durations are interpreted as independent  $U_B$  and  $U_A$  durations. In case of single-phase interruption, the  $DIPST$  output is active when either  $ST_A$  or  $ST_B$  is active. The measured variation durations are the times measured between the activation of the  $ST_A$  or  $ST_B$  outputs and deactivation of the  $ST_A$  or  $ST_B$  outputs. When the *Phase mode* setting is "Three Phase", the example case does not result in any activation.

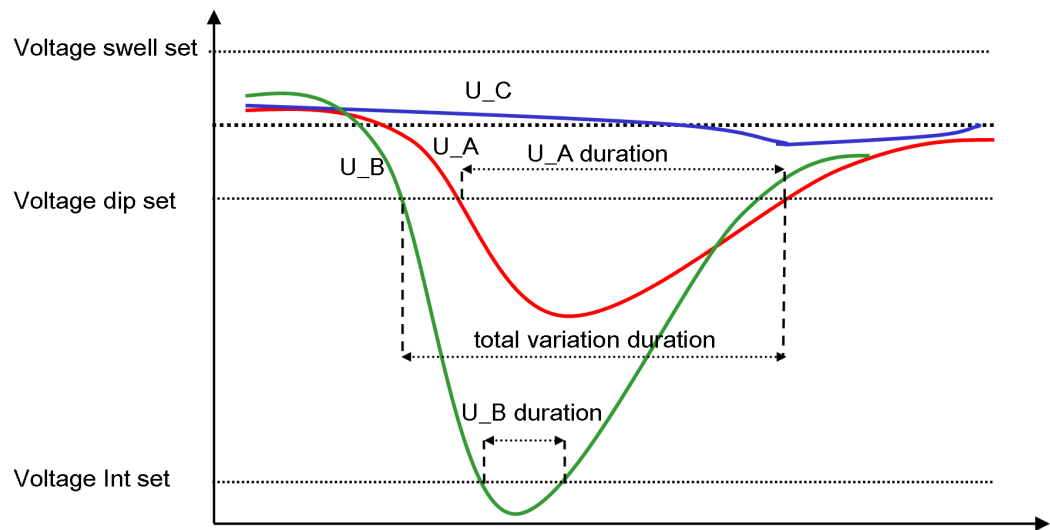


Figure 491: Single-phase interruption for the Phase mode value "Single Phase"

### 9.3.4.5 Three/single-phase selection variation examples

The provided rules always apply for single-phase (*Phase Mode* is "Single Phase") power systems. However, for three-phase power systems (where *Phase Mode* is "Three Phase"), it is required that all the phases have to be activated before the activation of the `START` output. Interruption event indication requires all three phases to undershoot *Voltage Int set* simultaneously, as shown in [Figure 487](#). When the requirement for interruption for "Three Phase" is no longer fulfilled, variation is indicated as a dip as long as all phases are active.

In case of a single-phase interruption of [Chapter 9.3.4.4 Duration measurement](#), when there is a dip indicated in another phase but the third phase is not active, there is no variation indication start when *Phase Mode* is "Three Phase". In this case, only the *Phase Mode* value "Single Phase" results in the `ST_B` interruption and the `ST_A` dip.

It is also possible that there are simultaneously a dip in one phase and a swell in other phases. The functionality of the corresponding event indication with one inactive phase is shown in [Chapter 9.3.4.5 Three/single-phase selection variation examples](#). Here, the "Swell + dip" variation type of *Phase mode* is "Single Phase". For the selection "Three Phase" of *Phase mode*, no event indication or any activation takes place due to a non-active phase.

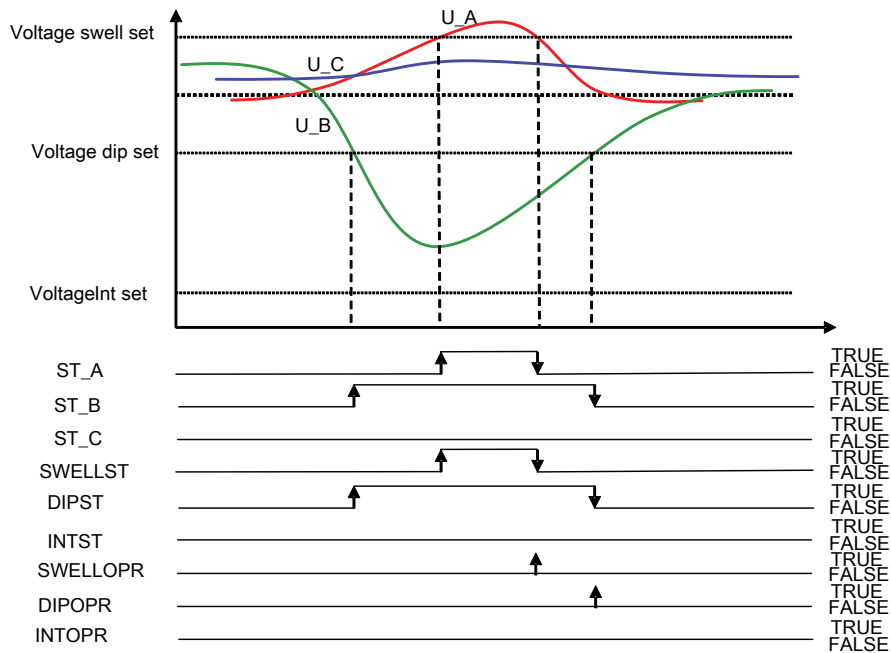


Figure 492: Concurrent dip and swell when Phase mode is "Single Phase"

In [Figure 493](#), one phase is in dip and two phases have a swell indication. For the *Phase Mode* value "Three Phase", the activation occurs only when all the phases are active. Furthermore, both swell and dip variation event detections take place simultaneously. In case of a concurrent voltage dip and voltage swell, both SWELLCNT and DIPCNT are incremented by one.

Also [Figure 493](#) shows that for the *Phase Mode* value "Three Phase", two different time moment variation event swell detections take place and, consequently, DIPCNT is incremented by one but SWELLCNT is totally incremented by two. Both in [Figure 492](#) and [Figure 493](#) it is assumed that variation durations are sufficient for detections to take place.



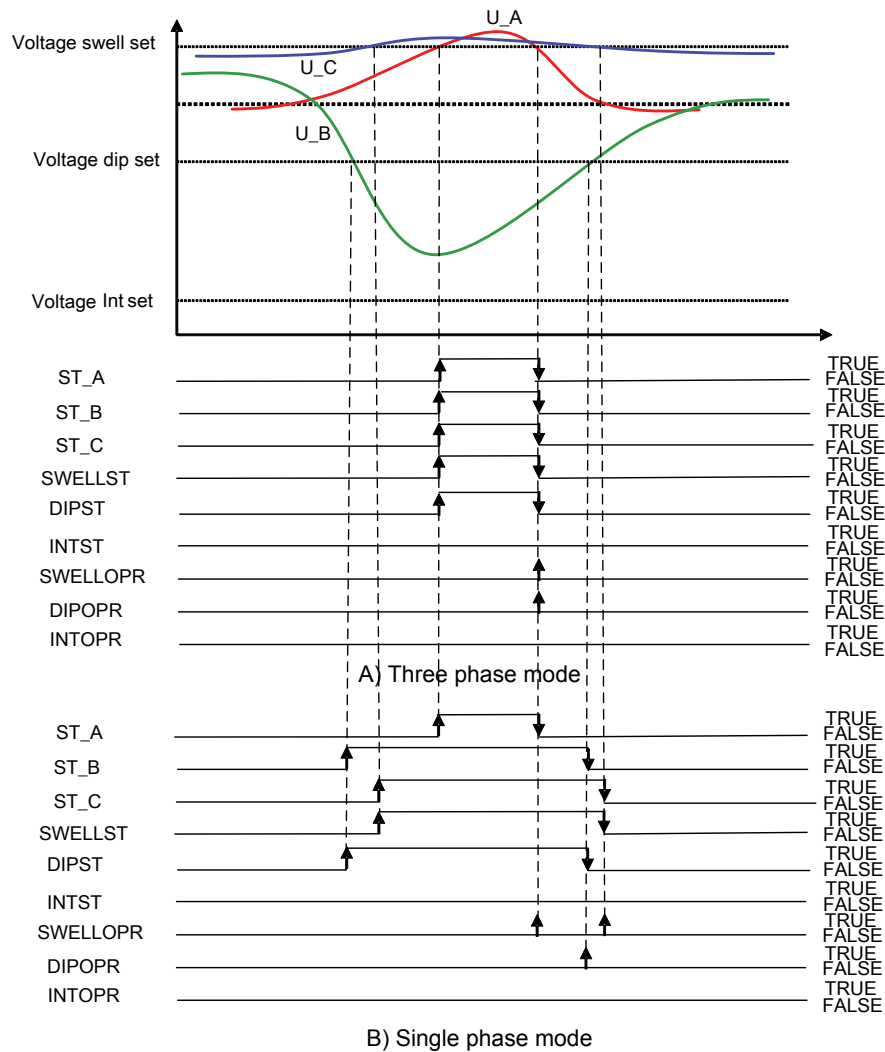


Figure 493: Concurrent dip and two-phase swell

### 9.3.5 Recorded data

Besides counter increments, the information required for a later fault analysis is stored after a valid voltage variation is detected.

#### Recorded data information

When voltage variation starts, the phase current magnitudes preceding the activation moment are stored. Also, the initial voltage magnitudes are temporarily stored at the variation starting moment. If the variation is, for example, a two-phase voltage dip, the voltage magnitude of the non-active phase is stored from this same moment, as shown in Figure 494. The function tracks each variation-active voltage phase, and the minimum or maximum magnitude corresponding to swell or dip/interruption during variation is temporarily stored. If the minimum or maximum is found in tracking and a new magnitude is stored, also the inactive phase voltages are stored at the same moment, that is, the inactive phases are not magnitude-tracked. The time instant (time stamp) at which the minimum or

maximum magnitude is measured is also temporarily stored for each voltage phase where variation is active. Finally, variation detection triggers the recorded data update when the variation activation ends and the maximum duration time is not exceeded.

The data objects to be recorded for PHQVVR are given in [Table 866](#). There are totally three data banks, and the information given in the table refers to one data bank content.

The three sets of recorded data available are saved in data banks 1-3. The data bank 1 holds always the most recent recorded data, and the older data sets are moved to the next banks (1→2 and 2→3) when a valid voltage variation is detected. When all three banks have data and a new variation is detected, the newest data are placed into bank 1 and the data in bank 3 are overwritten by the data from bank 2.

[Figure 494](#) shows a valid recorded voltage interruption and two dips for the *Phase mode* value "Single Phase". The first dip event duration is based on the  $U_A$  duration, while the second dip is based on the time difference between the dip stop and start times. The first detected event is an interruption based on the  $U_B$  duration given in [Figure 494](#). It is shown also with dotted arrows how voltage time stamps are taken before the final time stamp for recording, which is shown as a solid arrow. Here, the  $U_B$  timestamp is not taken when the  $U_A$  activation starts.

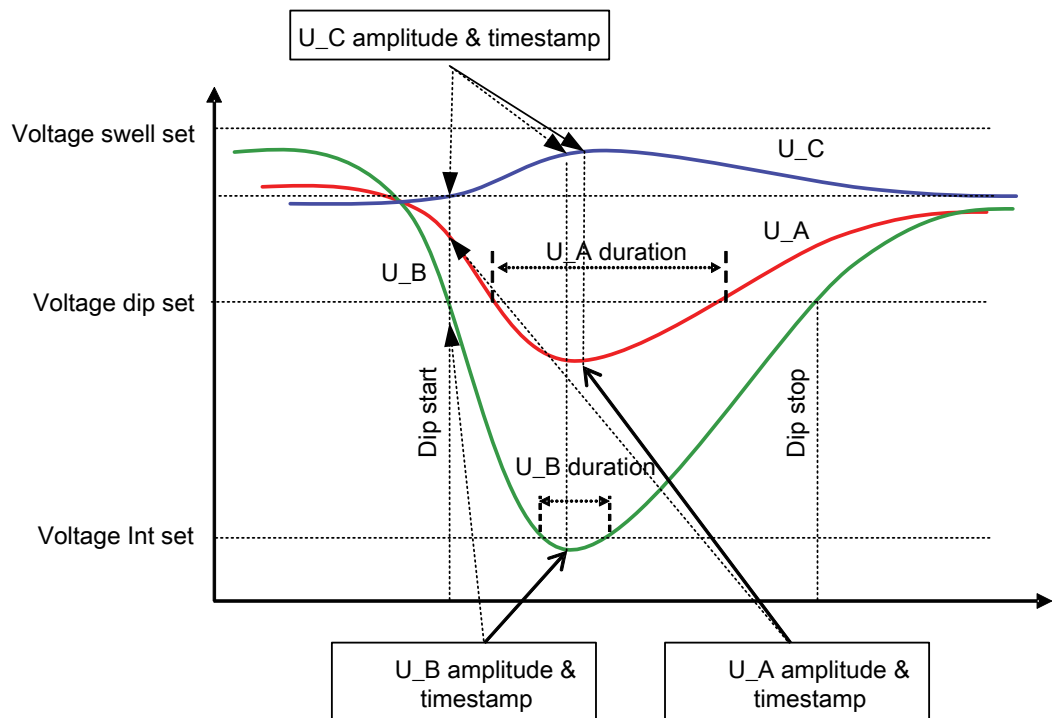


Figure 494: Valid recorded voltage interruption and two dips

Table 866: PHQVVR recording data bank parameters

| Parameter description                 | Parameter name |
|---------------------------------------|----------------|
| Event detection triggering time stamp | Time           |
| Variation type                        | Variation type |
| Variation magnitude Ph A              | Variation Ph A |

Table continues on the next page

| Parameter description  | Parameter name     |
|--|--------------------|
| Variation magnitude Ph A time stamp (maximum/minimum magnitude measuring time moment during variation) | Var Ph A rec time  |
| Variation magnitude Ph B   | Variation Ph B     |
| Variation magnitude Ph B time stamp (maximum/minimum magnitude measuring time moment during variation) | Var Ph B rec time  |
| Variation magnitude Ph C   | Variation Ph C     |
| Variation magnitude Ph C time stamp (maximum/minimum magnitude measuring time moment during variation) | Var Ph C rec time  |
| Variation duration Ph A  | Variation Dur Ph A |
| Variation Ph A start time stamp (phase A variation start time moment)                                  | Var Dur Ph A time  |
| Variation duration Ph B  | Variation Dur Ph B |
| Variation Ph B start time stamp (phase B variation start time moment)                                  | Var Dur Ph B time  |
| Variation duration Ph C  | Variation Dur Ph C |
| Variation Ph C start time stamp (phase C variation start time moment)                                  | Var Dur Ph C time  |
| Current magnitude Ph A preceding variation   | Var current Ph A   |
| Current magnitude Ph B preceding variation   | Var current Ph B   |
| Current magnitude Ph C preceding variation   | Var current Ph C   |

**Table 867: Enumeration values for the recorded data parameters**

| Setting name   | Enum name     | Value |
|----------------|---------------|-------|
| Variation type | Swell         | 1     |
| Variation type | Dip           | 2     |
| Variation type | Swell + dip   | 3     |
| Variation type | Interruption  | 4     |
| Variation type | Swell + Int   | 5     |
| Variation type | Dip + Int     | 6     |
| Variation type | Swell+dip+Int | 7     |

### 9.3.6 Application

Voltage variations are the most typical power quality variations on the public electric network. Typically, short-duration voltage variations are defined to last more than half of the nominal frequency period and less than one minute (European Standard EN 50160 and IEEE Std 1159-1995).

These short-duration voltage variations are almost always caused by a fault condition. Depending on where the fault is located, it can cause either a temporary

voltage rise (swell) or voltage drop (dip). A special case of voltage drop is the complete loss of voltage (interruption).

PHQVVR is used for measuring short-duration voltage variations in distribution networks. The power quality is evaluated in the voltage waveform by measuring the voltage swells, dips and interruptions.

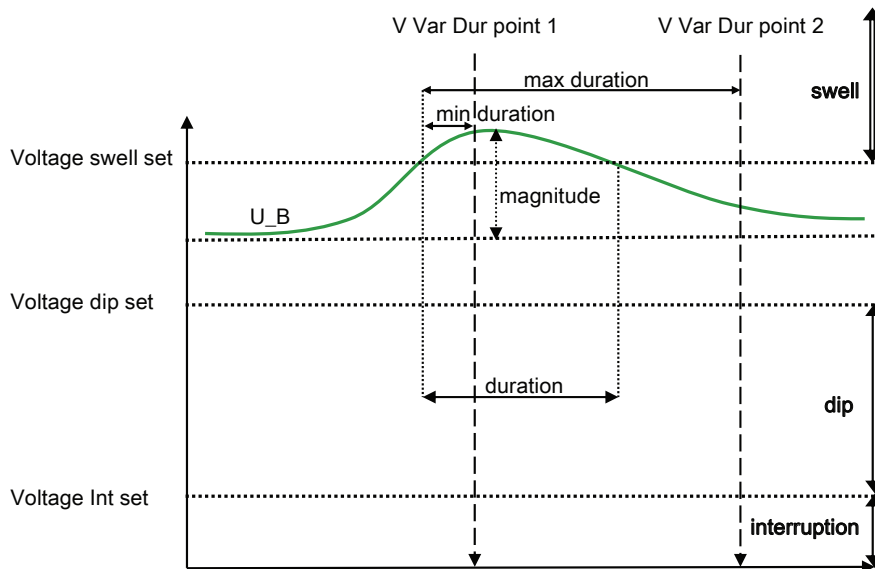


Figure 495: Duration and voltage magnitude limits for swell, dip and interruption measurement

Voltage dips disturb the sensitive equipment such as computers connected to the power system and may result in the failure of the equipment. Voltage dips are typically caused by faults occurring in the power distribution system. Typical reasons for the faults are lightning strikes and tree contacts. In addition to fault situations, the switching of heavy loads and starting of large motors also cause dips.

Voltage swells cause extra stress for the network components and the devices connected to the power system. Voltage swells are typically caused by the earth faults that occur in the power distribution system.

Voltage interruptions are typically associated with the switchgear operation related to the occurrence and termination of short circuits. The operation of a circuit breaker disconnects a part of the system from the source of energy. In the case of overhead networks, automatic reclosing sequences are often applied to the circuit breakers that interrupt fault currents. All these actions result in a sudden reduction of voltages on all voltage phases.

Due to the nature of voltage variations, the power quality standards do not specify any acceptance limits. There are only indicative values for, for example, voltage dips in the European standard EN 50160. However, the power quality standards like the international standard IEC 61000-4-30 specify that the voltage variation event is characterized by its duration and magnitude. Furthermore, IEEE Std 1159-1995 gives the recommended practice for monitoring the electric power quality.

Voltage variation measurement can be done to the phase-to-earth and phase-to-phase voltages. The power quality standards do not specify whether the measurement should be done to phase or phase-to-phase voltages. However, in

some cases it is preferable to use phase-to-earth voltages for measurement. The measurement mode is always TRMS.

## 9.3.7 Signals

### 9.3.7.1 PHQVVR Input signals

Table 868: PHQVVR Input signals

| Name  | Type    | Default | Description                                   |
|-------|---------|---------|---|
| I_A   | SIGNAL  | 0       | Phase A current magnitude                     |
| I_B   | SIGNAL  | 0       | Phase B current magnitude                     |
| I_C   | SIGNAL  | 0       | Phase C current magnitude                     |
| U_A   | SIGNAL  | 0       | Phase-to-earth voltage A                      |
| U_B   | SIGNAL  | 0       | Phase-to-earth voltage B                      |
| U_C   | SIGNAL  | 0       | Phase-to-earth voltage C                      |
| BLOCK | BOOLEAN | 0=False | Block signal for activating the blocking mode |

### 9.3.7.2 PHQVVR Output signals

Table 869: PHQVVR Output signals

| Name    | Type    | Description                 |
|---------|---------|-----------------------------|
| OPERATE | BOOLEAN | Voltage variation detected  |
| START   | BOOLEAN | Voltage variation present   |
| SWELLST | BOOLEAN | Voltage swell active        |
| DIPST   | BOOLEAN | Voltage dip active          |
| INTST   | BOOLEAN | Voltage interruption active |

## 9.3.8 Settings

### 9.3.8.1 PHQVVR Settings

**Table 870: PHQVVR Group settings (Basic)**

| Parameter           | Values (Range) | Unit   | Step | Default | Description                                  |
|---------------------|----------------|--------|------|---------|--|
| Reference voltage   | 10.0...200.0   | %Un    | 0.1  | 57.7    | Reference supply voltage in %                |
| Voltage dip set 1   | 10.0...100.0   | %      | 0.1  | 80.0    | Dip limit 1 in % of reference voltage        |
| VVa dip time 1      | 0.5...54.0     | cycles | 0.1  | 3.0     | Voltage variation dip duration 1             |
| Voltage dip set 2   | 10.0...100.0   | %      | 0.1  | 80.0    | Dip limit 2 in % of reference voltage        |
| VVa dip time 2      | 10.0...180.0   | cycles | 0.1  | 30.0    | Voltage variation dip duration 2             |
| Voltage dip set 3   | 10.0...100.0   | %      | 0.1  | 80.0    | Dip limit 3 in % of reference voltage        |
| VVa dip time 3      | 2000...60000   | ms     | 10   | 3000    | Voltage variation dip duration 3             |
| Voltage swell set 1 | 100.0...140.0  | %      | 0.1  | 120.0   | Swell limit 1 in % of reference voltage      |
| VVa swell time 1    | 0.5...54.0     | cycles | 0.1  | 0.5     | Voltage variation swell duration 1           |
| Voltage swell set 2 | 100.0...140.0  | %      | 0.1  | 120.0   | Swell limit 2 in % of reference voltage      |
| VVa swell time 2    | 10.0...80.0    | cycles | 0.1  | 10.0    | Voltage variation swell duration 2           |
| Voltage swell set 3 | 100.0...140.0  | %      | 0.1  | 120.0   | Swell limit 3 in % of reference voltage      |
| VVa swell time 3    | 2000...60000   | ms     | 10   | 2000    | Voltage variation swell duration 3           |
| Voltage Int set     | 0.0...100.0    | %      | 0.1  | 10.0    | Interruption limit in % of reference voltage |

*Table continues on the next page*

| Parameter      | Values (Range) | Unit   | Step | Default | Description                               |
|----------------|----------------|--------|------|---------|---|
| VVa Int time 1 | 0.5...30.0     | cycles | 0.1  | 3.0     | Voltage variation Int duration 1          |
| VVa Int time 2 | 10.0...180.0   | cycles | 0.1  | 30.0    | Voltage variation Int duration 2          |
| VVa Int time 3 | 2000...60000   | ms     | 10   | 3000    | Voltage variation interruption duration 3 |
| VVa Dur Max    | 100...3600000  | ms     | 100  | 60000   | Maximum voltage variation duration        |

Table 871: PHQVVR Non group settings (Basic)

| Parameter        | Values (Range)   | Unit | Step | Default         | Description           |
|------------------|--|------|------|-----------------|-----------------------|
| Operation        | 1=on<br>5=off  |      |      | 1=on            | Operation Off / On    |
| Variation enable | 1=Swell<br>2=Dip<br>3=Swell + dip<br>4=Interruption<br>5=Swell + Int<br>6=Dip + Int<br>7=Swell+dip+Int |      |      | 7=Swell+dip+Int | Enable variation type |

Table 872: PHQVVR Non group settings (Advanced)

| Parameter         | Values (Range)   | Unit | Step | Default        | Description             |
|-------------------|--|------|------|----------------|-------------------------|
| Phase supervision | 1=Ph A<br>2=Ph B<br>3=Ph A + B<br>4=Ph C<br>5=Ph A + C<br>6=Ph B + C |      |      | 7=Ph A + B + C | Monitored voltage phase |

*Table continues on the next page*

| Parameter  | Values (Range)                  | Unit | Step | Default        | Description             |
|------------|---------------------------------|------|------|----------------|-------------------------|
|            | 7=Ph A + B + C                  |      |      |                |                         |
| Phase mode | 1=Three Phase<br>2=Single Phase |      |      | 2=Single Phase | Three/Single phase mode |

## 9.3.9 Monitored data

### 9.3.9.1 PHQVVR Monitored data

Table 873: PHQVVR Monitored data

| Name            | Type    | Values (Range)    | Unit | Description   |
|-----------------|---------|-------------------|------|---|
| ST_A            | BOOLEAN | 0=False<br>1=True |      | Start Phase A (Voltage Variation Event in progress) |
| ST_B            | BOOLEAN | 0=False<br>1=True |      | Start Phase B (Voltage Variation Event in progress) |
| ST_C            | BOOLEAN | 0=False<br>1=True |      | Start Phase C (Voltage Variation Event in progress) |
| INSTSWELLCNT    | INT32   | 0...2147483647    |      | Instantaneous swell operation counter               |
| MOMSWELLCNT     | INT32   | 0...2147483647    |      | Momentary swell operation counter                   |
| TEMPSWELLCNT    | INT32   | 0...2147483647    |      | Temporary swell operation counter                   |
| MAXDURS-WELLCNT | INT32   | 0...2147483647    |      | Maximum duration swell operation counter            |
| INSTDIPCNT      | INT32   | 0...2147483647    |      | Instantaneous dip operation counter                 |
| MOMDIPCNT       | INT32   | 0...2147483647    |      | Momentary dip operation counter                     |

Table continues on the next page



| Name              | Type      | Values (Range)   | Unit | Description                                     |
|-------------------|-----------|--|------|---|
| TEMPDIPCNT        | INT32     | 0...2147483647   |      | Temporary dip operation counter                 |
| MAXDURDIPCNT      | INT32     | 0...2147483647   |      | Maximum duration dip operation counter          |
| MOMINTCNT         | INT32     | 0...2147483647   |      | Momentary interruption operation counter        |
| TEMPINTCNT        | INT32     | 0...2147483647   |      | Temporary interruption operation counter        |
| SUSTINTCNT        | INT32     | 0...2147483647   |      | Sustained interruption operation counter        |
| MAXDURINTCNT      | INT32     | 0...2147483647   |      | Maximum duration interruption operation counter |
| PHQVVR            | Enum      | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off   |      | Status  |
| Time              | Timestamp |  |      | Time  |
| Variation type    | Enum      | 0=No variation<br>1=Swell<br>2=Dip<br>3=Swell + dip<br>4=Interruption<br>5=Swell + Int<br>6=Dip + Int<br>7=Swell+dip+Int |      | Variation type                                  |
| Variation Ph A    | FLOAT32   | 0.00...5.00  | xUn  | Variation magnitude Phase A                     |
| Var Ph A rec time | Timestamp |  |      | Variation magnitude Phase A time stamp          |
| Variation Ph B    | FLOAT32   | 0.00...5.00  | xUn  | Variation magnitude Phase B                     |

*Table continues on the next page*

| Name               | Type      | Values (Range)   | Unit | Description                                   |
|--------------------|-----------|--|------|---|
| Var Ph B rec time  | Timestamp |  |      | Variation magnitude Phase B time stamp        |
| Variation Ph C     | FLOAT32   | 0.00...5.00  | xUn  | Variation magnitude Phase C                   |
| Var Ph C rec time  | Timestamp |  |      | Variation magnitude Phase C time stamp        |
| Variation Dur Ph A | FLOAT32   | 0.000...3600.000   | s    | Variation duration Phase A                    |
| Var Dur Ph A time  | Timestamp |  |      | Variation Ph A start time stamp               |
| Variation Dur Ph B | FLOAT32   | 0.000...3600.000   | s    | Variation duration Phase B                    |
| Var Dur Ph B time  | Timestamp |  |      | Variation Ph B start time stamp               |
| Variation Dur Ph C | FLOAT32   | 0.000...3600.000   | s    | Variation duration Phase C                    |
| Var Dur Ph C time  | Timestamp |  |      | Variation Ph C start time stamp               |
| Var current Ph A   | FLOAT32   | 0.00...60.00   | xIn  | Current magnitude Phase A preceding variation |
| Var current Ph B   | FLOAT32   | 0.00...60.00   | xIn  | Current magnitude Phase B preceding variation |
| Var current Ph C   | FLOAT32   | 0.00...60.00   | xIn  | Current magnitude Phase C preceding variation |
| Time               | Timestamp |  |      | Time  |
| Variation type     | Enum      | 0=No variation<br>1=Swell<br>2=Dip<br>3=Swell + dip<br>4=Interruption<br>5=Swell + Int<br>6=Dip + Int<br>7=Swell+dip+Int |      | Variation type                                |
| Variation Ph A     | FLOAT32   | 0.00...5.00  | xUn  | Variation magnitude Phase A                   |

*Table continues on the next page*

| Name               | Type      | Values (Range)   | Unit | Description                                   |
|--------------------|-----------|--|------|---|
| Var Ph A rec time  | Timestamp |  |      | Variation magnitude Phase A time stamp        |
| Variation Ph B     | FLOAT32   | 0.00...5.00  | xUn  | Variation magnitude Phase B                   |
| Var Ph B rec time  | Timestamp |  |      | Variation magnitude Phase B time stamp        |
| Variation Ph C     | FLOAT32   | 0.00...5.00  | xUn  | Variation magnitude Phase C                   |
| Var Ph C rec time  | Timestamp |  |      | Variation magnitude Phase C time stamp        |
| Variation Dur Ph A | FLOAT32   | 0.000...3600.000   | s    | Variation duration Phase A                    |
| Var Dur Ph A time  | Timestamp |  |      | Variation Ph A start time stamp               |
| Variation Dur Ph B | FLOAT32   | 0.000...3600.000   | s    | Variation duration Phase B                    |
| Var Dur Ph B time  | Timestamp |  |      | Variation Ph B start time stamp               |
| Variation Dur Ph C | FLOAT32   | 0.000...3600.000   | s    | Variation duration Phase C                    |
| Var Dur Ph C time  | Timestamp |  |      | Variation Ph C start time stamp               |
| Var current Ph A   | FLOAT32   | 0.00...60.00   | xIn  | Current magnitude Phase A preceding variation |
| Var current Ph B   | FLOAT32   | 0.00...60.00   | xIn  | Current magnitude Phase B preceding variation |
| Var current Ph C   | FLOAT32   | 0.00...60.00   | xIn  | Current magnitude Phase C preceding variation |
| Time               | Timestamp |  |      | Time  |
| Variation type     | Enum      | 0=No variation<br>1=Swell<br>2=Dip<br>3=Swell + dip<br>4=Interruption<br>5=Swell + Int |      | Variation type                                |

*Table continues on the next page*

| Name               | Type      | Values (Range)                 | Unit | Description                                   |
|--------------------|-----------|--------------------------------|------|---|
|                    |           | 6=Dip + Int<br>7=Swell+dip+Int |      |   |
| Variation Ph A     | FLOAT32   | 0.00...5.00                    | xUn  | Variation magnitude Phase A                   |
| Var Ph A rec time  | Timestamp |                                |      | Variation magnitude Phase A time stamp        |
| Variation Ph B     | FLOAT32   | 0.00...5.00                    | xUn  | Variation magnitude Phase B                   |
| Var Ph B rec time  | Timestamp |                                |      | Variation magnitude Phase B time stamp        |
| Variation Ph C     | FLOAT32   | 0.00...5.00                    | xUn  | Variation magnitude Phase C                   |
| Var Ph C rec time  | Timestamp |                                |      | Variation magnitude Phase C time stamp        |
| Variation Dur Ph A | FLOAT32   | 0.000...3600.000               | s    | Variation duration Phase A                    |
| Var Dur Ph A time  | Timestamp |                                |      | Variation Ph A start time stamp               |
| Variation Dur Ph B | FLOAT32   | 0.000...3600.000               | s    | Variation duration Phase B                    |
| Var Dur Ph B time  | Timestamp |                                |      | Variation Ph B start time stamp               |
| Variation Dur Ph C | FLOAT32   | 0.000...3600.000               | s    | Variation duration Phase C                    |
| Var Dur Ph C time  | Timestamp |                                |      | Variation Ph C start time stamp               |
| Var current Ph A   | FLOAT32   | 0.00...60.00                   | xIn  | Current magnitude Phase A preceding variation |
| Var current Ph B   | FLOAT32   | 0.00...60.00                   | xIn  | Current magnitude Phase B preceding variation |
| Var current Ph C   | FLOAT32   | 0.00...60.00                   | xIn  | Current magnitude Phase C preceding variation |

### 9.3.10 Technical data

Table 874: PHQVVR Technical data

| Characteristic     | Value  |
|--------------------|--|
| Operation accuracy | ±1.5% of the set value or ±0.2% of reference voltage |
| Reset ratio        | Typically 0.96 (Swell), 1.04 (Dip, Interruption)     |

### 9.3.11 Technical revision history

Table 875: PHQVVR Technical revision history

| Technical revision | Change                |
|--------------------|-----------------------|
| B                  | Internal improvement. |
| C                  | Internal improvement. |
| D                  | Internal improvement. |

## 9.4 Voltage unbalance VSQVUB

### 9.4.1 Identification

| Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number |
|----------------------|--------------------------|--------------------------|-------------------------------|
| Voltage unbalance    | VSQVUB                   | PQUUB                    | PQVUB                         |

### 9.4.2 Function block

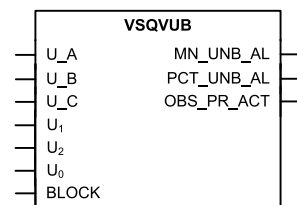


Figure 496: Function block

### 9.4.3 Functionality

The voltage unbalance function VSQVUB monitors voltage unbalance conditions in power transmission and distribution networks. It can be applied to identify a network and load unbalance that can cause sustained voltage unbalance. VSQVUB is also used to monitor the commitment of the power supply utility of providing a high-quality, that is, a balanced voltage supply on a continuous basis.

VSQVUB uses five different methods for calculating voltage unbalance. The methods are negative-sequence voltage magnitude, zero-sequence voltage magnitude, ratio of the negative-sequence voltage magnitude to the positive-sequence voltage magnitude, ratio of the zero-sequence voltage magnitude to the positive-sequence voltage magnitude and ratio of maximum phase voltage magnitude deviation from the mean voltage magnitude to the mean of the phase voltage magnitude.

VSQVUB provides statistics which can be used to verify the compliance of the power quality with the European standard EN 50160 (2000). The statistics over selected period include a freely selectable percentile for unbalance. VSQVUB also includes an alarm functionality providing a maximum unbalance value and the date and time of occurrence.

VSQVUB contains a blocking functionality. It is possible to block a set of function outputs or the function itself, if desired.

### 9.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of VSQVUB can be described with a module diagram. All the modules in the diagram are explained in the next sections.

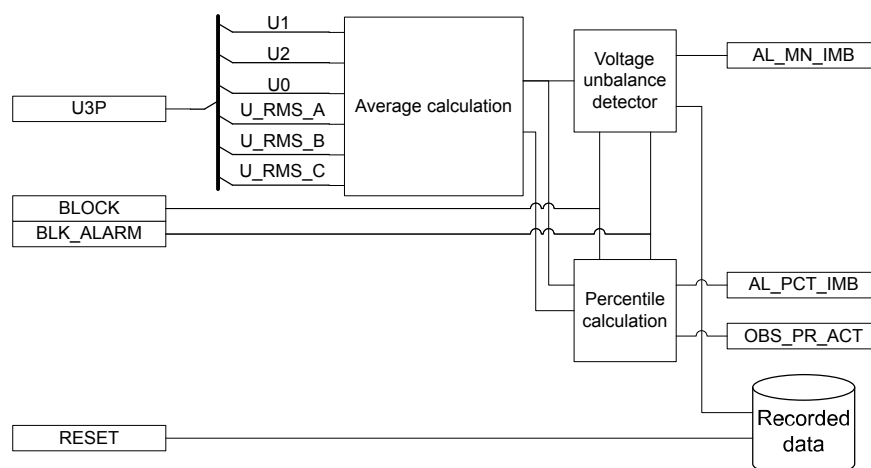


Figure 497: Functional module diagram

#### Average calculation

VSQVUB calculates two sets of measured voltage unbalance values, a three-second and a ten-minute non-sliding average value. The three-second average value is used for continuous monitoring. The ten-minute average is used for percentile calculation for a longer period.

The Average calculation module uses five different methods for the average calculation. The required method can be selected with the *Unb detection method* parameter.

When the "Neg Seq" mode is selected with *Unb detection method*, the voltage unbalance is calculated based on the negative-sequence voltage magnitude. Similarly, when the "Zero Seq" mode is selected, the voltage unbalance is calculated based on the zero-sequence voltage magnitude. When the "Neg to Pos Seq" mode is selected, the voltage unbalance is calculated based on the ratio of the negative-sequence voltage magnitude to the positive-sequence magnitude. When the "Zero to Pos Seq" mode is selected, the voltage unbalance is calculated based on the ratio of the zero-sequence voltage magnitude to the positive-sequence magnitude. When the "Ph vectors Comp" mode is selected, the ratio of the maximum phase voltage magnitude deviation from the mean voltage magnitude to the mean of the phase voltage magnitude is used for voltage unbalance calculation.

The calculated three-second value and ten-minute value are available in the Monitored data view through the outputs `3S_MN_UNB` and `10MN_MN_UNB`.



For VT connection = "Delta", the calculated zero-sequence voltage is always zero, hence, the setting *Unb detection method* = "Zero Seq" is not applicable in this VT configuration.

### Voltage unbalance detector

The three-second average value is calculated and compared to the set value *Unbalance start val*. If the voltage unbalance exceeds this limit, the `MN_UNB_AL` output is activated.

The activation of the `BLOCK` input blocks `MN_UNB_AL` output.

### Percentile calculation

The Percentile calculation module performs the statistics calculation for the level of voltage unbalance value for a settable duration. The operation of the Percentile calculation module can be described with a module diagram.

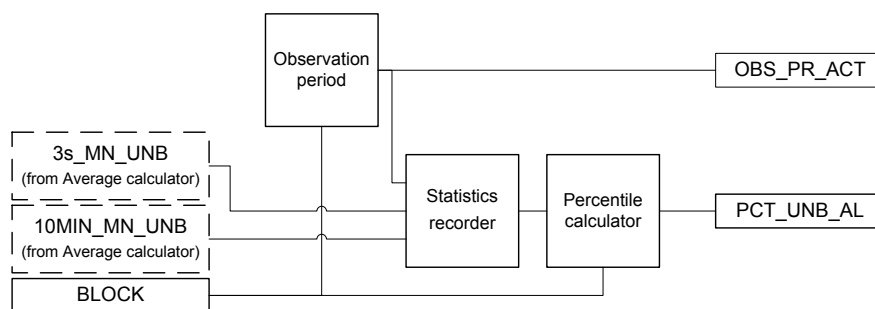


Figure 498: Percentile calculation

### Observation period

The Observation period module calculates the length of the observation time for the Statistics recorder sub-module as well as determines the possible start of a new one. A new period can be started by timed activation using calendar time settings *Obs period Str year*, *Obs period Str month*, *Obs period Str day* and *Obs period Str hour*.



The observation period start time settings *Obs period Str year*, *Obs period Str month*, *Obs period Str day* and *Obs period Str hour* are used to set the calendar time in UTC. These settings have to be adjusted according to the local time and local daylight saving time.

A preferable way of continuous statistics recordings can be selected over a longer period (months, years). With the *Trigger mode* setting, the way the next possible observation time is activated after the former one has finished can be selected.

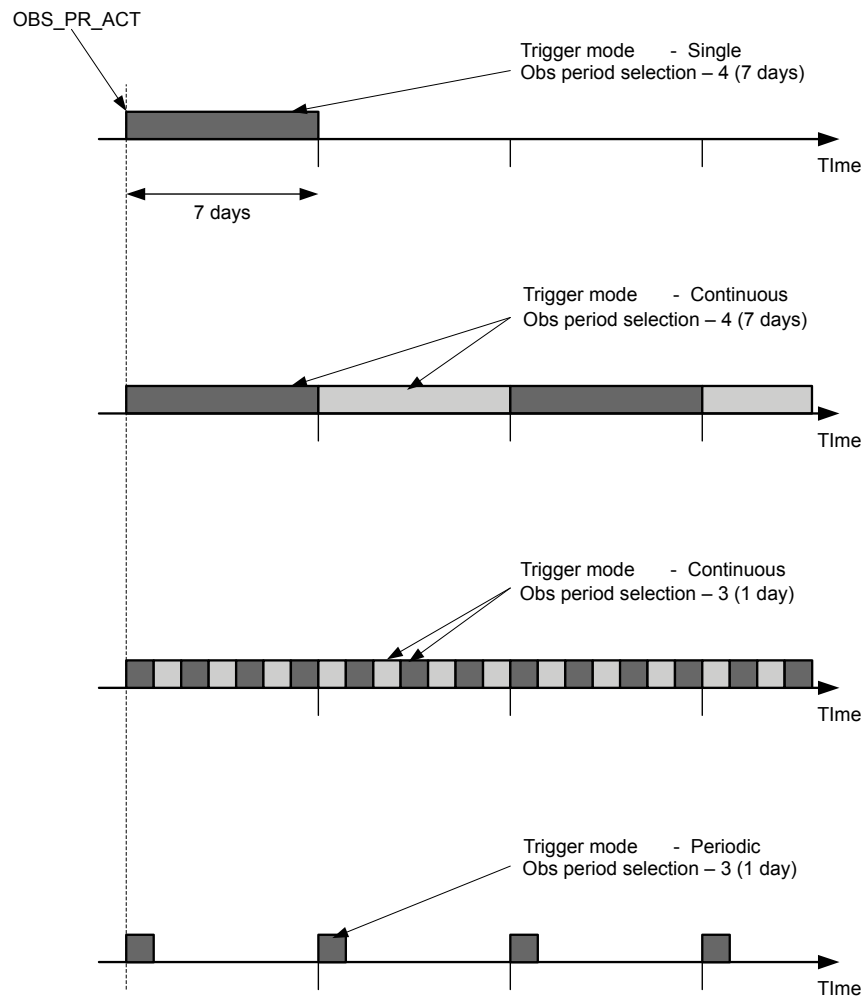
**Table 876: Trigger mode observation times**

| Trigger mode | Observation time   |
|--------------|--|
| Single       | Only one period of observation time is activated.                                |
| Periodic     | The time gap between the two trigger signals is seven days.                      |
| Continuous   | The next period starts right after the previous observation period is completed. |

The length of the period is determined by the settings *Obs period selection* and *User Def Obs period*. The `OBS_PR_ACT` output is an indication signal which exhibits rising edge (TRUE) when the observation period starts and falling edge (FALSE) when the observation period ends.

If the *Percentile unbalance*, *Trigger mode* or *Obs period duration* settings change when `OBS_PR_ACT` is active, `OBS_PR_ACT` deactivates immediately.





*Figure 499: Periods for statistics recorder with different trigger modes and period settings*

The `BLOCK` input blocks the `OBS_PR_ACT` output, which then disables the maximum value calculation of the Statistics recorder module. If the trigger mode is selected "Periodic" or "Continuous" and the blocking is deactivated before the next observation period is due to start, the scheduled period starts normally.

### Statistics recorder

The Statistics recorder module provides readily calculated three-second or ten-minute values of the selected phase to the percentile calculator module based on the length of the active observation period. If the observation period is less than one day, the three-second average values are used. If the observation period is one day or longer, the ten-minute average values are used.

The maximum three-second or ten-minute mean voltage unbalance is recorded during the active observation period. The observation period start time `PR_STR_TIME`, observation period end time `PR_END_TIME`, maximum voltage

unbalance value during observation period active, *MAX\_UNB\_VAL* and time of occurrence *MAX\_UNB\_TIME* are available through the Monitored data view. These outputs are updated once *OBS\_PR\_ACT* deactivates.

### Percentile calculator

The purpose of the Percentile calculator module is to find the voltage unbalance level so that during the observation time 95 percent (default value of the *Percentile unbalance* setting) of all the measured voltage unbalance amplitudes are less than or equal to the calculated percentile.

The computed output value *PCT\_UNB\_VAL*, below which the percentile of the values lies, is available in the Monitored data view. The *PCT\_UNB\_VAL* output value is updated at the end of the observation period.

If the output *PCT\_UNB\_VAL* is higher than the defined setting *Unbalance start val* at the end of the observation period, an alarm output *PCT\_UNB\_AL* is activated. The *PCT\_UNB\_AL* output remains active for the whole period before the next period completes.

The *BLOCK* input blocks the output *PCT\_UNB\_VAL*.

### Recorded data

The information required for a later fault analysis is stored when the Recorded data module is triggered. This happens when a voltage unbalance is detected by the Voltage unbalance detector module.

Three sets of recorded data are available in total. The sets are saved in data banks 1...3. The data bank 1 holds the most recent recorded data. Older data are moved to the subsequent banks (1 to 2 and 2 to 3) when a voltage unbalance is detected. When all three banks have data and a new variation is detected, the latest data set is placed into bank 1 and the data in bank 3 is overwritten by the data from bank 2.

The recorded data can be reset with the *RESET* binary input signal by navigating to the HMI reset (**Main menu > Clear > Reset recorded data > VSQVUBx**) or through tools via communications.

When a voltage unbalance is detected in the system, *VSQVUB* responds with the *MN\_UNB\_AL* alarm signal. During the alarm situation, *VSQVUB* stores the maximum magnitude and the time of occurrence and the duration of alarm *MN\_UNB\_AL*. The recorded data is stored when *MN\_UNB\_AL* is deactivated.

**Table 877: Recorded data**

| Parameter           | Description                                 |
|---------------------|---|
| Alarm high mean Dur | Time duration for alarm high mean unbalance |
| Max unbalance Volt  | Maximum three-second voltage                |
| Time Max Unb Volt   | Time stamp of voltage unbalance             |

## 9.4.5 Application

Voltage unbalance is one of the basic power quality parameters.

Ideally, in a three-phase or multiphase power system, the frequency and voltage magnitude of all the phases are equal and the phase displacement between any two consecutive phases is also equal. This is called a balanced source. Apart from the balanced source, usually the power system network and loads are also balanced, implying that network impedance and load impedance in each phase are equal. In some cases, the condition of a balance network and load is not met completely, which leads to a current and voltage unbalance in the system. Providing unbalanced supply voltage has a detrimental effect on load operation. For example, a small magnitude of a negative-sequence voltage applied to an induction motor results in a significant heating of the motor.

A balanced supply, balanced network and balanced load lead to a better power quality. When one of these conditions is disturbed, the power quality is deteriorated. VSQVUB monitors voltage unbalance conditions in power transmission and distribution networks. VSQVUB calculates two sets of measured values, a three-second and a ten-minute non-sliding average value. The three-second average value is used for continuous monitoring while the ten-minute average value is used for percentile calculation for a longer period of time. It can be applied to identify the network and load unbalance that may cause sustained voltage unbalance. A single-phase or phase-to-phase fault in the network or load side can create voltage unbalance but, as faults are usually isolated in a short period of time, the voltage unbalance is not a sustained one. Therefore, the voltage unbalance may not be covered by VSQVUB.

Another major application is the long-term power quality monitoring. This can be used to confirm a compliance to the standard power supply quality norms. The function provides a voltage unbalance level which corresponds to the 95<sup>th</sup> percentile of the ten minutes' average values of voltage unbalance recorded over a period of up to one week. It means that for 95 percent of time during the observation period the voltage unbalance was less than or equal to the calculated percentile. An alarm can be obtained if this value exceeds the value that can be set.

The function uses five different methods for calculating voltage unbalance.

- Negative-sequence voltage magnitude
- Zero-sequence voltage magnitude
- Ratio of negative-sequence to positive-sequence voltage magnitude
- Ratio of zero-sequence to positive-sequence voltage magnitude
- Ratio of maximum phase voltage magnitude deviation from the mean voltage magnitude to the mean of phase voltage magnitude.

Usually, the ratio of the negative-sequence voltage magnitude to the positive-sequence voltage magnitude is selected for monitoring the voltage unbalance. However, other methods may also be used if required.

## 9.4.6 Signals

### 9.4.6.1 VSQVUB Input signals

Table 878: VSQVUB Input signals

| Name           | Type    | Default | Description                              |
|----------------|---------|---------|--|
| U_A            | SIGNAL  | 0       | Phase A voltage                          |
| U_B            | SIGNAL  | 0       | Phase B voltage                          |
| U_C            | SIGNAL  | 0       | Phase C voltage                          |
| U <sub>1</sub> | SIGNAL  | 0       | Positive phase sequence voltage          |
| U <sub>2</sub> | SIGNAL  | 0       | Negative phase sequence voltage          |
| U <sub>0</sub> | SIGNAL  | 0       | Zero sequence voltage                    |
| BLOCK          | BOOLEAN | 0=False | Block all outputs except measured values |

### 9.4.6.2 VSQVUB Output signals

Table 879: VSQVUB Output signals

| Name       | Type    | Description   |
|------------|---------|---|
| MN_UNB_AL  | BOOLEAN | Alarm active when 3 sec voltage unbalance exceeds the limit |
| PCT_UNB_AL | BOOLEAN | Alarm active when percentile unbalance exceeds the limit    |
| OBS_PR_ACT | BOOLEAN | Observation period is active                                |

## 9.4.7 Settings

### 9.4.7.1 VSQVUB Settings

Table 880: VSQVUB Non group settings (Basic)

| Parameter            | Values (Range)          | Unit | Step | Default          | Description  |
|----------------------|-------------------------|------|------|------------------|--|
| Operation            | 1=on<br>5=off           |      |      | 1=on             | Operation On/Off   |
| Unb detection method | 1=Neg Seq<br>2=Zero Seq |      |      | 3=Neg to Pos Seq | Set the operation mode for voltage unbalance calculation |

*Table continues on the next page*

| Parameter            | Values (Range)   | Unit | Step | Default        | Description   |
|----------------------|--|------|------|----------------|---|
|                      | 3=Neg to Pos Seq<br>4=Zero to Pos Seq<br>5=Ph vectors Comp                     |      |      |                |   |
| Unbalance start Val  | 1...100  | %    | 1    | 1              | Voltage unbalance start value                                   |
| Trigger mode         | 1=Single<br>2=Periodic<br>3=Continuous   |      |      | 3=Continuous   | Specifies the observation period triggering mode                |
| Percentile unbalance | 1...100  | %    | 1    | 95             | The percent to which percentile value PCT_UNB_VAL is calculated |
| Obs period selection | 1=1 Hour<br>2=12 Hours<br>3=1 Day<br>4=7 Days<br>5=User defined                |      |      | 5=User defined | Observation period for unbalance calculation                    |
| User Def Obs period  | 1...168  | h    | 1    | 168            | User define observation period for statistic calculation        |
| Obs period Str year  | 2008...2076  |      |      | 2011           | Calendar time for observation period start year in YYYY         |
| Obs period Str month | 0=reserved<br>1=January<br>2=February<br>3=March<br>4=April<br>5=May<br>6=June |      |      | 1=January      | Calendar time for observation period start month                |

*Table continues on the next page*

| Parameter              | Values (Range)  | Unit | Step | Default | Description                                     |
|------------------------|---|------|------|---------|---|
|                        | 7=July<br>8=August<br>9=September<br>10=October<br>11=November<br>12=December |      |      |         |   |
| Obs period<br>Str day  | 1...31  |      |      | 1       | Calendar time for observation period start day  |
| Obs period<br>Str hour | 0...23  | h    |      | 0       | Calendar time for observation period start hour |

## 9.4.8 Monitored data

### 9.4.8.1 VSQVUB Monitored data

Table 881: VSQVUB Monitored data

| Name         | Type      | Values (Range) | Unit | Description  |
|--------------|-----------|----------------|------|--|
| 3S_MN_UNB    | FLOAT32   | 0.00...150.00  | %    | Non sliding 3 second mean value of voltage unbalance         |
| 10MIN_MN_UNB | FLOAT32   | 0.00...150.00  | %    | Sliding 10 minutes mean value of voltage unbalance           |
| PCT_UNB_VAL  | FLOAT32   | 0.00...150.00  | %    | Limit below which percentile unbalance of the values lie     |
| MAX_UNB_VAL  | FLOAT32   | 0.00...150.00  | %    | Maximum voltage unbalance measured in the observation period |
| MAX_UNB_TIME | Timestamp |                |      | Time stamp at which maximum voltage unbalance measured       |

*Table continues on the next page*

| Name                | Type      | Values (Range)   | Unit | Description   |
|---------------------|-----------|--|------|---|
|                     |           |  |      | ured in the observation period                            |
| PR_STR_TIME         | Timestamp |  |      | Time stamp of starting of the previous observation period |
| PR_END_TIME         | Timestamp |  |      | Time stamp of end of previous observation period          |
| Alarm high mean Dur | FLOAT32   | 0.000...3600.000                                       | s    | Time duration for alarm high mean unbalance               |
| Max unbalance Volt  | FLOAT32   | 0.00...150.00  | %    | Maximum 3 seconds unbalance voltage                       |
| Time Max Unb Volt   | Timestamp |  |      | Time stamp of maximum voltage unbalance                   |
| Alarm high mean Dur | FLOAT32   | 0.000...3600.000                                       | s    | Time duration for alarm high mean unbalance               |
| Max unbalance Volt  | FLOAT32   | 0.00...150.00  | %    | Maximum 3 seconds unbalance voltage                       |
| Time Max Unb Volt   | Timestamp |  |      | Time stamp of maximum voltage unbalance                   |
| Alarm high mean Dur | FLOAT32   | 0.000...3600.000                                       | s    | Time duration for alarm high mean unbalance               |
| Max unbalance Volt  | FLOAT32   | 0.00...150.00  | %    | Maximum 3 seconds unbalance voltage                       |
| Time Max Unb Volt   | Timestamp |  |      | Time stamp of maximum voltage unbalance                   |
| VSQVUB              | Enum      | 1=on<br>2=blocked<br>3=test<br>4=test/blocked<br>5=off |      | Status  |

## 9.4.9 Technical data

**Table 882: VSQVUB Technical data**

| Characteristic     | Value  |
|--------------------|--|
| Operation accuracy | $\pm 1.5\%$ of the set value or $\pm 0.002 \times U_n$ |
| Reset ratio        | Typically 0.96   |



## 10 General function block features

### 10.1 Definite time characteristics

#### 10.1.1 Definite time operation

The DT mode is enabled when the *Operating curve type* setting is selected either as "ANSI Def. Time" or "IEC Def. Time". In the DT mode, the `OPERATE` output of the function is activated when the time calculation exceeds the set *Operate delay time*.

The user can determine the reset in the DT mode with the *Reset delay time* setting, which provides the delayed reset property when needed.



The *Type of reset curve* setting has no effect on the reset method when the DT mode is selected, but the reset is determined solely with the *Reset delay time* setting.

The purpose of the delayed reset is to enable fast clearance of intermittent faults, for example self-sealing insulation faults, and severe faults which may produce high asymmetrical fault currents that partially saturate the current transformers. It is typical for an intermittent fault that the fault current contains so called drop-off periods, during which the fault current falls below the set start current, including hysteresis. Without the delayed reset function, the operate timer would reset when the current drops off. In the same way, an apparent drop-off period of the secondary current of the saturated current transformer can also reset the operate timer.

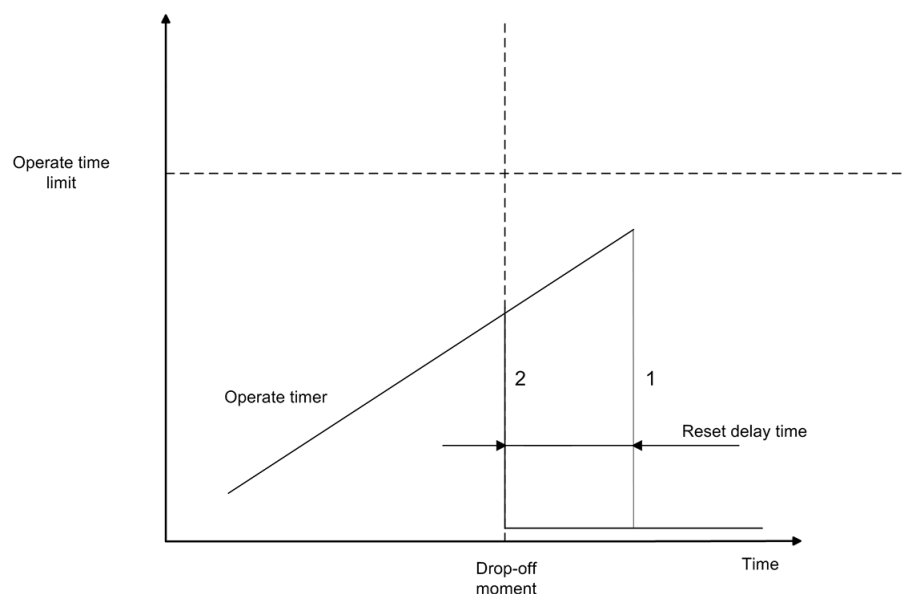


Figure 500: Operation of the counter in drop-off

In case 1, the reset is delayed with the *Reset delay time* setting and in case 2, the counter is reset immediately, because the *Reset delay time* setting is set to zero.

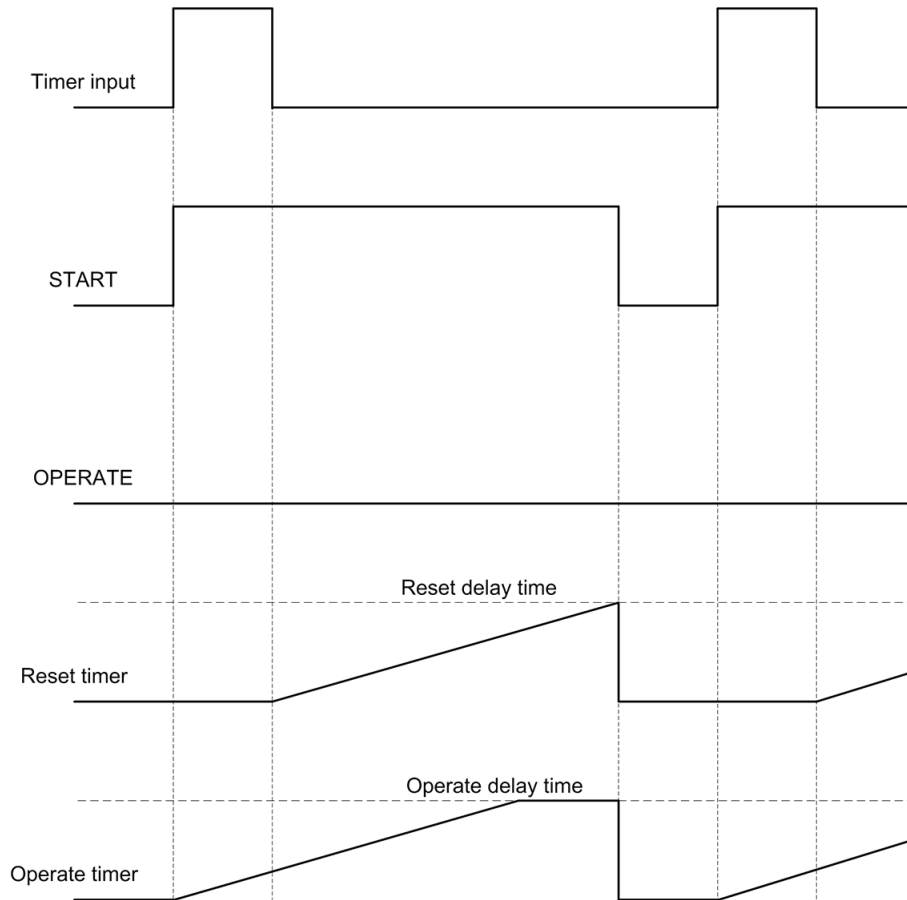


Figure 501: Drop-off period is longer than the set Reset delay time

When the drop-off period is longer than the set *Reset delay time*, as described in [Figure 502](#), the input signal for the definite timer (here: timer input) is active, provided that the current is above the set *Start value*. The input signal is inactive when the current is below the set *Start value* and the set hysteresis region. The timer input rises when a fault current is detected. The definite timer activates the *START* output and the operate timer starts elapsing. The reset (drop-off) timer starts when the timer input falls, that is, the fault disappears. When the reset (drop-off) timer elapses, the operate timer is reset. Since this happens before another start occurs, the *OPERATE* output is not activated.

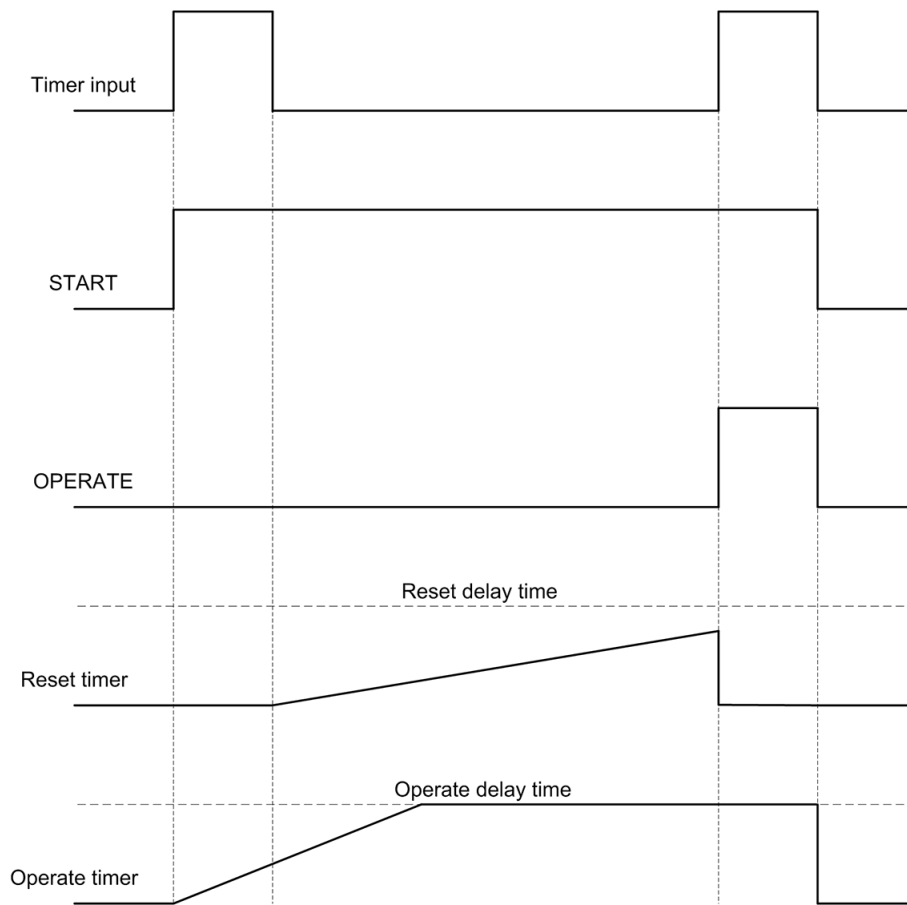


Figure 502: Drop-off period is shorter than the set Reset delay time

When the drop-off period is shorter than the set *Reset delay time*, as described in [Figure 503](#), the input signal for the definite timer (here: timer input) is active, provided that the current is above the set *Start value*. The input signal is inactive when the current is below the set *Start value* and the set hysteresis region. The timer input rises when a fault current is detected. The definite timer activates the *START* output and the operate timer starts elapsing. The Reset (drop-off) timer starts when the timer input falls, that is, the fault disappears. Another fault situation occurs before the reset (drop-off) timer has elapsed. This causes the activation of the *OPERATE* output, since the operate timer already has elapsed.

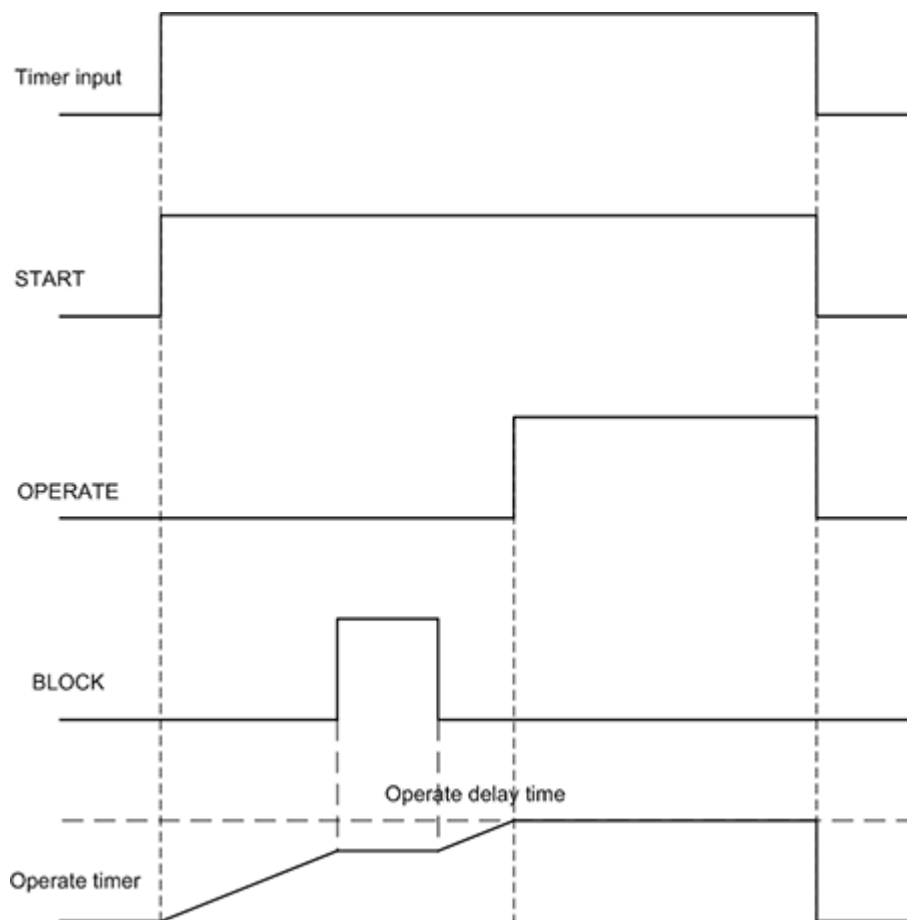


Figure 503: Operating effect of the BLOCK input when the selected blocking mode is "Freeze timer"

If the BLOCK input is activated when the operate timer is running, as described in [Figure 501](#), the timer is frozen during the time BLOCK remains active. If the timer input is not active longer than specified by the *Reset delay time* setting, the operate timer is reset in the same way as described in [Figure 501](#), regardless of the BLOCK input.



The selected blocking mode is "Freeze timer".

## 10.2 Current based inverse definite minimum time characteristics

### 10.2.1 IDMT curves for overcurrent protection

In the inverse-time modes, the operation time depends on the momentary value of the current: the higher the current, the faster the operation time. The operation time

calculation or integration starts immediately when the current exceeds the set *Start value* and the *START* output is activated.

The *OPERATE* output of the component is activated when the cumulative sum of the integrator calculating the overcurrent situation exceeds the value set by the inverse-time mode. The set value depends on the selected curve type and the setting values used. The curve scaling is determined with the *Time multiplier* setting.

There are two methods to level out the inverse-time characteristic.

- The *Minimum operate time* setting defines the minimum operating time for the IDMT curve, that is, the operation time is always at least the *Minimum operate time* setting.
- Alternatively, the *IDMT Sat point* is used for giving the leveling-out point as a multiple of the *Start value* setting. (Global setting: **Configuration** > **System** > **IDMT Sat point**). The default parameter value is 50. This setting affects only the overcurrent and earth-fault IDMT timers.



IDMT operation time at currents over 50 x  $I_n$  is not guaranteed.

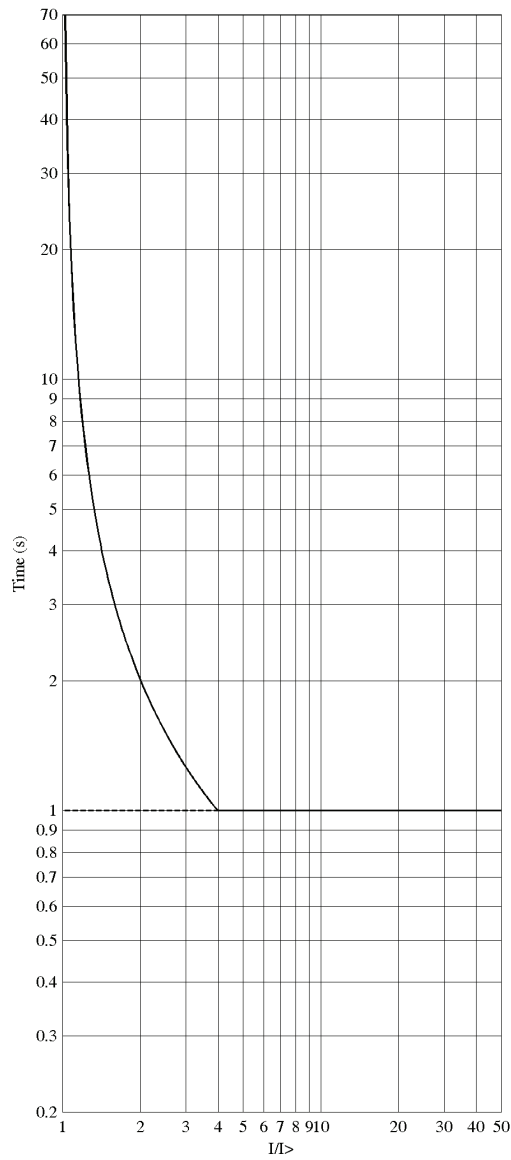


Figure 504: Operation time curve based on the IDMT characteristic leveled out with the Minimum operate time setting is set to 1000 milliseconds (the IDMT Sat point setting is set to maximum).

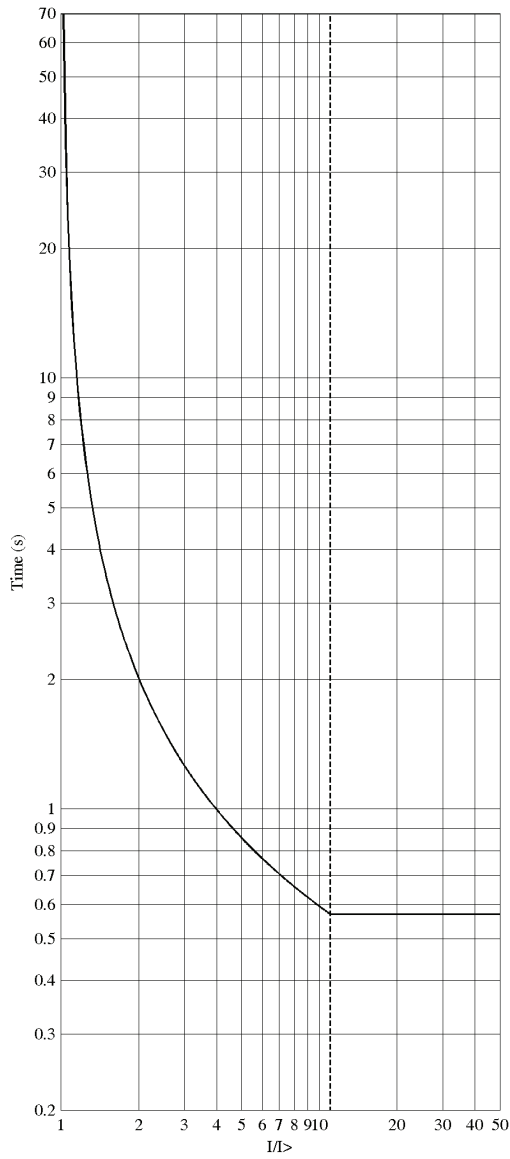


Figure 505: Operation time curve based on the IDMT characteristic leveled out with IDMT Sat point setting value "11" (the Minimum operate time setting is set to minimum).

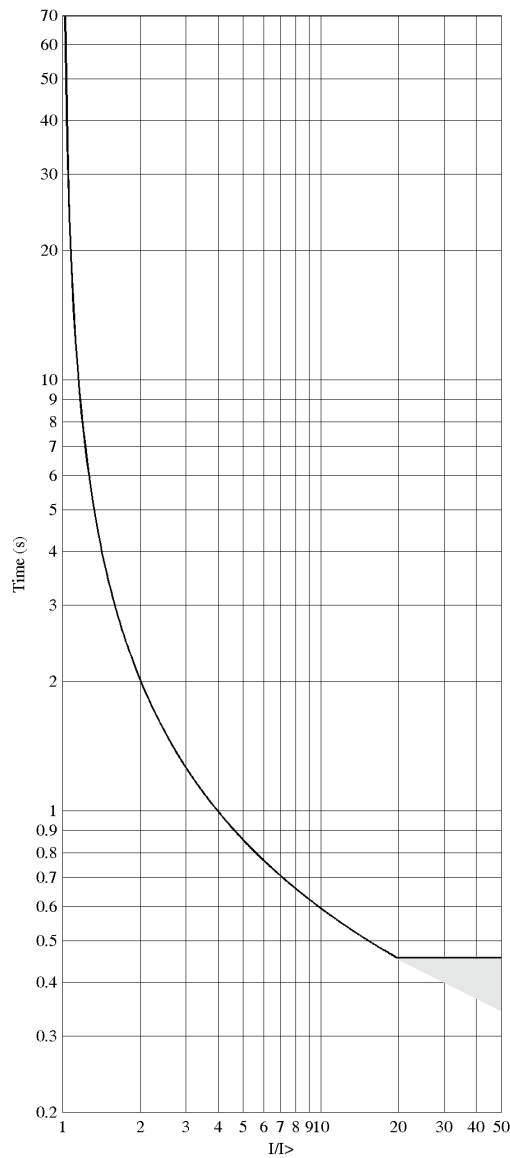


Figure 506: Example of how the inverse time characteristic is leveled out with currents over 50 x In and the Setting Start value setting “2.5 x In”. (the IDMT Sat point setting is set to maximum and the Minimum operate time setting is set to minimum).

The grey zone in Figure 506 shows the behavior of the curve in case the measured current is outside the guaranteed measuring range. Also, the maximum measured current of 50 x In gives the leveling-out point  $50/2.5 = 20 \times I/I>$ .

### 10.2.1.1 Standard inverse-time characteristics

For inverse-time operation, both IEC and ANSI/IEEE standardized inverse-time characteristics are supported.

The operate times for the ANSI and IEC IDMT curves are defined with the coefficients A, B and C.

The values of the coefficients can be calculated according to the formula:



$$t[s] = \left( \frac{A}{\left( \frac{I}{I>} \right)^c + B} \right) \cdot k$$

|      |                            |
|------|----------------------------|
| t[s] | Operate time in seconds    |
| I    | measured current           |
| I>   | set <i>Start value</i>     |
| k    | set <i>Time multiplier</i> |

**Table 883: Curve parameters for ANSI and IEC IDMT curves**

| Curve name                      | A      | B      | C    |
|---------------------------------|--------|--------|------|
| (1) ANSI Extremely Inverse      | 28.2   | 0.1217 | 2.0  |
| (2) ANSI Very Inverse           | 19.61  | 0.491  | 2.0  |
| (3) ANSI Normal Inverse         | 0.0086 | 0.0185 | 0.02 |
| (4) ANSI Moderately Inverse     | 0.0515 | 0.1140 | 0.02 |
| (6) Long Time Extremely Inverse | 64.07  | 0.250  | 2.0  |
| (7) Long Time Very Inverse      | 28.55  | 0.712  | 2.0  |
| (8) Long Time Inverse           | 0.086  | 0.185  | 0.02 |
| (9) IEC Normal Inverse          | 0.14   | 0.0    | 0.02 |
| (10) IEC Very Inverse           | 13.5   | 0.0    | 1.0  |
| (11) IEC Inverse                | 0.14   | 0.0    | 0.02 |
| (12) IEC Extremely Inverse      | 80.0   | 0.0    | 2.0  |
| (13) IEC Short Time Inverse     | 0.05   | 0.0    | 0.04 |
| (14) IEC Long Time Inverse      | 120    | 0.0    | 1.0  |

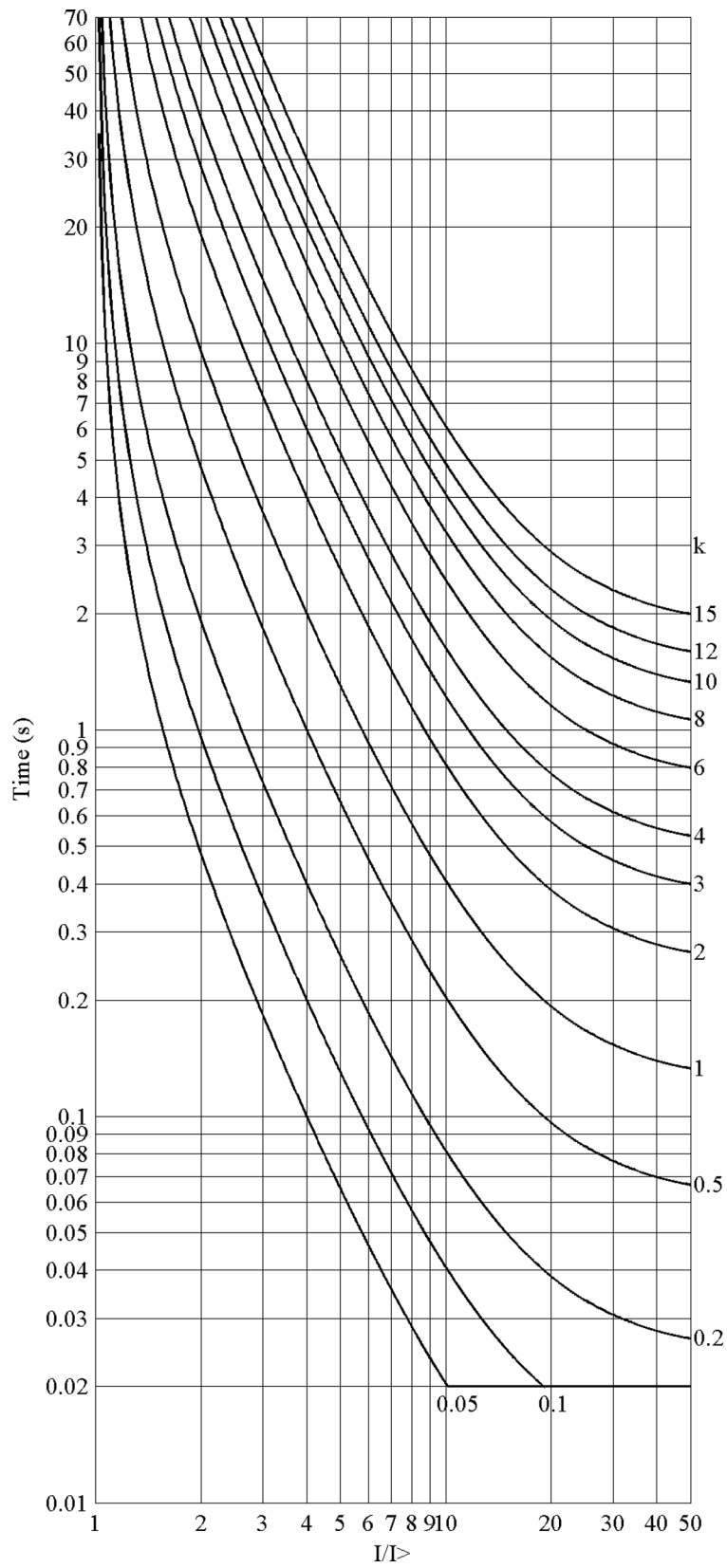


Figure 507: ANSI extremely inverse-time characteristics

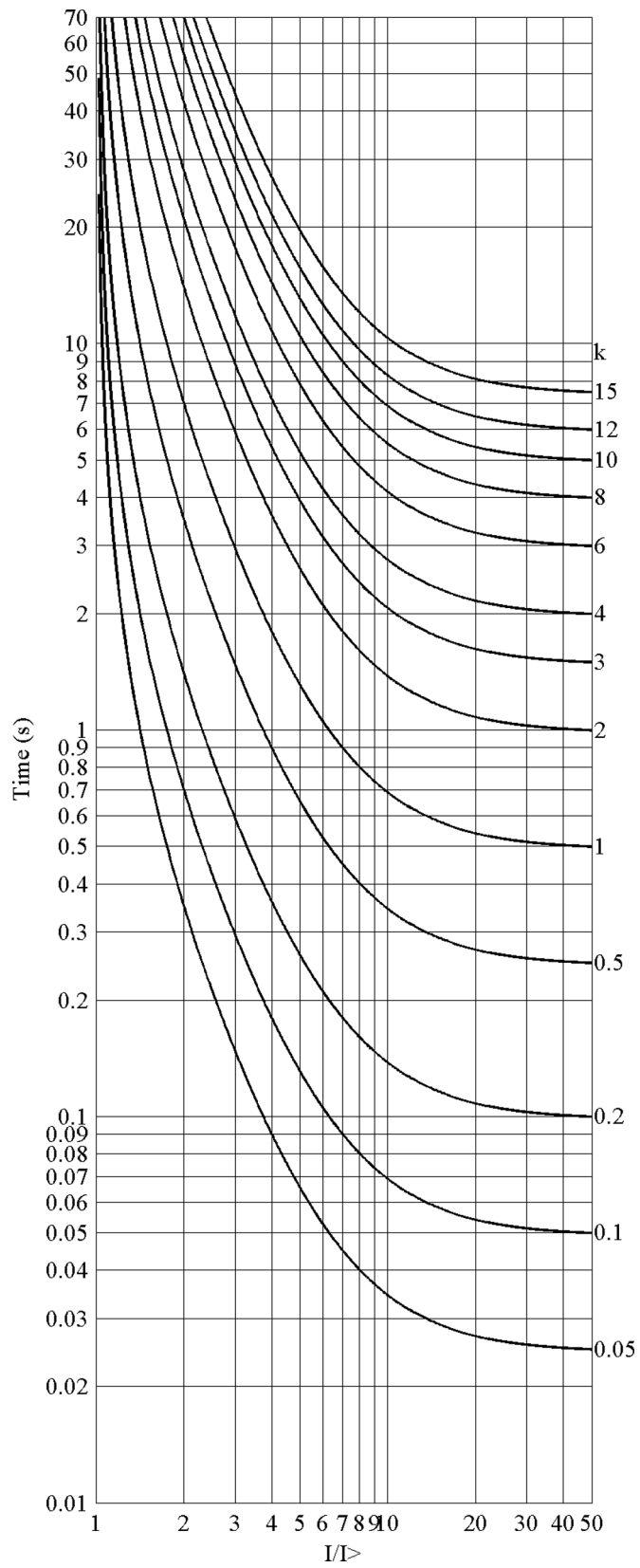


Figure 508: ANSI very inverse-time characteristics

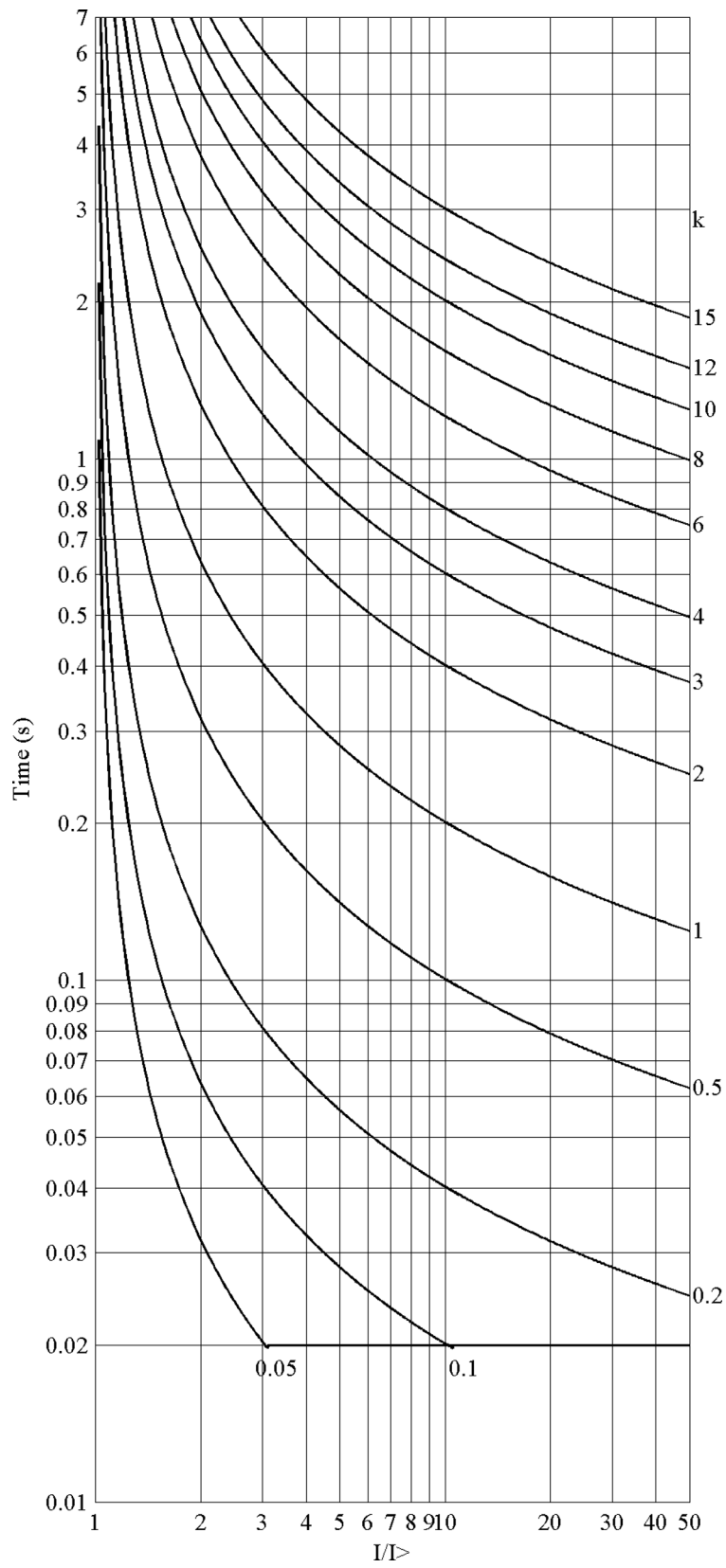


Figure 509: ANSI normal inverse-time characteristics

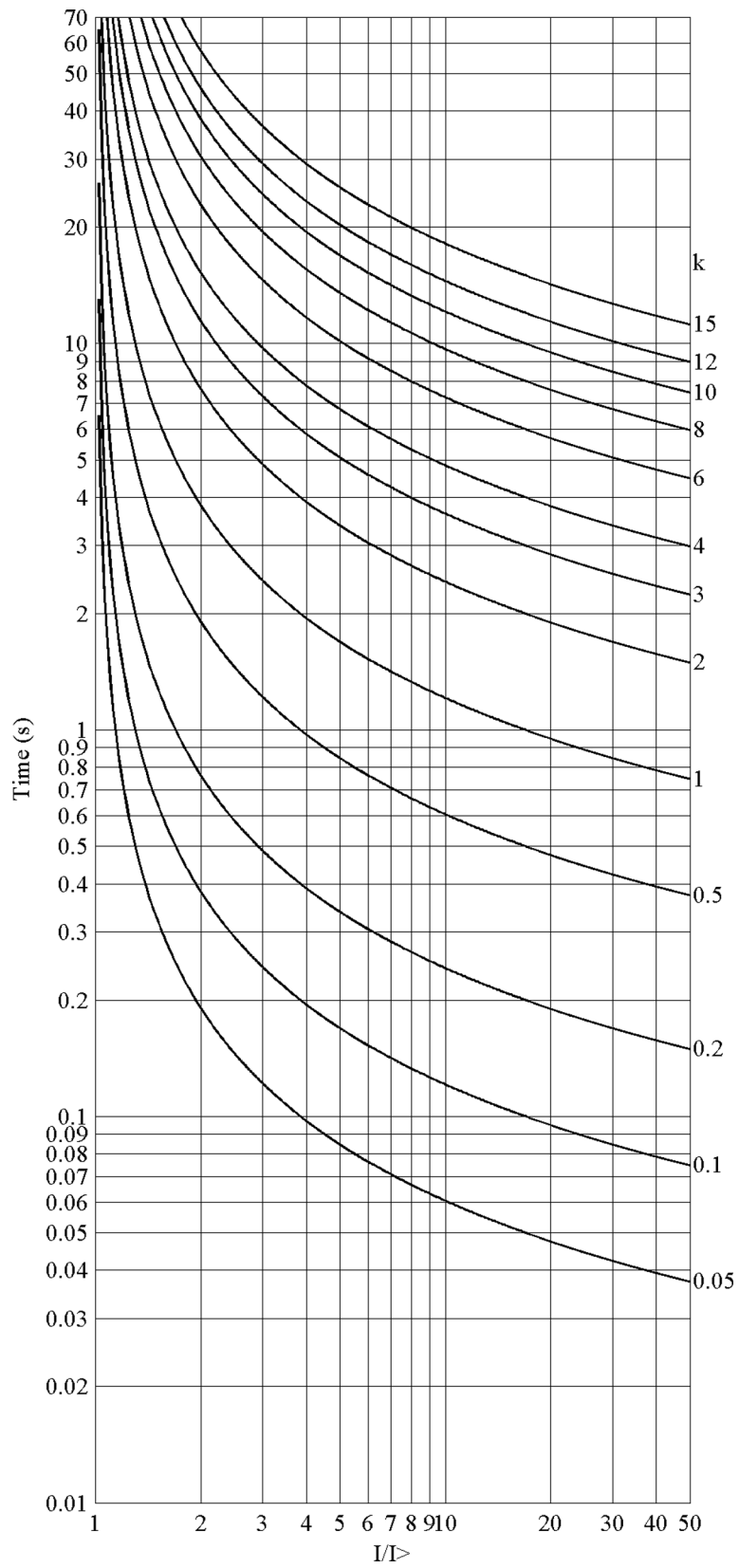


Figure 510: ANSI moderately inverse-time characteristics

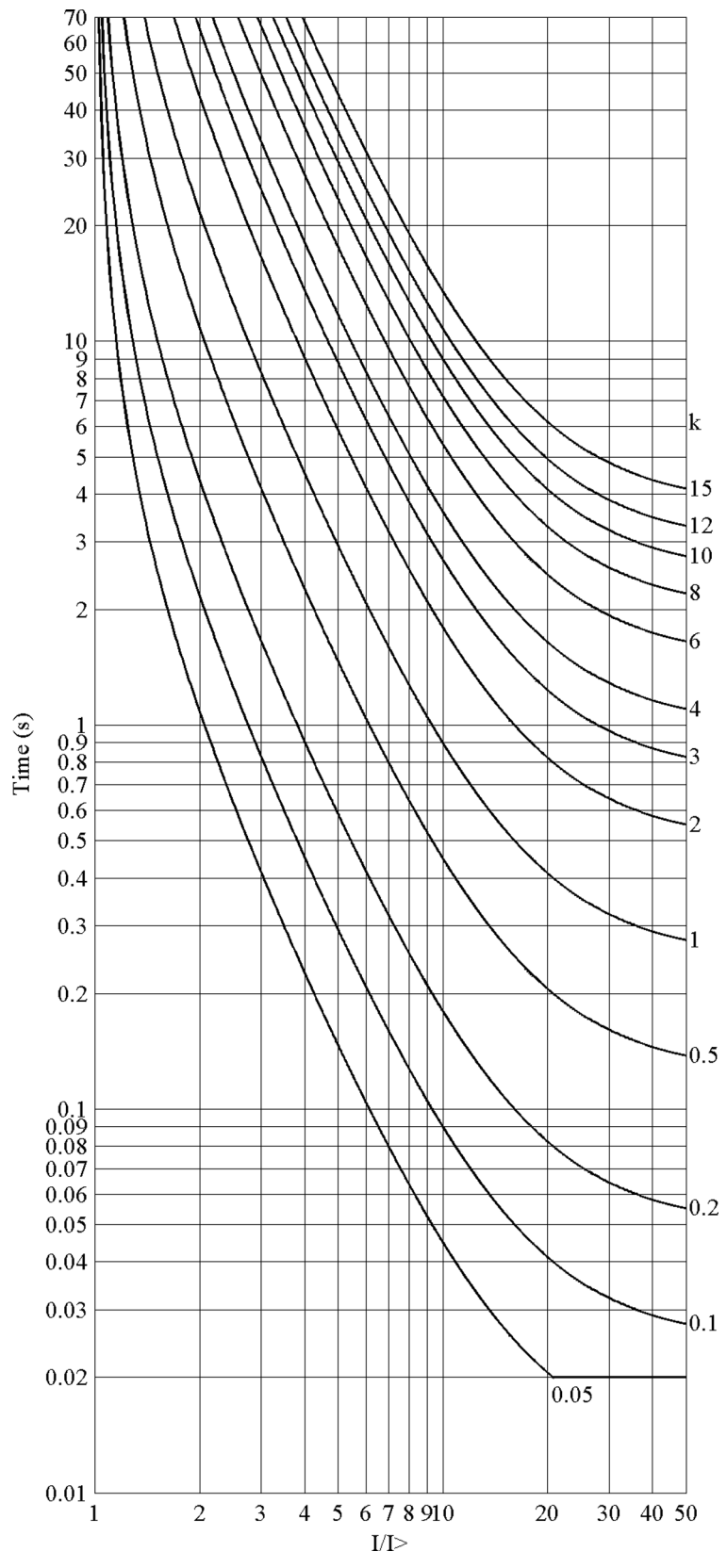


Figure 511: ANSI long-time extremely inverse-time characteristics

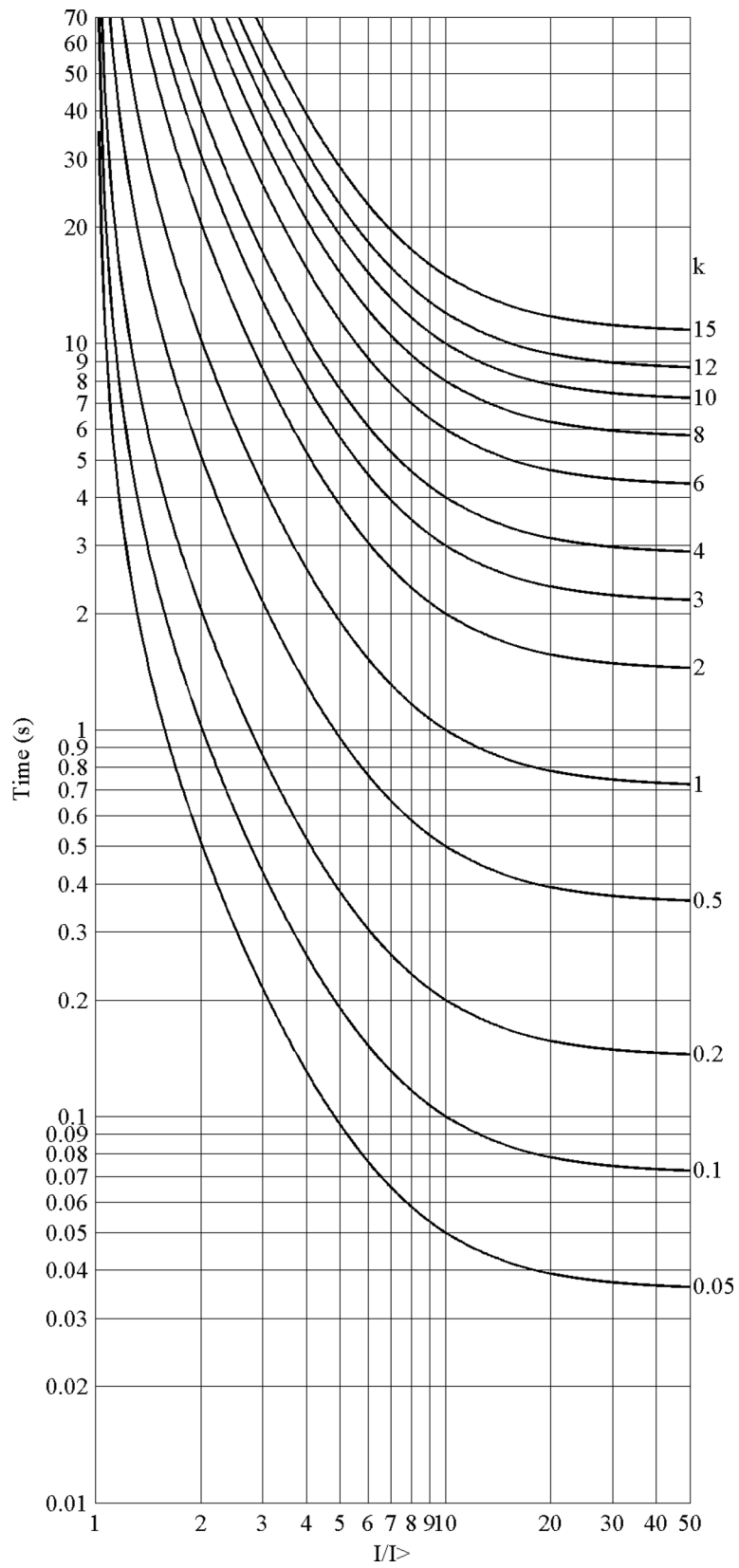


Figure 512: ANSI long-time very inverse-time characteristics

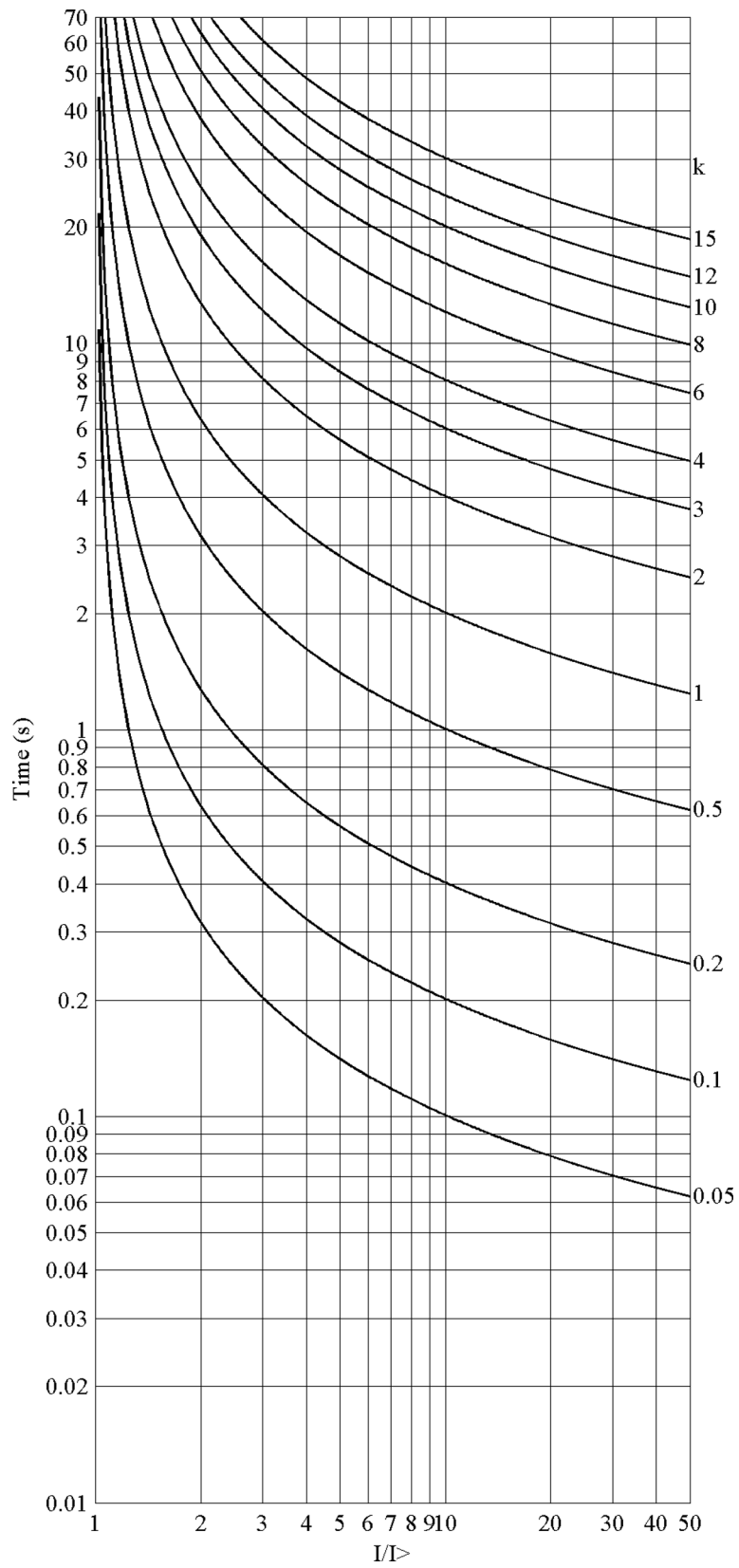


Figure 513: ANSI long-time inverse-time characteristics



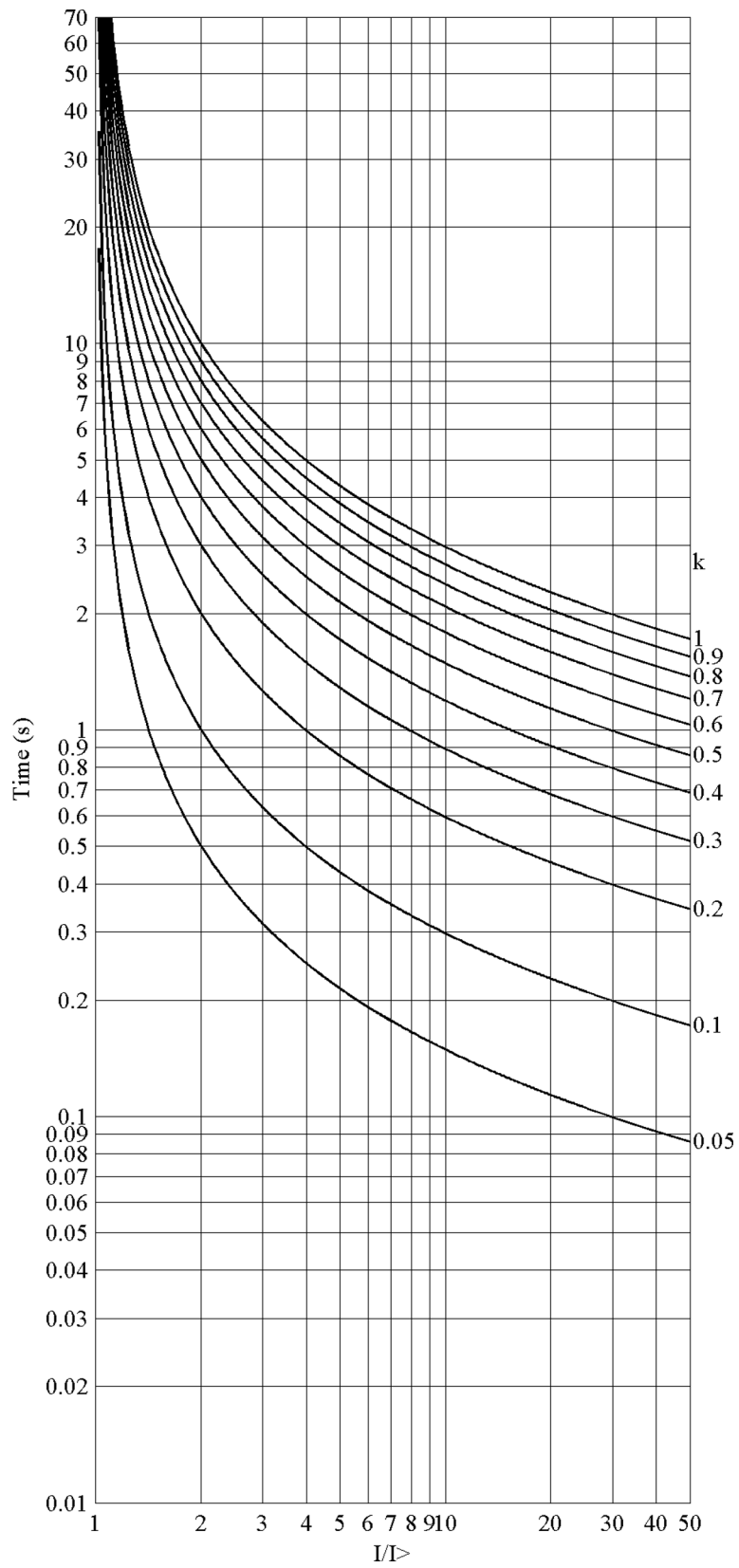


Figure 514: IEC normal inverse-time characteristics

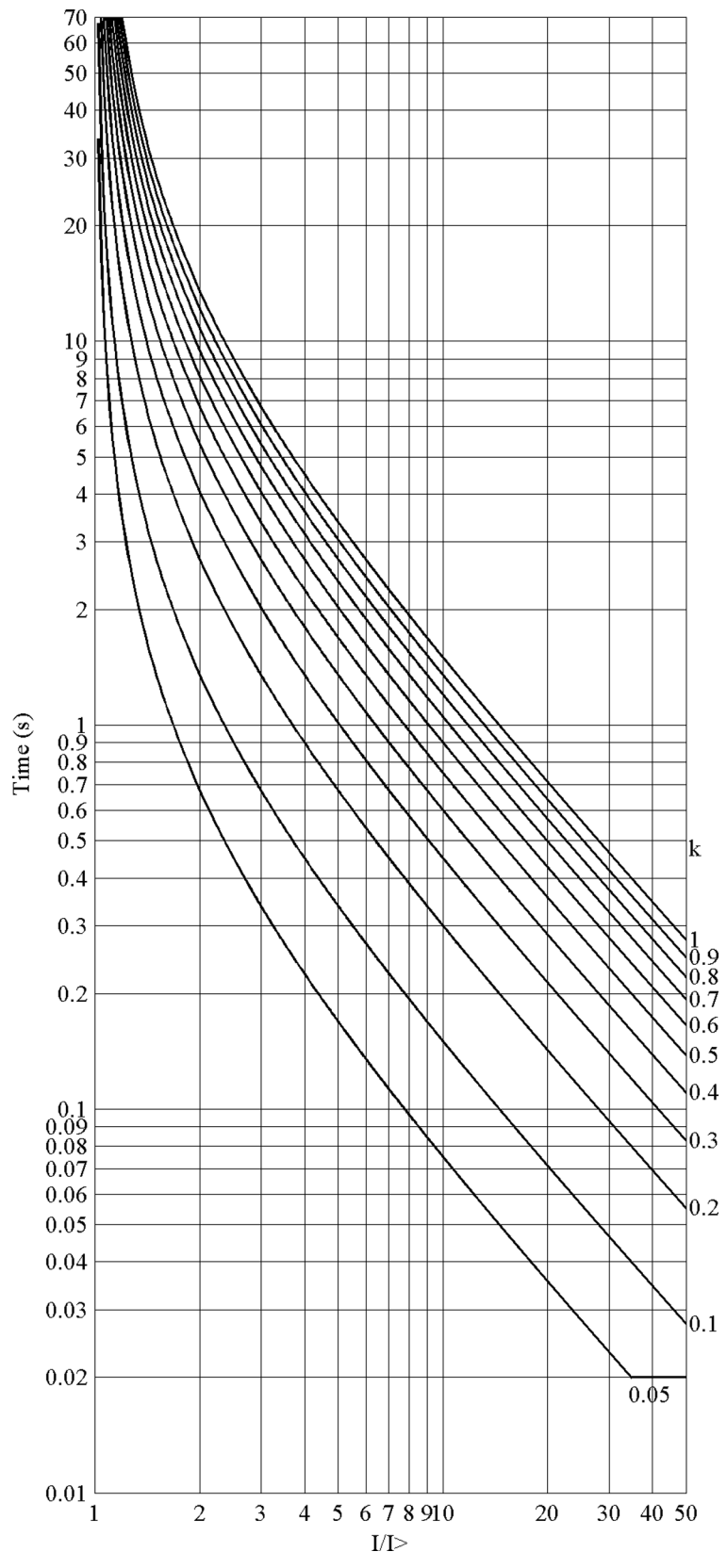


Figure 515: IEC very inverse-time characteristics

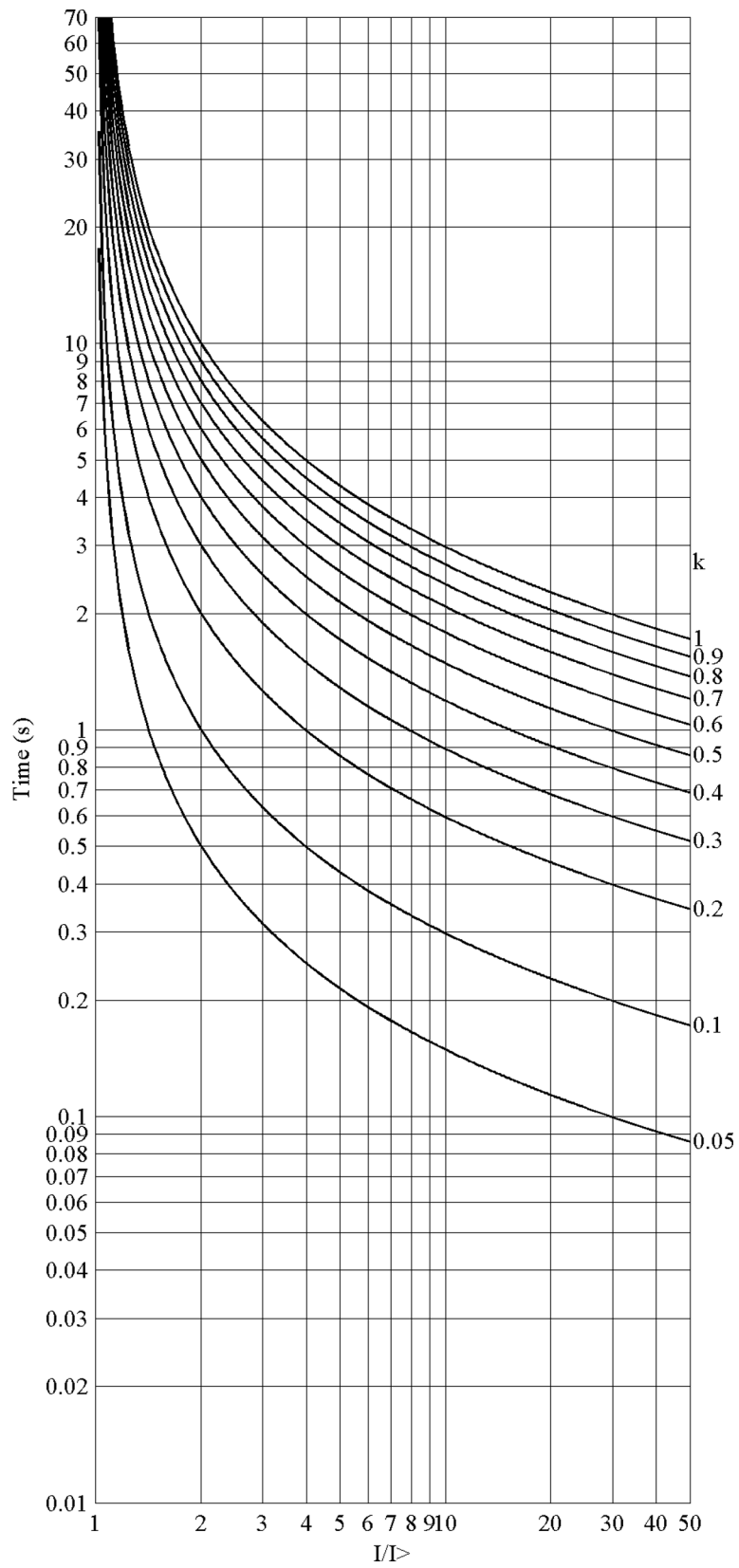


Figure 516: IEC inverse-time characteristics

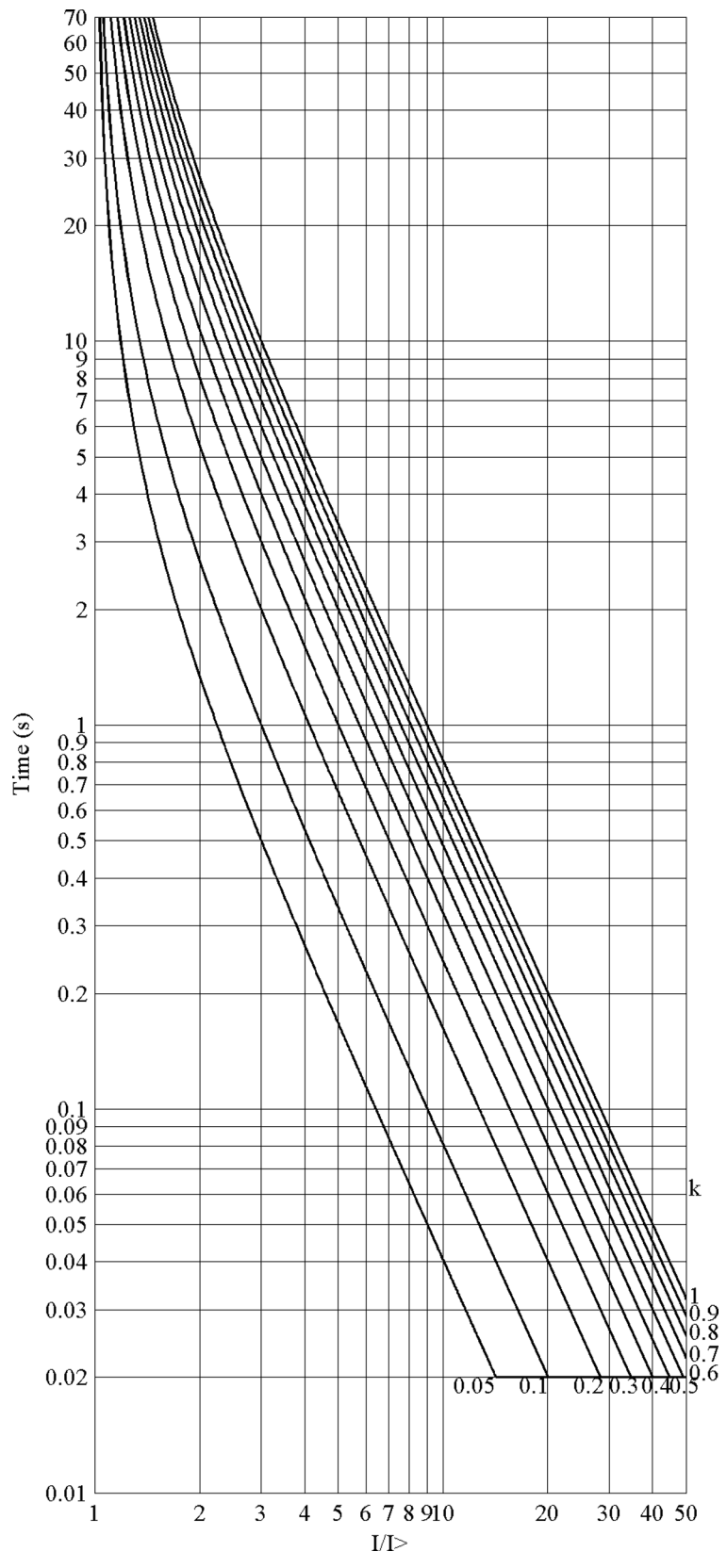


Figure 517: IEC extremely inverse-time characteristics

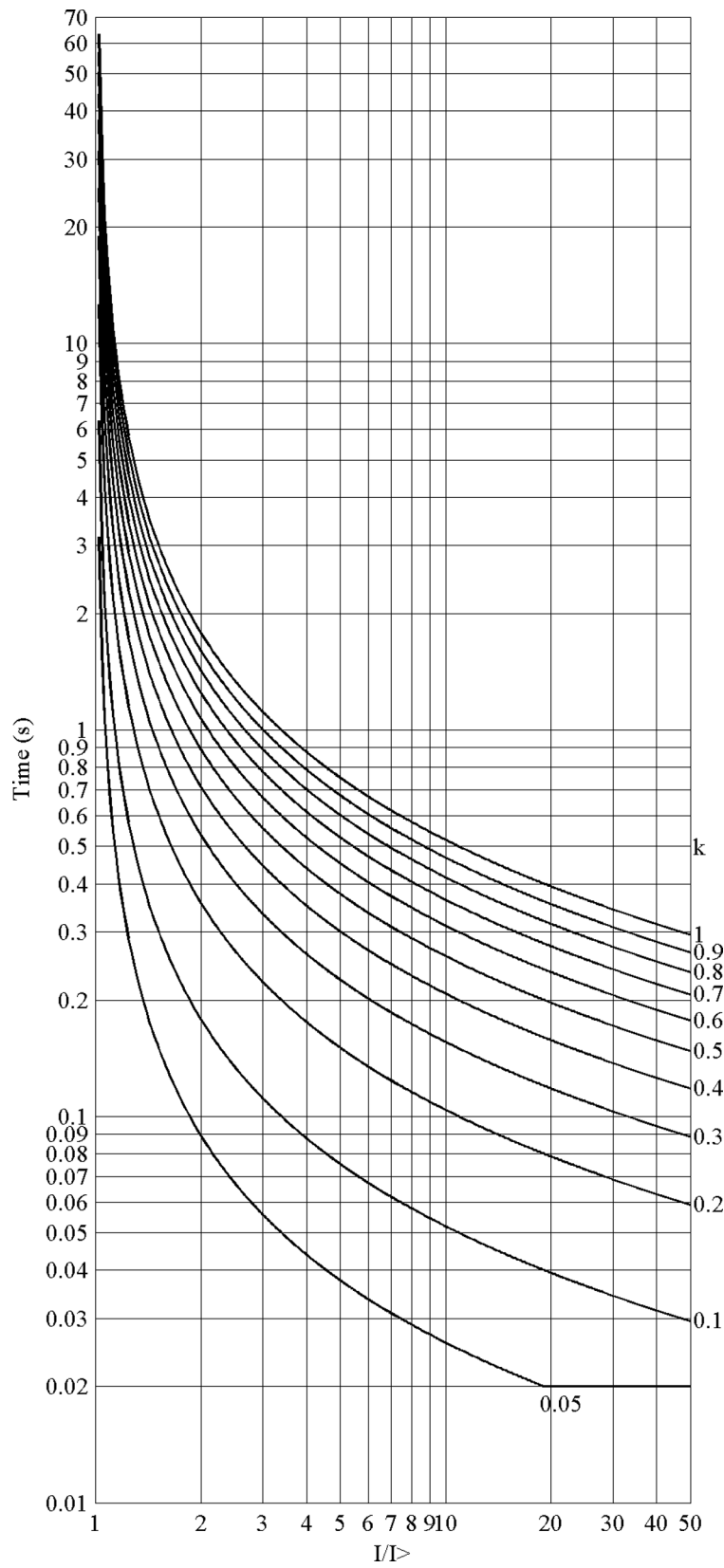


Figure 518: IEC short-time inverse-time characteristics

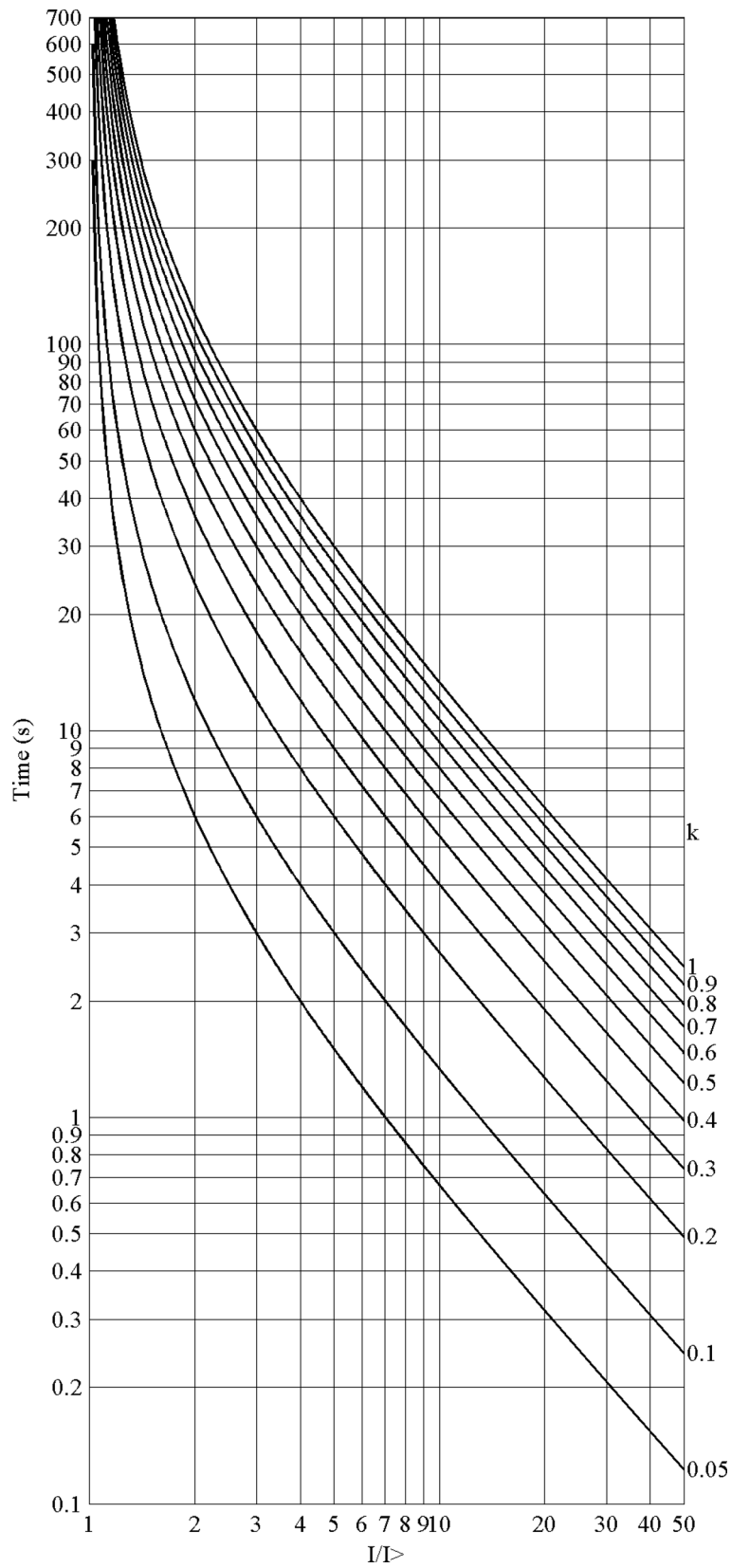


Figure 519: IEC long-time inverse-time characteristics

### 10.2.1.2 User-programmable inverse-time characteristics

The user can define curves by entering parameters into the following standard formula:

$$t[s] = \left( \frac{A}{\left( \frac{I}{I>} \right)^C - E} + B \right) \cdot k$$

|      |                              |
|------|------------------------------|
| t[s] | Operate time (in seconds)    |
| A    | set <i>Curve parameter A</i> |
| B    | set <i>Curve parameter B</i> |
| C    | set <i>Curve parameter C</i> |
| E    | set <i>Curve parameter E</i> |
| I    | Measured current             |
| I>   | set <i>Start value</i>       |
| k    | set <i>Time multiplier</i>   |

### 10.2.1.3 RI and RD-type inverse-time characteristics

The RI-type simulates the behavior of electromechanical relays. The RD-type is an earth-fault specific characteristic.

The RI-type is calculated using the formula

$$t[s] = \left( \frac{k}{0.339 - 0.236 \times \frac{I>}{I}} \right)$$

The RD-type is calculated using the formula

$$t[s] = 5.8 - 1.35 \times \ln \left( \frac{I}{k \times I>} \right)$$

|      |                            |
|------|----------------------------|
| t[s] | Operate time (in seconds)  |
| k    | set <i>Time multiplier</i> |
| I    | Measured current           |
| I>   | set <i>Start value</i>     |

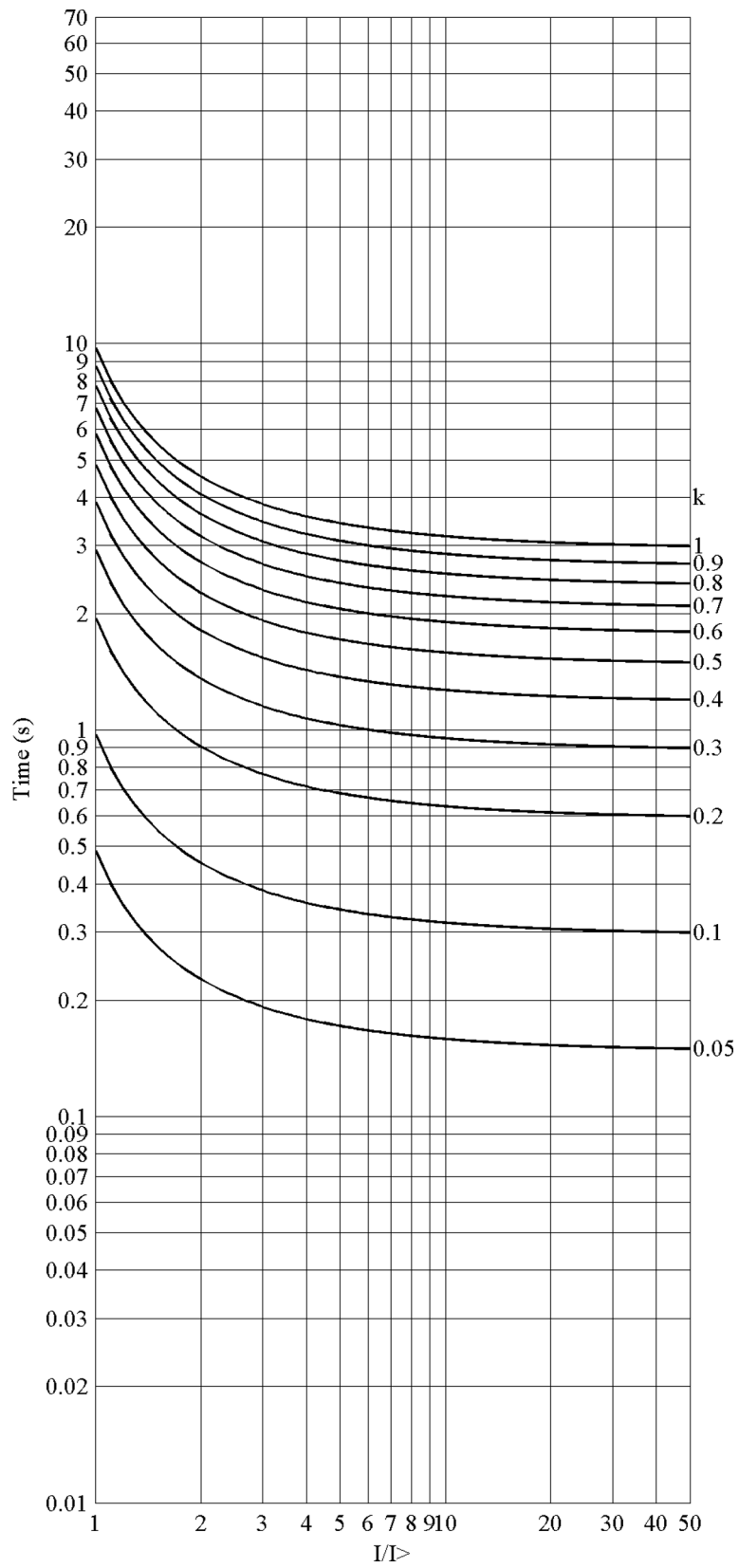


Figure 520: RI-type inverse-time characteristics



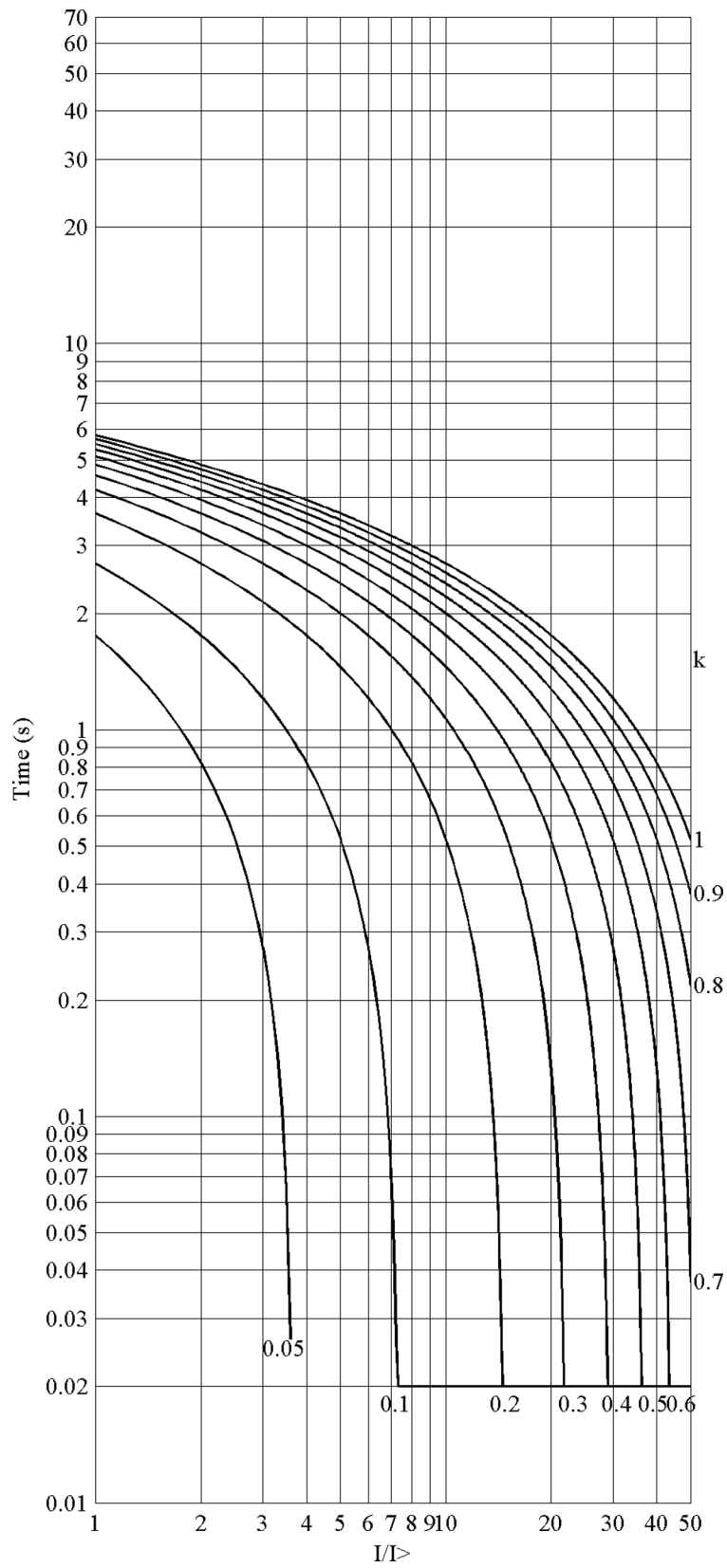


Figure 521: RD-type inverse-time characteristics

#### 10.2.1.4 UK rectifier inverse-time characteristic

The UK rectifier type simulates the rectifier bridge.

The operate times are defined with the coefficients A, B and C.

The values of the coefficients can be calculated according to the formula

$$t[s] = \left( \frac{A}{\left( \frac{I}{I>} \right)^C - 1} + B \right) \cdot k$$

t[s] Operate time in seconds

I Measured current

I> Set *Start value*

k Set *Time multiplier*

**Table 884: Curve parameters for UK rectifier**

| Operating curve type | A     | B | C   |
|----------------------|-------|---|-----|
| (20) UK rectifier    | 45900 | 0 | 5.6 |

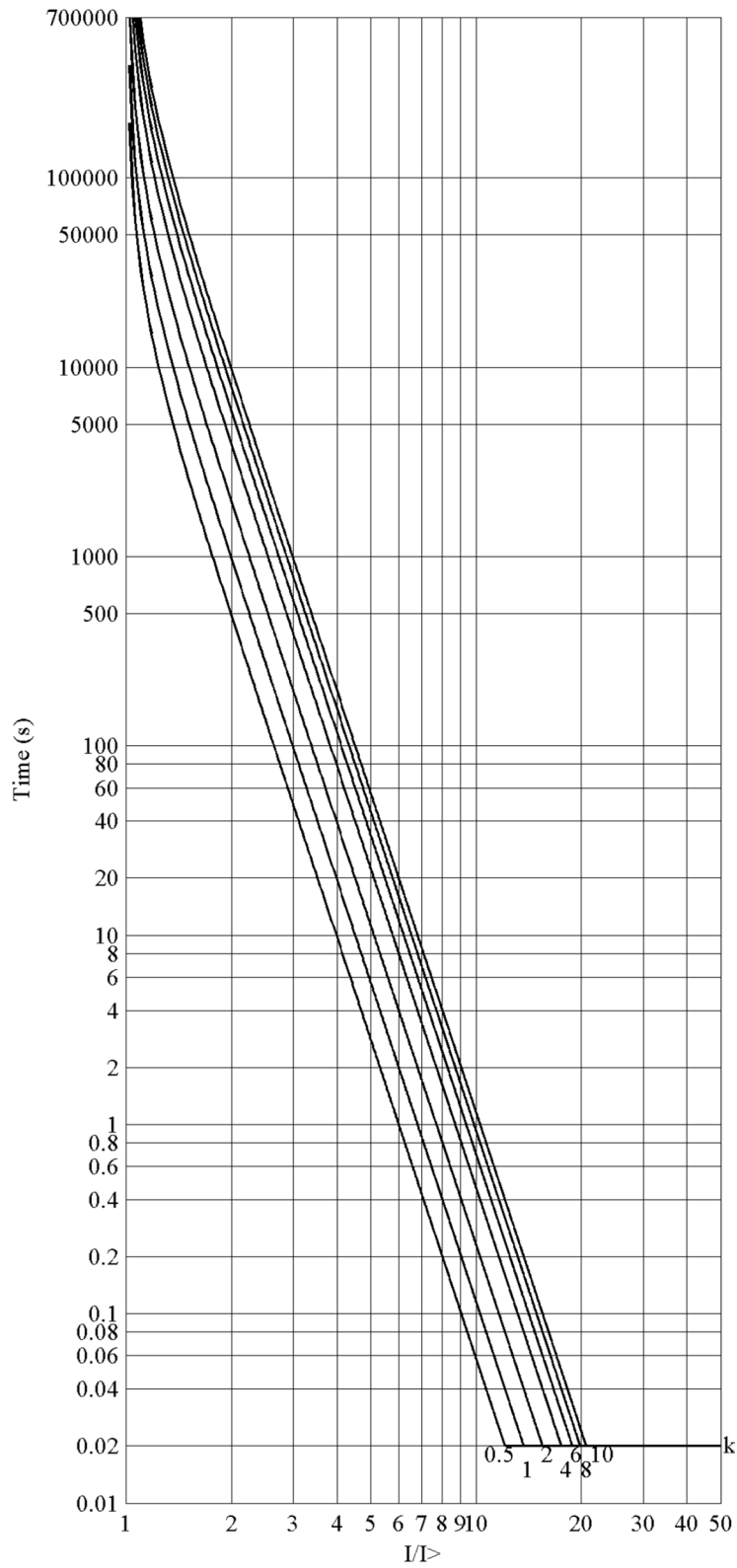


Figure 522: UK rectifier inverse-time characteristic

## 10.2.2 Reset in inverse-time modes

The user can select the reset characteristics by using the *Type of reset curve* setting.

**Table 885: Values for reset mode**

| Setting name               | Possible values                                    |
|----------------------------|--|
| <i>Type of reset curve</i> | 1=Immediate<br>2=Def time reset<br>3=Inverse reset |

### Immediate reset

If the *Type of reset curve* setting in a drop-off case is selected as "Immediate", the inverse timer resets immediately.

### Definite time reset

The definite type of reset in the inverse-time mode can be achieved by setting the *Type of reset curve* parameter to "Def time reset". As a result, the operate inverse-time counter is frozen for the time determined with the *Reset delay time* setting after the current drops below the set *Start value*, including hysteresis. The integral sum of the inverse-time counter is reset, if another start does not occur during the reset delay.



If the *Type of reset curve* setting is selected as "Def time reset", the current level has no influence on the reset characteristic.

### Inverse reset



Inverse reset curves are available only for ANSI and user-programmable curves. If you use other curve types, immediate reset occurs.

### Standard delayed inverse reset

The reset characteristic required in ANSI (IEEE) inverse-time modes is provided by setting the *Type of reset curve* parameter to "Inverse reset". In this mode, the time delay for reset is given with the following formula using the coefficient D, which has its values defined in the table below.

$$t[s] = \left( \frac{D}{\left( \frac{I}{I>} \right)^2 - 1} \right) \cdot k$$

t[s]

Reset time (in seconds)

k

set *Time multiplier*

I

Measured current

I>

set *Start value*

**Table 886: Coefficients for ANSI delayed inverse reset curves**

| <b>Curve name</b>               | <b>D</b> |
|---------------------------------|----------|
| (1) ANSI Extremely Inverse      | 29.1     |
| (2) ANSI Very Inverse           | 21.6     |
| (3) ANSI Normal Inverse         | 0.46     |
| (4) ANSI Moderately Inverse     | 4.85     |
| (6) Long Time Extremely Inverse | 30       |
| (7) Long Time Very Inverse      | 13.46    |
| (8) Long Time Inverse           | 4.6      |

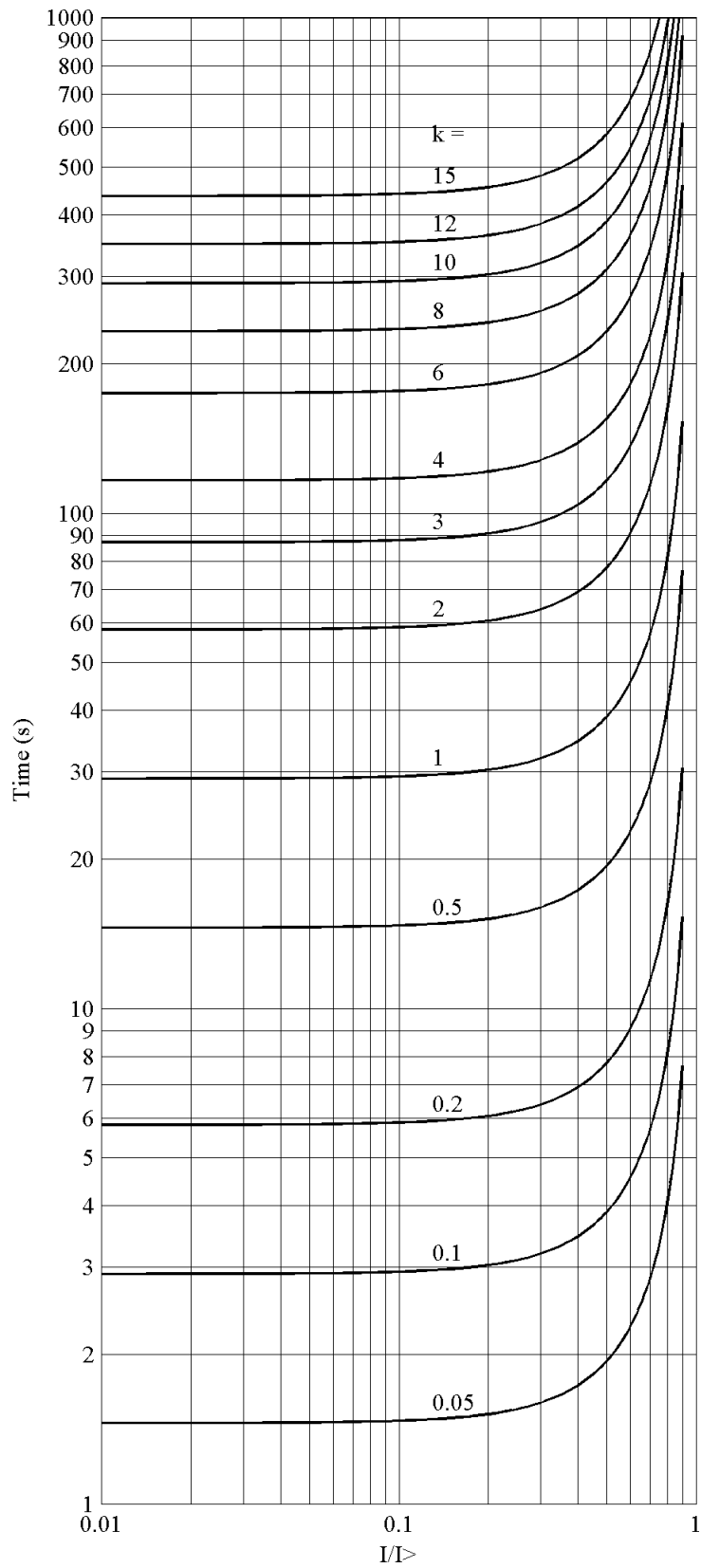


Figure 523: ANSI extremely inverse reset time characteristics

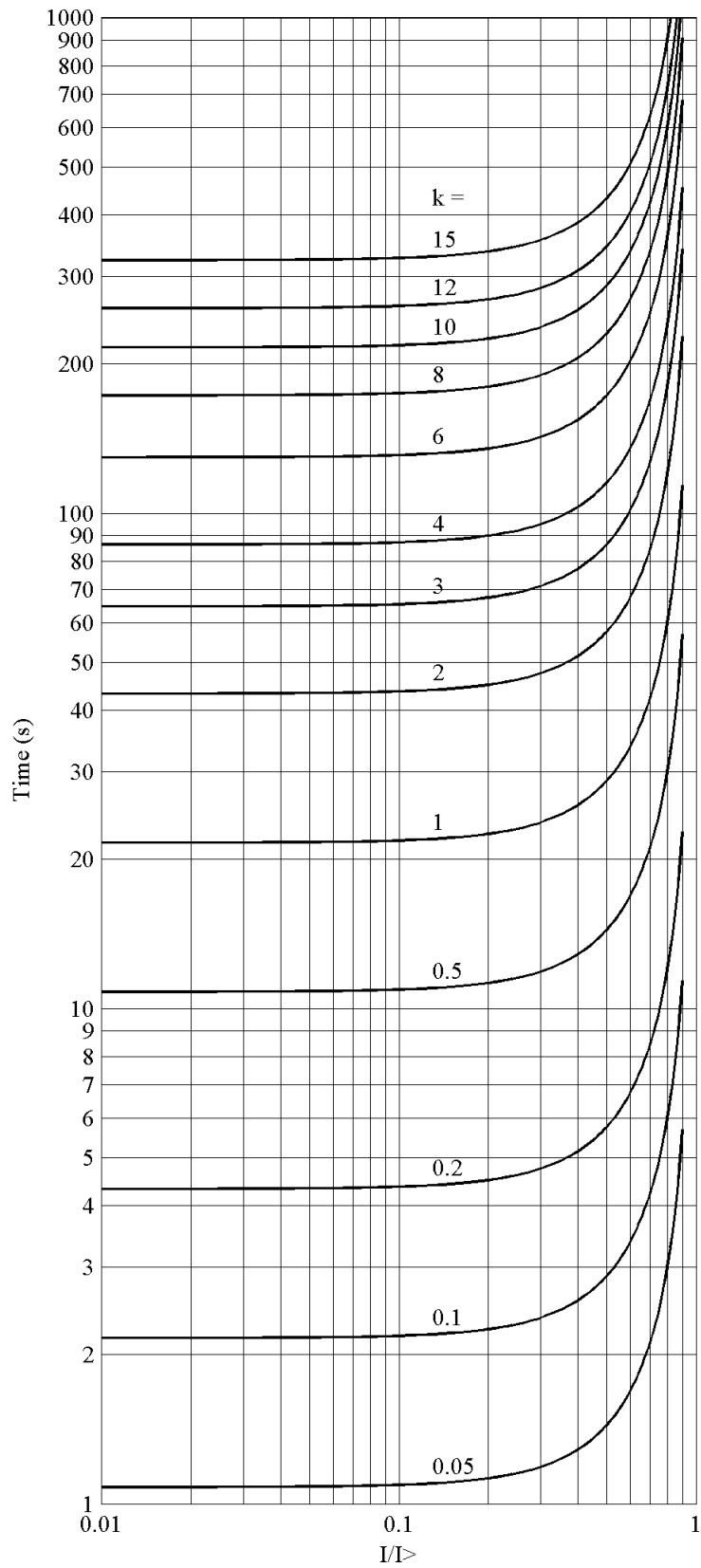


Figure 524: ANSI very inverse reset time characteristics

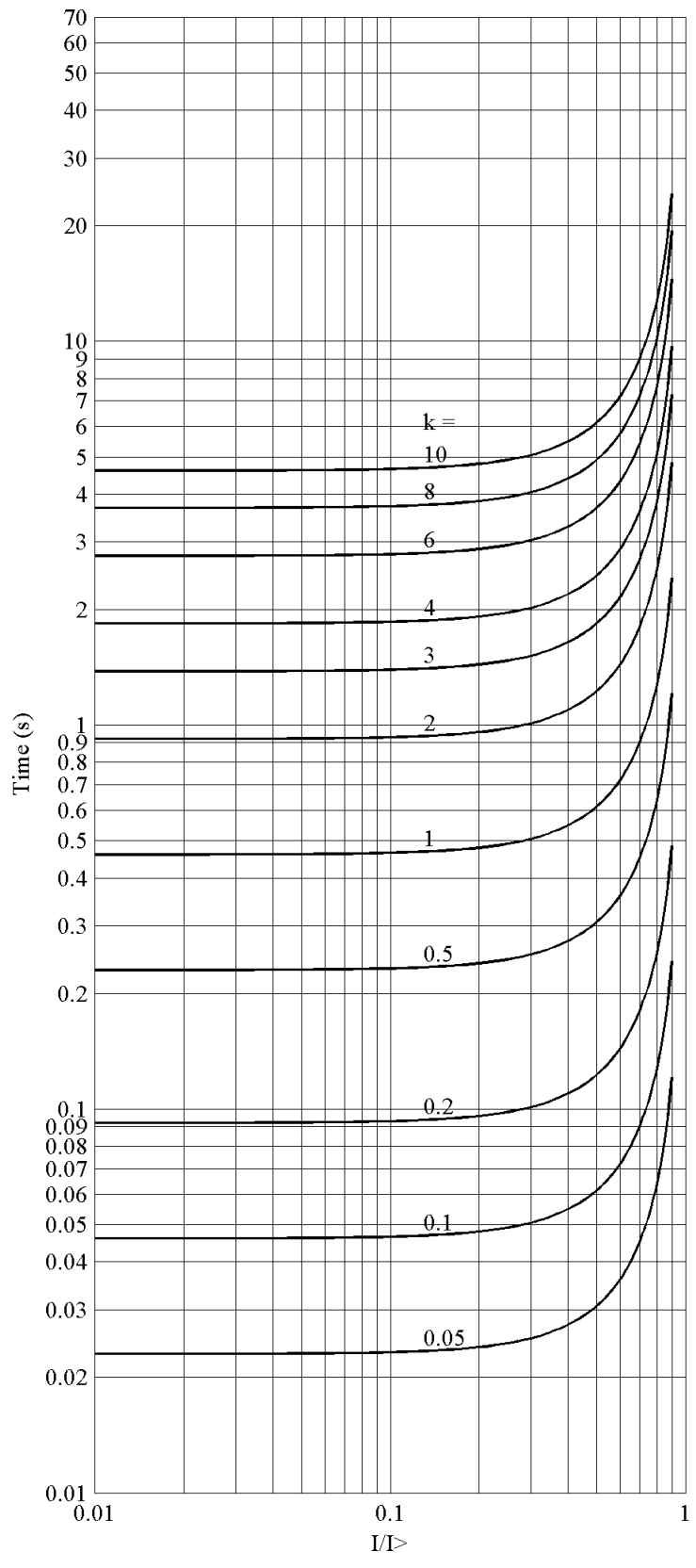


Figure 525: ANSI normal inverse reset time characteristics



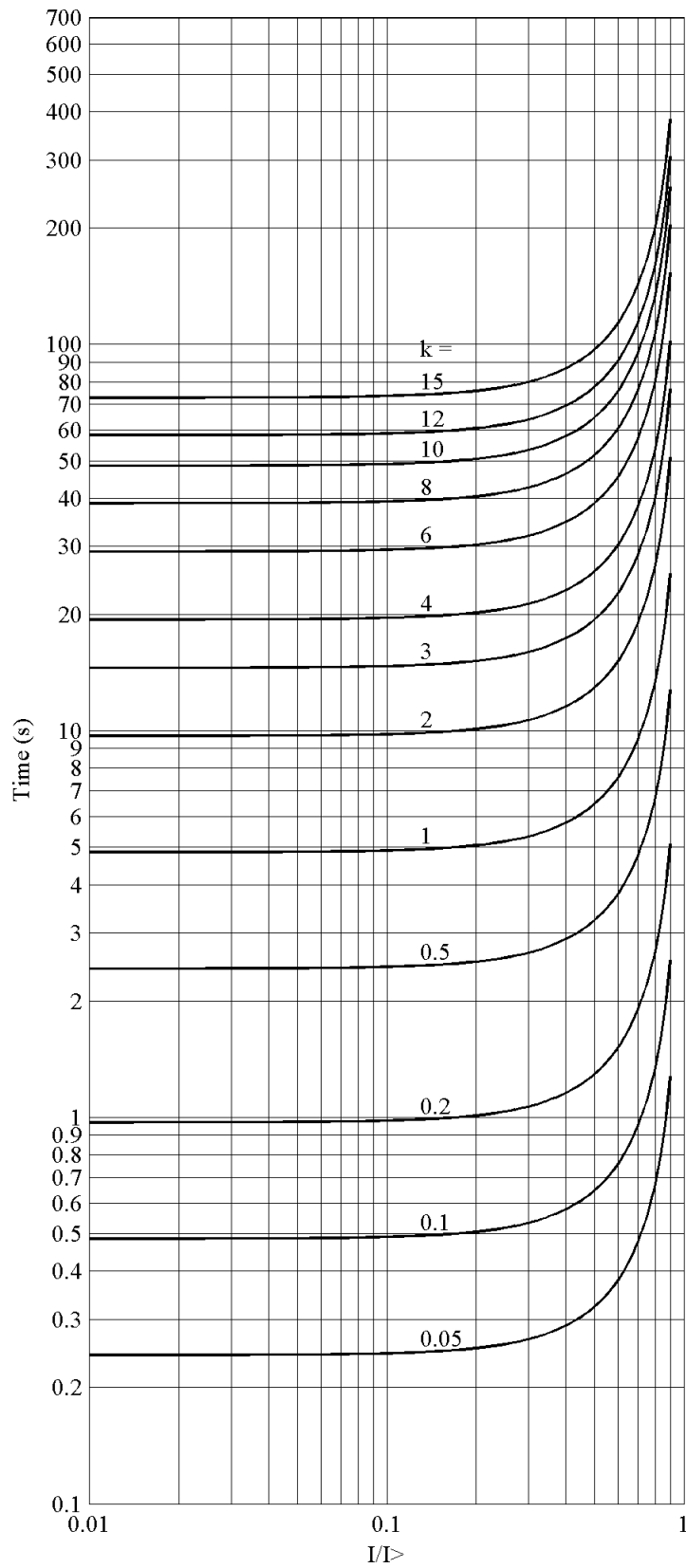


Figure 526: ANSI moderately inverse reset time characteristics

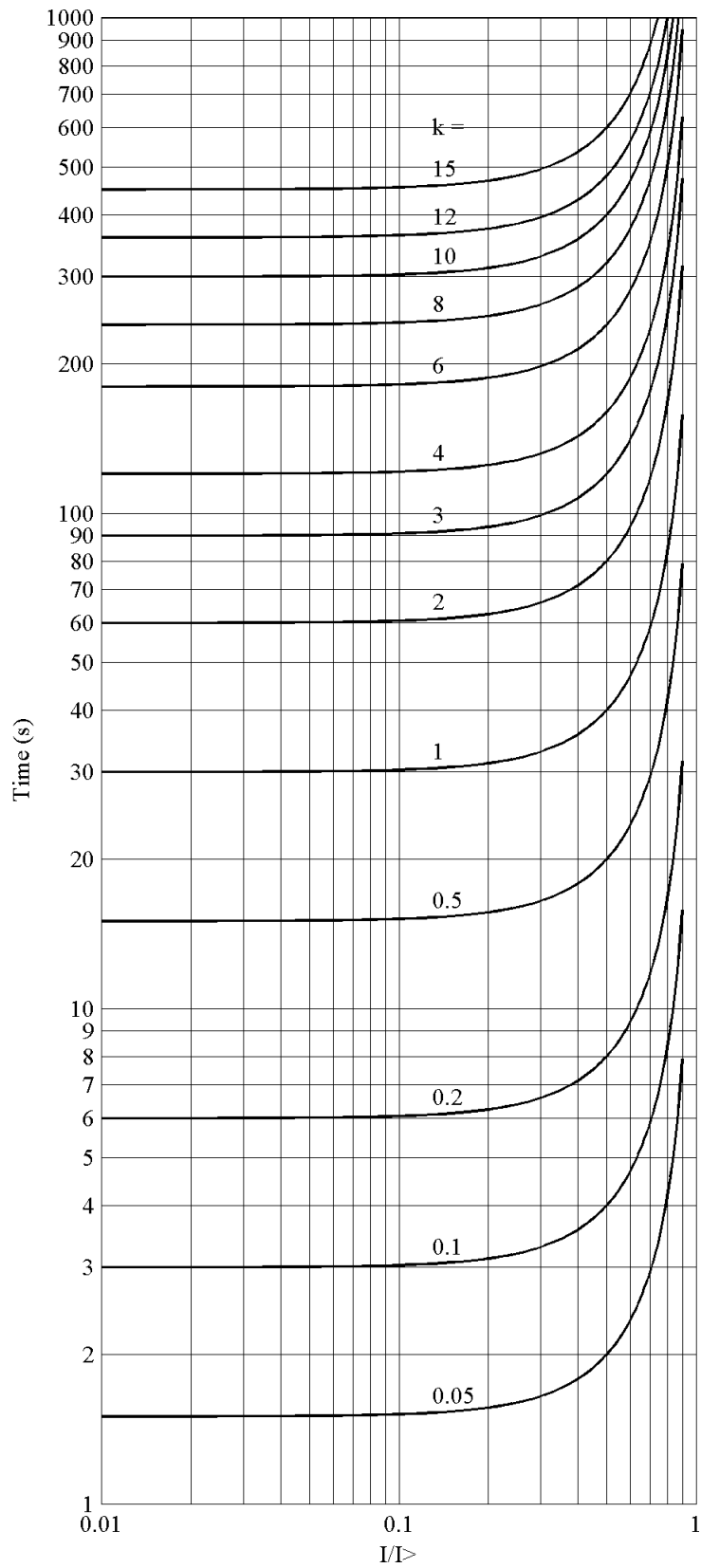


Figure 527: ANSI long-time extremely inverse reset time characteristics

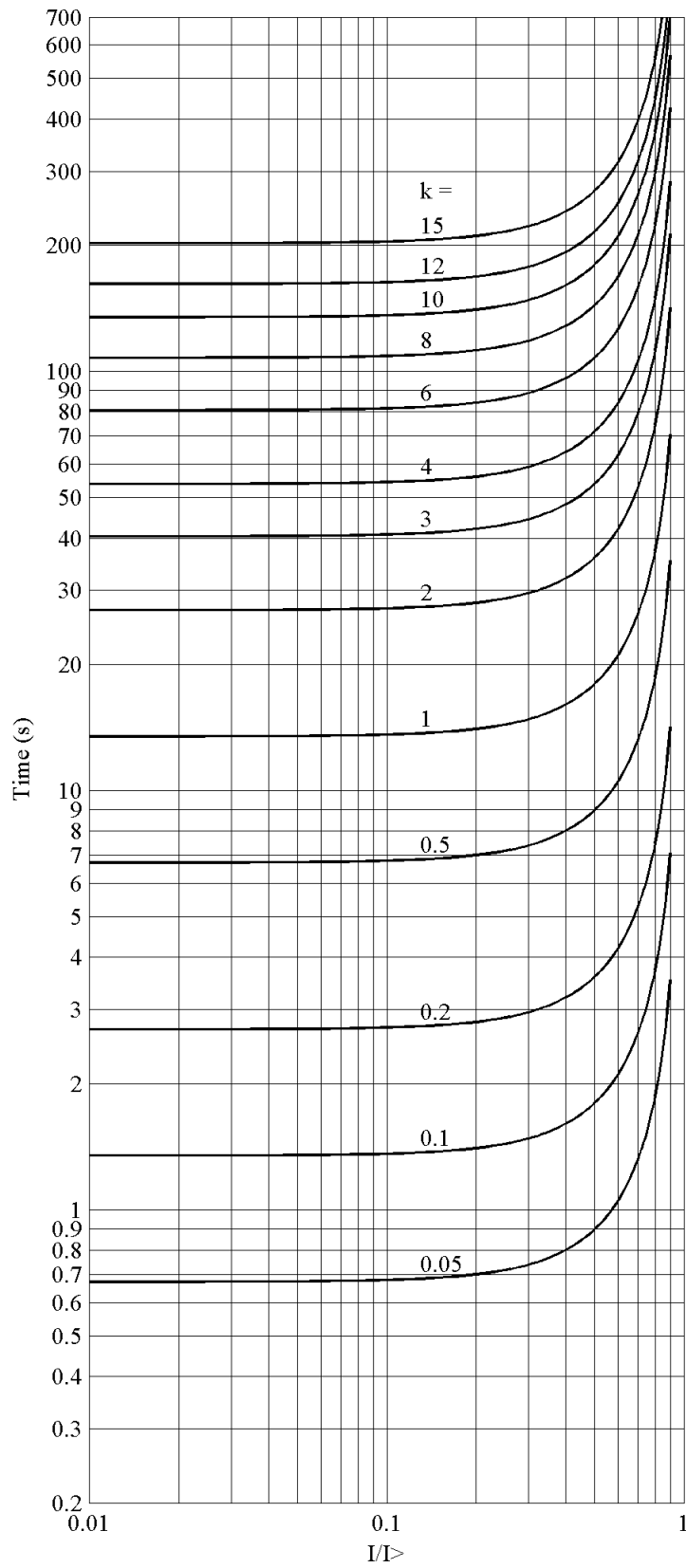


Figure 528: ANSI long-time very inverse reset time characteristics

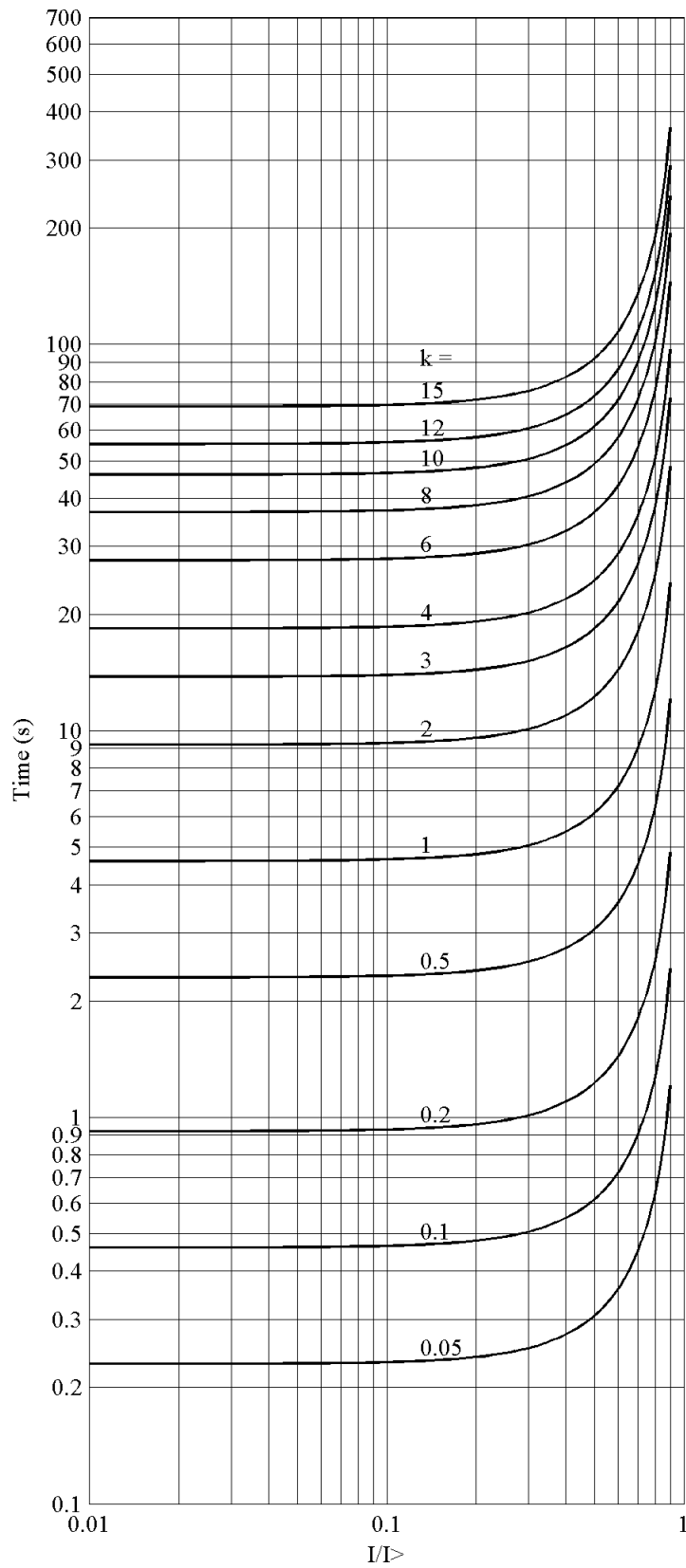


Figure 529: ANSI long-time inverse reset time characteristics



The delayed inverse-time reset is not available for IEC-type inverse time curves.

### User-programmable delayed inverse reset

The user can define the delayed inverse reset time characteristics with the following formula using the set *Curve parameter D*.

$$t[s] = \left( \frac{D}{\left( \frac{I}{I>} \right)^2 - 1} \right) \cdot k$$

|      |                              |
|------|------------------------------|
| t[s] | Reset time (in seconds)      |
| k    | set <i>Time multiplier</i>   |
| D    | set <i>Curve parameter D</i> |
| I    | Measured current             |
| I>   | set <i>Start value</i>       |

## 10.2.3 Inverse timer freezing

When the **BLOCK** input is active, the internal value of the time counter is frozen at the value of the moment just before the freezing. Freezing of the counter value is chosen when the user does not wish the counter value to count upwards or to be reset. This may be the case, for example, when the inverse-time function of an IED needs to be blocked to enable the definite-time operation of another IED for selectivity reasons, especially if different relaying techniques (old and modern relays) are applied.



The selected blocking mode is "Freeze timer".



The activation of the **BLOCK** input also lengthens the minimum delay value of the timer.

Activating the **BLOCK** input alone does not affect the operation of the **START** output. It still becomes active when the current exceeds the set *Start value*, and inactive when the current falls below the set *Start value* and the set *Reset delay time* has expired.

## 10.3 Voltage based inverse definite minimum time characteristics

### 10.3.1 IDMT curves for overvoltage protection

In inverse-time modes, the operate time depends on the momentary value of the voltage, the higher the voltage, the faster the operate time. The operate time calculation or integration starts immediately when the voltage exceeds the set value of the *Start value* setting and the `START` output is activated.

The `OPERATE` output of the component is activated when the cumulative sum of the integrator calculating the overvoltage situation exceeds the value set by the inverse time mode. The set value depends on the selected curve type and the setting values used. The user determines the curve scaling with the *Time multiplier* setting.

The *Minimum operate time* setting defines the minimum operate time for the IDMT mode, that is, it is possible to limit the IDMT based operate time for not becoming too short. For example:

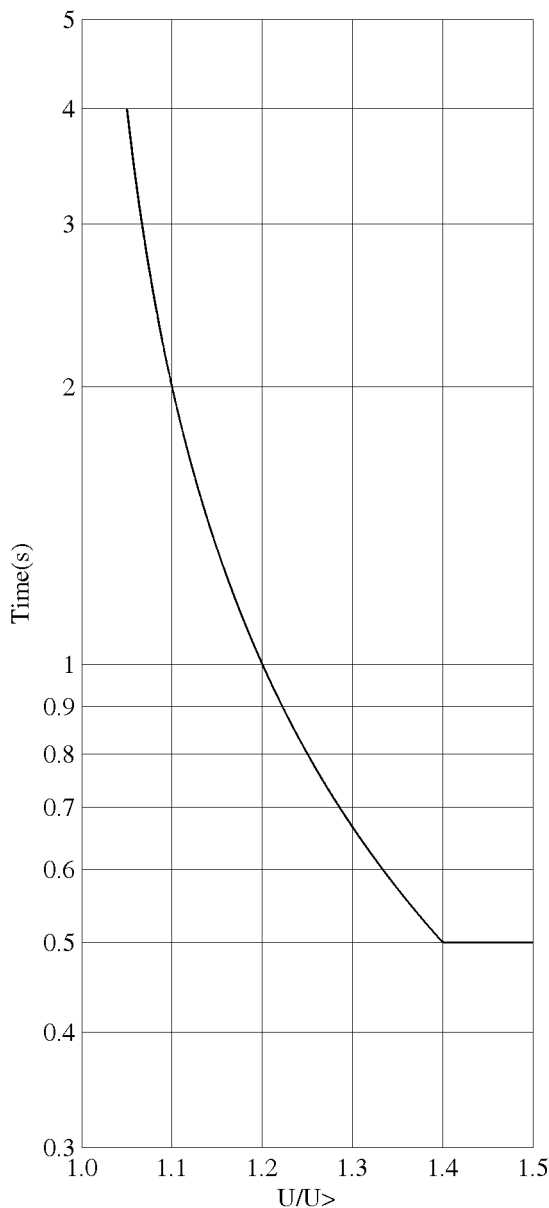


Figure 530: Operate time curve based on IDMT characteristic with Minimum operate time set to 0.5 second

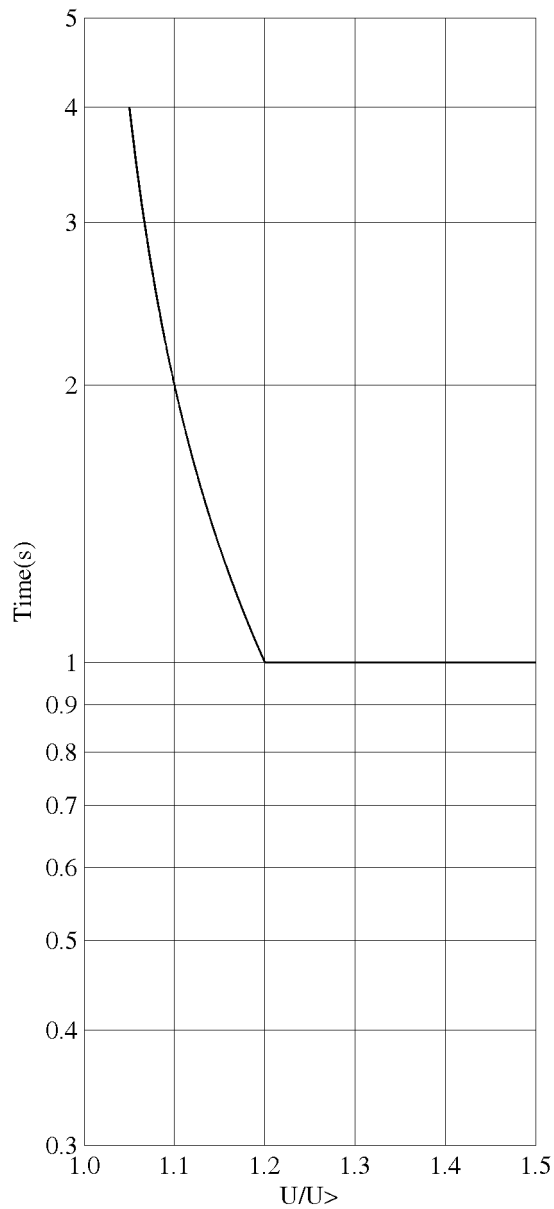


Figure 531: Operate time curve based on IDMT characteristic with Minimum operate time set to 1 second

### 10.3.1.1 Standard inverse-time characteristics for overvoltage protection

The operate times for the standard overvoltage IDMT curves are defined with the coefficients A, B, C, D and E.

The inverse operate time can be calculated with the formula:

$$t [s] = \frac{k \cdot A}{\left( B \times \frac{U - U >}{U >} - C \right)^E} + D$$

|       |   |
|-------|---|
| t [s] | operate time in seconds                 |
| U     | measured voltage                        |
| U>    | the set value of <i>Start value</i>     |
| k     | the set value of <i>Time multiplier</i> |

**Table 887: Curve coefficients for the standard overvoltage IDMT curves**

| Curve name           | A   | B  | C   | D     | E |
|----------------------|-----|----|-----|-------|---|
| (17) Inverse Curve A | 1   | 1  | 0   | 0     | 1 |
| (18) Inverse Curve B | 480 | 32 | 0.5 | 0.035 | 2 |
| (19) Inverse Curve C | 480 | 32 | 0.5 | 0.035 | 3 |



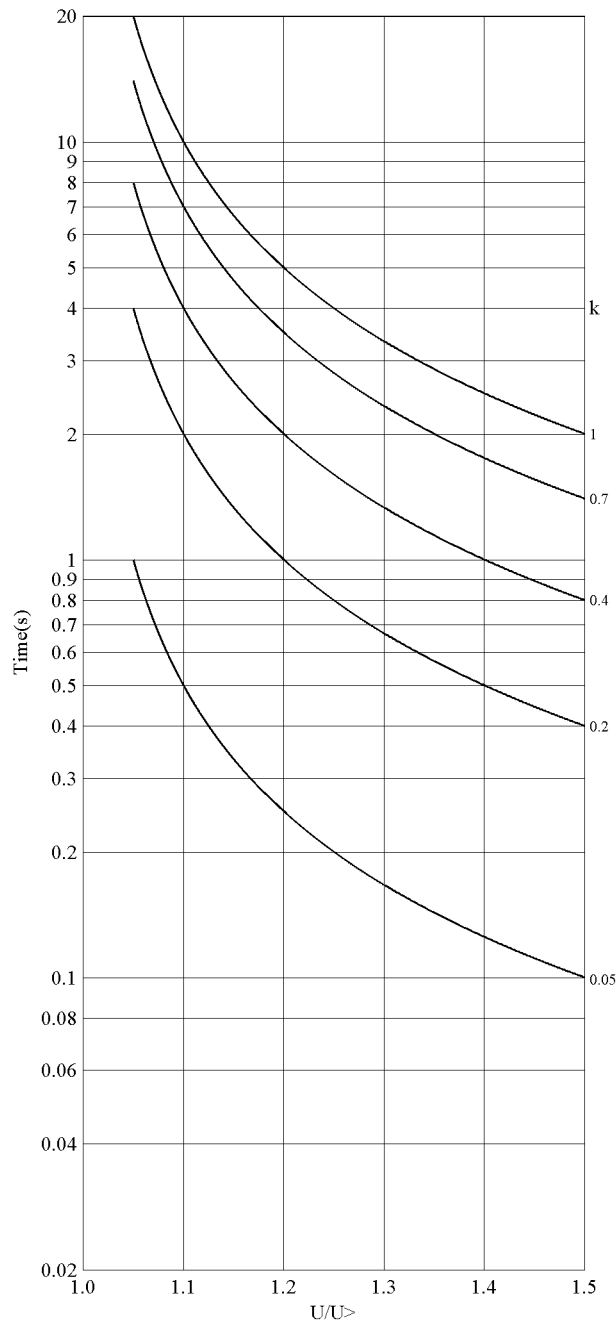


Figure 532: Inverse curve A characteristic of overvoltage protection

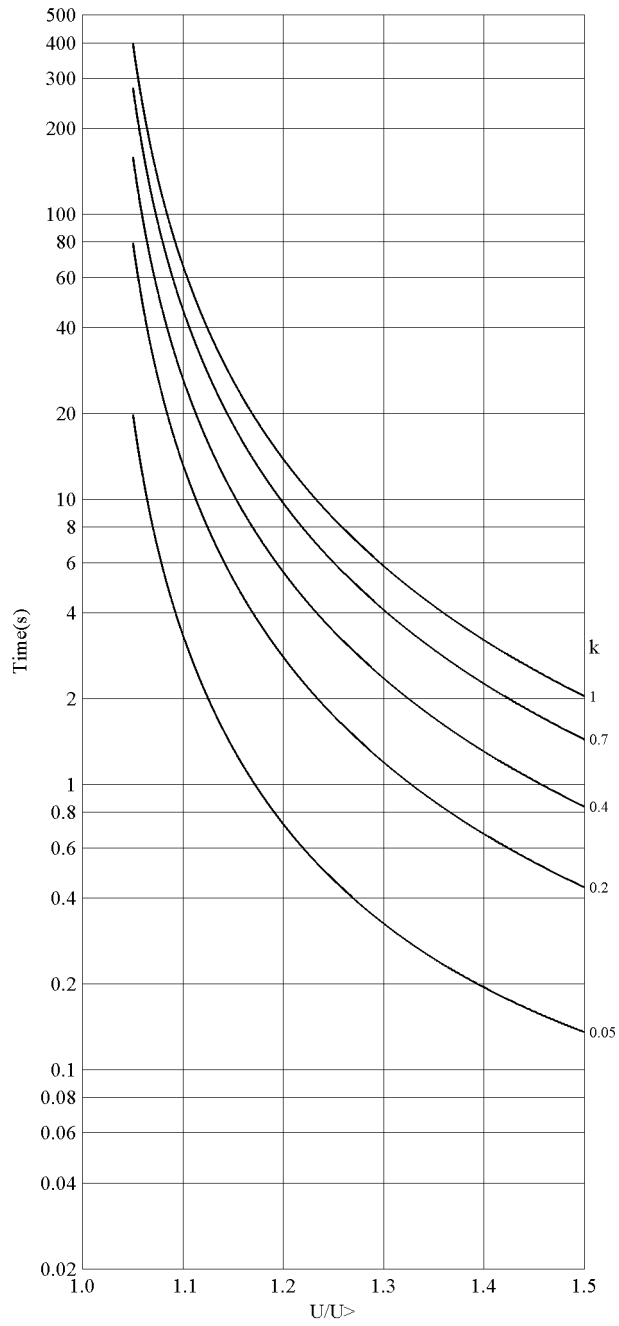


Figure 533: Inverse curve B characteristic of overvoltage protection

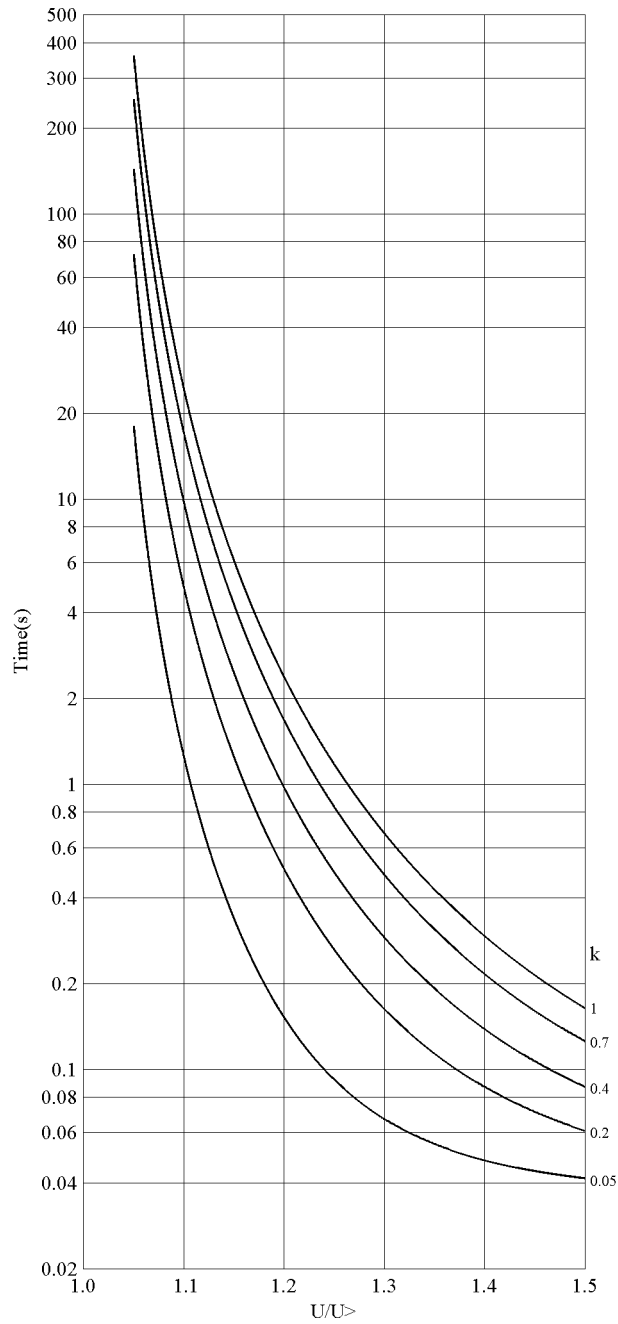


Figure 534: Inverse curve C characteristic of overvoltage protection

### 10.3.1.2 User programmable inverse-time characteristics for overvoltage protection

The user can define the curves by entering the parameters using the standard formula:

$$t[S] = \frac{k \cdot A}{\left( B \times \frac{U - U >}{U >} - C \right)^E} + D$$

|      |   |
|------|---|
| t[s] | operate time in seconds                   |
| A    | the set value of <i>Curve parameter A</i> |
| B    | the set value of <i>Curve parameter B</i> |
| C    | the set value of <i>Curve parameter C</i> |
| D    | the set value of <i>Curve parameter D</i> |
| E    | the set value of <i>Curve parameter E</i> |
| U    | measured voltage                          |
| U>   | the set value of <i>Start value</i>       |
| k    | the set value of <i>Time multiplier</i>   |

### 10.3.1.3 IDMT curve saturation of overvoltage protection

For the overvoltage IDMT mode of operation, the integration of the operate time does not start until the voltage exceeds the value of *Start value*. To cope with discontinuity characteristics of the curve, a specific parameter for saturating the equation to a fixed value is created. The *Curve Sat Relative* setting is the parameter and it is given in percents compared to *Start value*. For example, due to the curve equation B and C, the characteristics equation output is saturated in such a way that when the input voltages are in the range of *Start value* to *Curve Sat Relative* in percent over *Start value*, the equation uses *Start value* \* (1.0 + *Curve Sat Relative* / 100 ) for the measured voltage. Although, the curve A has no discontinuities when the ratio U/U> exceeds the unity, *Curve Sat Relative* is also set for it. The *Curve Sat Relative* setting for curves A, B and C is 2.0 percent. However, it should be noted that the user must carefully calculate the curve characteristics concerning the discontinuities in the curve when the programmable curve equation is used. Thus, the *Curve Sat Relative* parameter gives another degree of freedom to move the inverse curve on the voltage ratio axis and it effectively sets the maximum operate time for the IDMT curve because for the voltage ratio values affecting by this setting, the operation time is fixed, that is, the definite time, depending on the parameters but no longer the voltage.

### 10.3.2 IDMT curves for undervoltage protection

In the inverse-time modes, the operate time depends on the momentary value of the voltage, the lower the voltage, the faster the operate time. The operate time calculation or integration starts immediately when the voltage goes below the set value of the *Start value* setting and the `START` output is activated.

The `OPERATE` output of the component is activated when the cumulative sum of the integrator calculating the undervoltage situation exceeds the value set by the inverse-time mode. The set value depends on the selected curve type and the setting values used. The user determines the curve scaling with the *Time multiplier* setting.

The *Minimum operate time* setting defines the minimum operate time possible for the IDMT mode. For setting a value for this parameter, the user should carefully study the particular IDMT curve.

### 10.3.2.1 Standard inverse-time characteristics for undervoltage protection

The operate times for the standard undervoltage IDMT curves are defined with the coefficients A, B, C, D and E.

The inverse operate time can be calculated with the formula:

$$t [s] = \frac{k \cdot A}{\left( B \times \frac{U < -U}{U <} - C \right)^E} + D$$

t [s] operate time in seconds

U measured voltage

U< the set value of the *Start value* setting

k the set value of the *Time multiplier* setting

**Table 888: Curve coefficients for standard undervoltage IDMT curves**

| Curve name           | A   | B  | C   | D     | E |
|----------------------|-----|----|-----|-------|---|
| (21) Inverse Curve A | 1   | 1  | 0   | 0     | 1 |
| (22) Inverse Curve B | 480 | 32 | 0.5 | 0.055 | 2 |

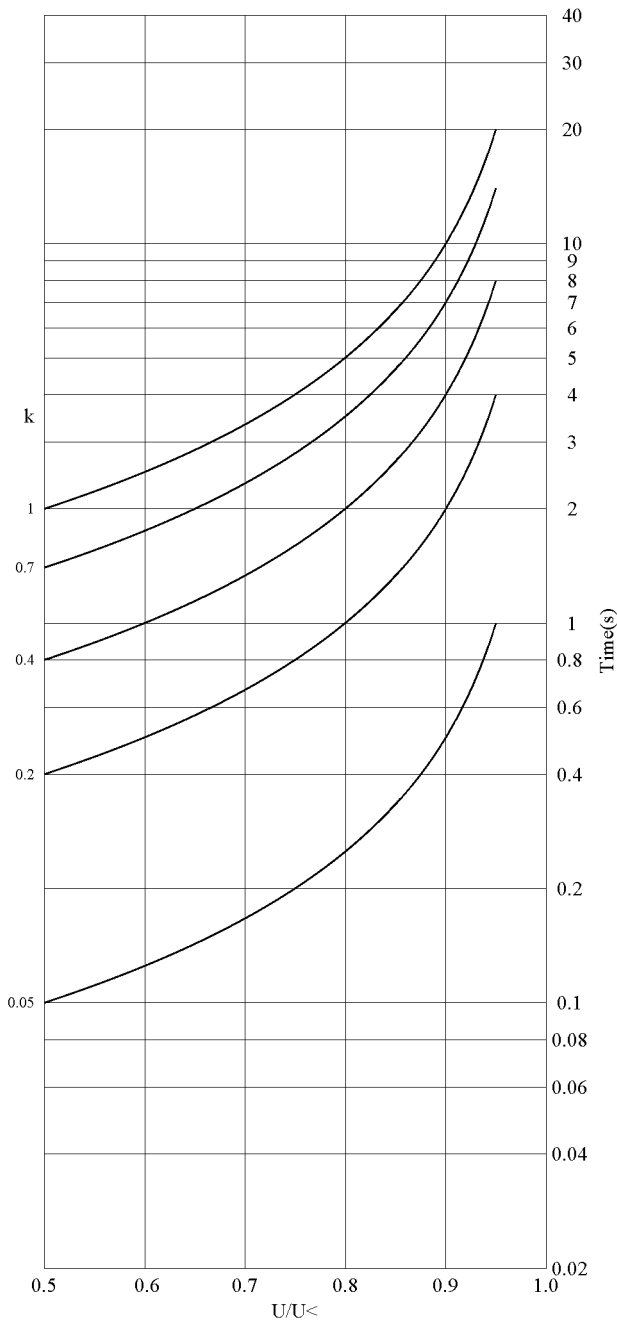


Figure 535: Inverse curve A characteristic of undervoltage protection

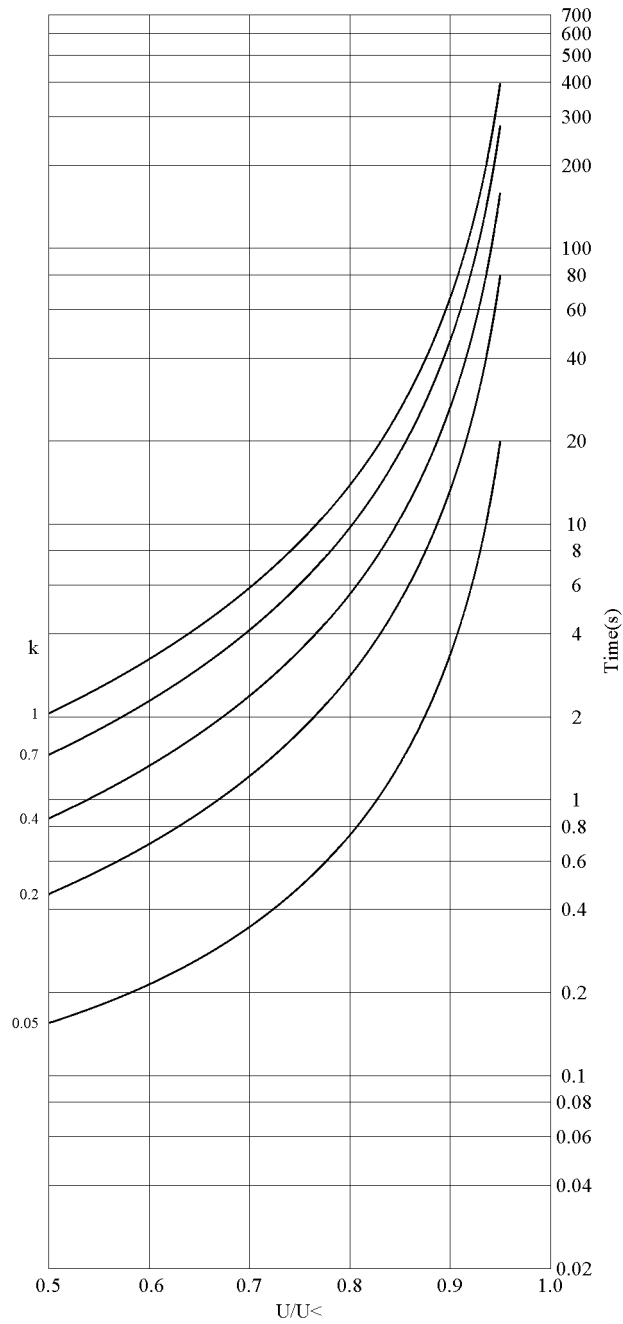


Figure 536: Inverse curve B characteristic of undervoltage protection

### 10.3.2.2 User-programmable inverse-time characteristics for undervoltage protection

The user can define curves by entering parameters into the standard formula:

$$t[S] = \frac{k \cdot A}{\left( B \times \frac{U < -U}{U <} - C \right)^E} + D$$

|      |   |
|------|---|
| t[s] | operate time in seconds                   |
| A    | the set value of <i>Curve parameter A</i> |
| B    | the set value of <i>Curve parameter B</i> |
| C    | the set value of <i>Curve parameter C</i> |
| D    | the set value of <i>Curve parameter D</i> |
| E    | the set value of <i>Curve parameter E</i> |
| U    | measured voltage                          |
| U<   | the set value of <i>Start value</i>       |
| k    | the set value of <i>Time multiplier</i>   |

### 10.3.2.3 IDMT curve saturation of undervoltage protection

For the undervoltage IDMT mode of operation, the integration of the operate time does not start until the voltage falls below the value of *Start value*. To cope with discontinuity characteristics of the curve, a specific parameter for saturating the equation to a fixed value is created. The *Curve Sat Relative* setting is the parameter and it is given in percents compared with *Start value*. For example, due to the curve equation B, the characteristics equation output is saturated in such a way that when input voltages are in the range from *Start value* to *Curve Sat Relative* in percents under *Start value*, the equation uses *Start value* \* (1.0 - *Curve Sat Relative*/ 100 ) for the measured voltage. Although, the curve A has no discontinuities when the ratio U/U> exceeds the unity, *Curve Sat Relative* is set for it as well. The *Curve Sat Relative* setting for curves A, B and C is 2.0 percent. However, it should be noted that the user must carefully calculate the curve characteristics concerning also discontinuities in the curve when the programmable curve equation is used. Thus, the *Curve Sat Relative* parameter gives another degree of freedom to move the inverse curve on the voltage ratio axis and it effectively sets the maximum operate time for the IDMT curve because for the voltage ratio values affecting by this setting, the operation time is fixed, that is, the definite time, depending on the parameters but no longer the voltage.

## 10.4 Frequency measurement and protection

All the function blocks that use frequency quantity as their input signal share the common features related to the frequency measurement algorithm. The frequency estimation is done from one phase (phase-to-phase or phase voltage) or from the positive phase sequence ( PPS). The voltage groups with three-phase inputs use PPS as the source. The frequency measurement range is 0.6...1.5 × F<sub>n</sub>. The df/dt measurement range always starts from 0.6 × F<sub>n</sub>. When the frequency exceeds these limits, it is regarded as out of range and a minimum or maximum value is held as the measured value respectively with appropriate quality information. The frequency estimation requires 160 ms to stabilize after a bad quality signal. Therefore, a delay



of 160 ms is added to the transition from the bad quality. The bad quality of the signal can be due to restrictions like:

- The source voltage is below  $0.02 \times U_n$  at  $F_n$ .
- The source voltage waveform is discontinuous.
- The source voltage frequency rate of change exceeds 15 Hz/s (including stepwise frequency changes).

When the bad signal quality is obtained, the nominal or zero (depending on the *Def frequency Sel* setting) frequency value is shown with appropriate quality information in the measurement view. The frequency protection functions are blocked when the quality is bad, thus the timers and the function outputs are reset. When the frequency is out of the function block's setting range but within the measurement range, the protection blocks are running. However, the OPERATE outputs are blocked until the frequency restores to a valid range.

## 10.5 Measurement modes

In many current or voltage dependent function blocks, there are various alternative measuring principles.

- RMS
- DFT which is a numerically calculated fundamental component of the signal
- Peak-to-peak
- Peak-to-peak with peak backup

Consequently, the measurement mode can be selected according to the application.

In extreme cases, for example with high overcurrent or harmonic content, the measurement modes function in a slightly different way. The operation accuracy is defined with the frequency range of  $f/f_n=0.95\dots1.05$ . In peak-to-peak and RMS measurement modes, the harmonics of the phase currents are not suppressed, whereas in the fundamental frequency measurement the suppression of harmonics is at least -50 dB at the frequency range of  $f=n \times f_n$ , where  $n = 2, 3, 4, 5, \dots$

### RMS

The RMS measurement principle is selected with the *Measurement mode* setting using the value "RMS". RMS consists of both AC and DC components. The AC component is the effective mean value of the positive and negative peak values. RMS is used in applications where the effect of the DC component must be taken into account.

RMS is calculated according to the formula:

$$I_{RMS} = \sqrt{\frac{1}{n} \sum_{i=1}^n I_i^2}$$

$n$

The number of samples in a calculation cycle

$I_i$

The current sample value

**DFT**

The DFT measurement principle is selected with the *Measurement mode* setting using the value "DFT". In the DFT mode, the fundamental frequency component of the measured signal is numerically calculated from the samples. In some applications, for example, it can be difficult to accomplish sufficiently sensitive settings and accurate operation of the low stage, which may be due to a considerable amount of harmonics on the primary side currents. In such a case, the operation can be based solely on the fundamental frequency component of the current. In addition, the DFT mode has slightly higher CT requirements than the peak-to-peak mode, if used with high and instantaneous stages.

**Peak-to-peak**

The peak-to-peak measurement principle is selected with the *Measurement mode* setting using the value "Peak-to-Peak". It is the fastest measurement mode, in which the measurement quantity is made by calculating the average from the positive and negative peak values. The DC component is not included. The retardation time is short. The damping of the harmonics is quite low and practically determined by the characteristics of the anti-aliasing filter of the IED inputs. Consequently, this mode is usually used in conjunction with high and instantaneous stages, where the suppression of harmonics is not so important. In addition, the peak-to-peak mode allows considerable CT saturation without impairing the performance of the operation.

**Peak-to-peak with peak backup**

The peak-to-peak with peak backup measurement principle is selected with the *Measurement mode* setting using the value "P-to-P+backup". It is similar to the peak-to-peak mode, with the exception that it has been enhanced with the peak backup. In the peak-to-peak with peak backup mode, the function starts with two conditions: the peak-to-peak value is above the set start current or the peak value is above two times the set *Start value*. The peak backup is enabled only when the function is used in the DT mode in high and instantaneous stages for faster operation.

## 10.6 Calculated measurements

**Calculated residual current and voltage**

The residual current is calculated from the phase currents according to equation:

$$\bar{I}_0 = -(\bar{I}_A + \bar{I}_B + \bar{I}_C)$$

The residual voltage is calculated from the phase-to-earth voltages when the VT connection is selected as "Wye" with the equation:

$$\bar{U}_0 = (\bar{U}_A + \bar{U}_B + \bar{U}_C)/3$$

**Sequence components**

The phase-sequence current components are calculated from the phase currents according to:

$$\bar{I}_0 = (\bar{I}_A + \bar{I}_B + \bar{I}_C)/3$$

$$\bar{I}_1 = (\bar{I}_A + a \cdot \bar{I}_B + a^2 \cdot \bar{I}_C) / 3$$

$$\bar{I}_2 = (\bar{I}_A + a^2 \cdot \bar{I}_B + a \cdot \bar{I}_C) / 3$$

The phase-sequence voltage components are calculated from the phase-to-earth voltages when *VT connection* is selected as "Wye" with the equations:

$$\bar{U}_0 = (\bar{U}_A + \bar{U}_B + \bar{U}_C) / 3$$

$$\bar{U}_1 = (\bar{U}_A + a \cdot \bar{U}_B + a^2 \cdot \bar{U}_C) / 3$$

$$\bar{U}_2 = (\bar{U}_A + a^2 \cdot \bar{U}_B + a \cdot \bar{U}_C) / 3$$

When *VT connection* is selected as "Delta", the positive and negative phase sequence voltage components are calculated from the phase-to-phase voltages according to the equations:

$$\bar{U}_1 = (\bar{U}_{AB} - a^2 \cdot \bar{U}_{BC}) / 3$$

$$\bar{U}_2 = (\bar{U}_{AB} - a \cdot \bar{U}_{BC}) / 3$$

The phase-to-earth voltages are calculated from the phase-to-phase voltages when *VT connection* is selected as "Delta" according to the equations.

$$\bar{U}_A = \bar{U}_0 + (\bar{U}_{AB} - \bar{U}_{CA}) / 3$$

$$\bar{U}_B = \bar{U}_0 + (\bar{U}_{BC} - \bar{U}_{AB}) / 3$$

$$\bar{U}_C = \bar{U}_0 + (\bar{U}_{CA} - \bar{U}_{BC}) / 3$$

If the  $\bar{U}_0$  channel is not valid, it is assumed to be zero.

The phase-to-phase voltages are calculated from the phase-to-earth voltages when *VT connection* is selected as "Wye" according to the equations.

$$\bar{U}_{AB} = \bar{U}_A - \bar{U}_B$$

$$\bar{U}_{BC} = \bar{U}_B - \bar{U}_C$$

$$\bar{U}_{CA} = \bar{U}_C - \bar{U}_A$$

# 11 Environmental aspects

## 11.1 Sustainable development

Sustainability has been taken into account from the beginning of the product design including the pro-environmental manufacturing process, long life time, operation reliability and disposing of the device.

The choice of materials and the suppliers have been made according to the EU RoHS directive (2011/65/EU). This directive limits the use of hazardous substances which are the following:

**Table 889: Maximum concentration values by weight per homogeneous material**

| Substance                             | Proposed maximum concentration |
|---------------------------------------|--------------------------------|
| Lead - Pb                             | 0.1%                           |
| Mercury - Hg                          | 0.1%                           |
| Cadmium - Cd                          | 0.01%                          |
| Hexavalent Chromium Cr (VI)           | 0.1%                           |
| Polybrominated biphenyls - PBB        | 0.1%                           |
| Polybrominated diphenyl ethers - PBDE | 0.1%                           |

Operational reliability and long life time have been assured with extensive testing during the design and manufacturing processes. Moreover, long life time is supported by maintenance and repair services as well as by the availability of spare parts.

Design and manufacturing have been done under a certified environmental system. The effectiveness of the environmental system is constantly evaluated by an external auditing body. We follow environmental rules and regulations systematically to evaluate their effect on our products and processes.

## 11.2 Disposal of an IED

Definitions and regulations of hazardous materials are country-specific and change when the knowledge of materials increases. The materials used in this product are typical for electric and electronic devices.

All parts used in this product are recyclable. When disposing of an IED or its parts contact a local waste handler who is authorized and specialized in disposing of electronic waste. These handlers can sort the material by using dedicated sorting processes and dispose of the product according to the local requirements.

## 12 IED and functionality tests

Table 890: Electromagnetic Compatibility (EMC)

| Description  | IEC 61850-3 Reference | Requirement   | Test standard                                    | Test ports  |
|--|-----------------------|---|--|-------------|
| Electrostatic discharge  | 6.7.3                 | 6 kV contact<br>8 kV air  | IEC 60255-26<br>IEC 61000-4-2                    | E           |
| Radiated, radiofrequency electromagnetic field 80 MHz - 2700 MHz | 6.7.3                 | AM 80% 1kHz, 10 V/m   | IEC 60255-26<br>IEC 61000-4-3                    | E           |
| Fast transient/burst   | 6.7.3                 | 2 kV<br>1 kV<br>2 kV  | IEC 60255-26<br>IEC 61000-4-4                    | A<br>B<br>D |
| Surge  | 6.7.3                 | line to ground 2,0 kV<br>line to line 1,0 kV<br>line to ground 2,0 kV   | IEC 60255-26<br>IEC 61000-4-5                    | A<br>A<br>B |
| Induced by radio frequency fields                                | 6.7.3                 | AM 80% 1kHz, 10 V   | IEC 60255-26<br>IEC 61000-4-6                    | A,B,D       |
| Power frequency magnetic field                                   | 6.7.3                 | 30 A/m continuous<br>300 A/m 3s   | IEC 60255-26<br>IEC 61000-4-8                    | E           |
| Voltage dips<br>Voltage interruptions                            | 6.7.3                 | 0%/50 ms Criterion A <sup>1</sup><br>40%/200 ms Criterion C<br>70%/500 ms Criterion C<br>0%/5000 ms Criterion C | IEC 60255-26<br>IEC 61000-4-11<br>IEC 61000-4-29 | A           |
| Ripple on d.c. power supply                                      | 6.7.3                 | 15% of $U_n$ <sup>2</sup>   | IEC 60255-26<br>IEC 61000-4-17                   | A           |
| Damped oscillatory wave  | 6.7.3                 | 2,5 kV CM<br>1,0 kV DM<br>1,0 kV CM   | IEC 60255-26<br>IEC 61000-4-18                   | A<br>A<br>B |
| Conducted emission   | 6.7.3                 | Class A   | IEC 60255-26<br>CISPR 22                         | A           |

Table continues on the next page

<sup>1</sup> 20 ms with low power supply variant

<sup>2</sup> With high power supply variant

| Description  | IEC 61850-3 Reference | Requirement | Test standard                        | Test ports |
|--|-----------------------|-------------|--------------------------------------|------------|
| Radiated emission  | 6.7.3                 | Class A     | IEC 60255-26<br>CISPR 22<br>CISPR 11 | E          |
| Port:<br>A Mains power supply input<br>B Ethernet port<br>D Functional earth port<br>H House |                       |             |                                      |            |

**Table 891: Safety-related tests**

| Test Description     | Requirement              | Test Standard                      |
|----------------------|--------------------------|------------------------------------|
| Dielectric test      | 2kV <sup>3</sup> , 0.5kV | IEEE 1613-2009 5.2<br>IEC 60255-27 |
| Impulse test         | 5kV                      | IEEE 1613-2009 5.3<br>IEC 60255-27 |
| Overvoltage category | II                       | IEEE 1613-2009<br>IEC 60255-27     |
| Pollution degree     | 2                        | IEEE 1613-2009<br>IEC 60255-27     |
| Insulation class     | Class I                  | IEEE 1613-2009<br>IEC 60255-27     |

**Table 892: Mechanical environmental condition**

| Test Description                      | IEC 61850-3 reference | Requirement | Test Standard         |
|---------------------------------------|-----------------------|-------------|-----------------------|
| Vibration response and endurance test | 6.10.1                | Class 1     | IEC 60255-21-1        |
| Shock response test                   | 6.10.2                | Class 1     | IEC 60255-21-2        |
| Shock endurance test                  | 6.10.2                | Class 1     | IEC 60255-21-2        |
| Bumb test                             | 6.10.2                | Class 1     | IEC 60255-21-2        |
| Dry heat test - Operational           | 6.9.3.1               | 70 °C       | IEC 60068-2-2 Test Bd |
| Cold test - Operational               | 6.9.3.2               | -20 °C      | IEC 60068-2-1 Test Ad |

*Table continues on the next page*

<sup>3</sup> 1,5kV with low power supply variant according to IEC 60947-1 and IEC 60255-27.

| Test Description                            | IEC 61850-3 reference | Requirement                        | Test Standard           |
|---|-----------------------|------------------------------------|-------------------------|
| Dry heat test - Maximum storage temperature | 6.9.3.3               | 85 °C                              | IEC 60068-2-2 Test Bb   |
| Cold test - Minimum storage temperature     | 6.9.3.4               | -30 °C                             | IEC 60068-2-1 Test Ad   |
| Change of temperature test                  | 6.9.3.5               | 70 °C and -20 °C                   | IEC 60068-2-14 Test Nb  |
| Damp heat steady state test                 | 6.9.3.6               | 93% humidity, 40 °C during 10 days | IEC 60068-2-78 Test Cab |

**Table 893: Product safety**

| Description  | Reference                               |
|--------------|---|
| LV directive | 2014/35/EU                              |
| Standard     | EN 60255-1 (2010)<br>EN 60255-27 (2017) |

**Table 894: EMC compliance**

| Description   | Reference          |
|---------------|--------------------|
| EMC directive | 2014/30/EU         |
| Standard      | EN 60255-26 (2013) |

**Table 895: RoHS compliance**

| Description                             |
|---|
| Complies with RoHS directive 2011/65/EU |

**Table 896: Certification**

| Description   |
|---|
| CE, FCC, CCC, Electricity IV level for China, IEC-61850-3, IEEE-1613, UL, CB, LVD |

# 13 Technical data

## 13.1 Dimensions

**Table 897: Dimensions**

| Dimension | Value  |
|-----------|--|
| Width     | 440 mm / 17.3"                                   |
| Height    | 88 mm / 3.4"                                     |
| Depth     | 220 mm / 8.6"                                    |
| Weight    | 6.0 kg   |
| Mounting  | 2U Rack mount (19"), fits into standard 19" rack |

## 13.2 Power supply

**Table 898: Power supply**

| Description   | High Voltage variant  | Low Voltage variant               |
|---|---|-----------------------------------|
| Nominal auxiliary voltage $U_n$   | 100...240 VAC 50 and 60Hz<br>100...240 VDC                            | 36...72 VDC                       |
| Maximum interruption time in the auxiliary DC voltage without re-setting the device | 50 ms at $U_n$  | 20 ms at 48 VDC<br>0 ms at 36 VDC |
| Auxiliary voltage variation   | 85...110% of $U_n$ (85...264VAC)<br>80...117% of $U_n$ (80...280 VDC) |                                   |
| Start-up threshold  |   |                                   |
| Power consumption   | 35 W (Typical)  | 35 W (Typical)                    |
| Ripple in the DC auxiliary voltage  | Max 10% of the DC value (at frequency of 100 Hz)                      |                                   |
| Fuse type   |   |                                   |



## 13.3 Data communication interfaces

All physical ports dedicated for station bus communication can be opened and closed in device configuration. Local port is used for engineering and it can be used only for point-to-point configuration access with PCM600 or WHMI. Local port should not be connected to any Ethernet network.

**Table 899: Physical ports on device's communication cards**

| Port name                 | Port ID    | IP                      | Default  | DHCP | WHMI L/R | Explanation                   |
|---------------------------|------------|-------------------------|----------|------|----------|-------------------------------|
| Local port                | LAN1       | 192.168.0.254           | Enabled  | Yes  | Local    | Local port                    |
| Remote / engineering port | LAN2       | 192.168.1.254           | Disabled | Yes  | Remote   | Remote port (for engineering) |
| Process bus LAN A         | LAN3       | N/A                     | Disabled | N/A  | N/A      | Process bus                   |
| Process bus LAN B         | LAN4       | N/A                     | Disabled | N/A  | N/A      | Process bus (with PRP)        |
| Rear port                 | LAN5       | 192.168.2.10 (settable) | Enabled  | No   | Remote   | Station bus                   |
| Spare port                | LAN6       | N/A                     | Disabled | N/A  | N/A      | Unused port                   |
| Service port              | LAN7       | 192.168.3.10 (settable) | Disabled | No   | Remote   | Service bus                   |
| Spare port                | LAN8       | N/A                     | Disabled | N/A  | N/A      | Unused port                   |
| Process bus LAN A (SFP)   | LAN1 (SFP) | N/A                     | Disabled | N/A  | N/A      | Process bus (SFP)             |
| Process bus LAN B (SFP)   | LAN2 (SFP) | N/A                     | Disabled | N/A  | N/A      | Process bus (SFP) (with PRP)  |

IEC 61850 protocol and LAN1 and LAN5 ports are by default activated as those are used for engineering of the protection device.

**Table 900: Fiber optic communication link**

| Connector | Fiber type                                     | Wave length | Typical max. length | Permitted path attenuation <sup>111</sup> |
|-----------|--|-------------|---------------------|---|
| SFP       | MM 62.5/125 or 50/125 $\mu$ m glass fiber core | 850 nm      | 550m                | <9,5 dB                                   |

Fiber optic communication in SSC600 is implemented with SFP connectors. Type of SFP connectors are freely choosable and should be selected based on the application needs.

<sup>111</sup> Maximum allowed attenuation caused by connectors and cable together

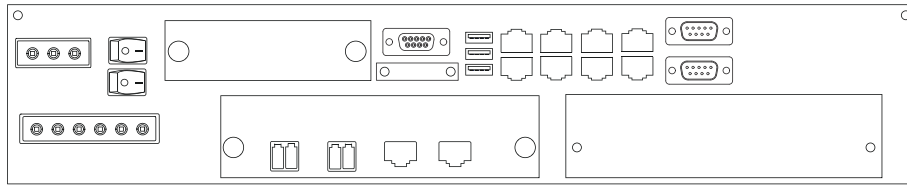


Figure 537: SSC600 backside

## 13.4 Enclosure class

Table 901: Degree of protection of device

| Description | Value |
|-------------|-------|
| Enclosure   | IP 30 |

## 13.5 Environmental conditions

Table 902: Environmental conditions

| Description                             | Value                             |
|---|-----------------------------------|
| Operating temperature range             | -20...+55°C (continuous)          |
| Short-time service temperature range    | -25...+70°C (<16h) <sup>112</sup> |
| Relative humidity                       | <95%, non-condensing              |
| Atmospheric pressure                    | 86...106 kPa                      |
| Altitude                                | Up to 2000m                       |
| Transport and storage temperature range | -30...+85°C                       |

<sup>112</sup> Degradation in MTBF performance outside the temperature range of -25...+55 °C

# 14 Applicable standards and regulations

## EU CE:

- EMC Directive 2014/30/EU
- Low-voltage directive 2014/35/EU
- RoHS Directive 2011/65/EU
- WEEE directive 2012/19/EU
  
- EN 60255-1
- EN 60255-26
- EN 60255-27
- EN 61000-6-2
- EN 61000-6-4

## UK UKCA:

- Electromagnetic Compatibility Regulations 2016
- Electrical Equipment (Safety) Regulations 2016
- The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2012
  
- BS EN 60255-1
- BS EN 60255-26
- BS EN 60255-27
- BS EN 61000-6-2
- BS EN 61000-6-4

## IEC:

- IEC 60255-1
- IEC 60255-26
- IEC 60255-27
- IEC 61000-6-2
- IEC 61000-6-4
- IEC 61850

# 15 Glossary

|                  |   |
|------------------|---|
| ACT              | 1. Application Configuration tool in PCM600<br>2. Trip status in IEC 61850                            |
| BCD              | Binary coded decimal  |
| BDEW             | Bundesverband der Energie- und Wasserwirtschaft   |
| CA               | Certification Authority   |
| CB               | Circuit breaker   |
| CBB              | Cycle building block  |
| CBFP             | Circuit breaker failure protection  |
| COMTRADE         | Common format for transient data exchange for power systems. Defined by the IEEE Standard.            |
| CT               | Current transformer   |
| DAN              | Doubly attached node  |
| DC               | 1. Direct current<br>2. Disconnecter<br>3. Double command   |
| DFT              | Discrete Fourier transform  |
| DT               | Definite time   |
| EMC              | Electromagnetic compatibility   |
| Ethernet         | A standard for connecting a family of frame-based computer networking technologies into a LAN         |
| FLC              | Full load current   |
| GFC              | General fault criteria  |
| GND              | Ground/earth  |
| GOOSE            | Generic Object-Oriented Substation Event  |
| GPS              | Global Positioning System   |
| HMI              | Human-machine interface   |
| HTTPS            | Hypertext Transfer Protocol Secure  |
| HV               | High voltage  |
| IDMT             | Inverse definite minimum time   |
| IEC              | International Electrotechnical Commission   |
| IEC 61850        | International standard for substation communication and modeling                                      |
| IEC 61850-8-1    | A communication protocol based on the IEC 61850 standard series                                       |
| IEC 61850-9-2    | A communication protocol based on the IEC 61850 standard series                                       |
| IEC 61850-9-2 LE | Lite Edition of IEC 61850-9-2 offering process bus interface  |
| IED              | Intelligent electronic device   |
| IEEE             | Institute of Electrical and Electronics Engineers, Inc.   |
| IEEE 1588 v2     | Standard for a Precision Clock Synchronization Protocol for networked measurement and control systems |

|                               |  |
|-------------------------------|--|
| IEEE 1686                     | Standard for Substation Intelligent Electronic Devices' (IEDs)' Cyber Security Capabilities  |
| IP                            | Internet Protocol  |
| IP address                    | A set of four numbers between 0 and 255, separated by periods. Each server connected to the Internet is assigned a unique IP address that specifies the location for the TCP/ IP protocol.   |
| L/R                           | Local/Remote   |
| LAN                           | Local area network   |
| LC                            | Connector type for glass fiber cable, IEC 61754-20   |
| LDC                           | Line drop compensation   |
| LE                            | Light Edition  |
| LED                           | Light-emitting diode   |
| LOG                           | Loss of grid   |
| LV                            | Low voltage  |
| M/F                           | Master/Follower  |
| MAC                           | Media access control   |
| MCC                           | Minimizing circulating current   |
| MM                            | 1. Multimode<br>2. Multimode optical fiber   |
| MMS                           | 1. Manufacturing message specification<br>2. Metering management system  |
| MSB                           | Most significant bit   |
| MV                            | Medium voltage   |
| NRP                           | Negative reactance principle   |
| P2P                           | peer-to-peer   |
| PC                            | 1. Personal computer<br>2. Polycarbonate   |
| PCM600                        | Protection and Control IED Manager   |
| Peak-to-peak                  | 1. The amplitude of a waveform between its maximum positive value and its maximum negative value.<br>2. A measurement principle where the measurement quantity is made by calculating the average from the positive and negative peak values without including the DC component. The peak-to-peak mode allows considerable CT saturation without impairing the performance of the operation. |
| Peak-to-peak with peak backup | A measurement principle similar to the peak-to-peak mode but with the function starting on two conditions: the peak-to-peak value is above the set start current or the peak value is above two times the set start value.   |
| PGU                           | Power generating unit  |
| PLC                           | Programmable logic controller  |
| PO                            | Power output   |
| PPS                           | Pulse per second   |
| PRP                           | Parallel redundancy protocol   |
| PTP                           | Precision Time Protocol  |
| RCA                           | Also known as MTA or base angle. Characteristic angle.   |

|        |  |
|--------|--|
| RJ-45  | Galvanic connector type  |
| RMS    | Root-mean-square (value)   |
| RTD    | Resistance temperature detector  |
| Rx     | Receive/Received   |
| SAN    | Single attached node   |
| SBO    | Select-before-operate  |
| SCADA  | Supervision, control and data acquisition                                    |
| SCL    | XML-based substation description configuration language defined by IEC 61850 |
| SMT    | Signal Matrix tool in PCM600   |
| SMV    | Sampled measured values  |
| SOTF   | Switch onto fault  |
| ST     | Connector type for glass fiber cable   |
| TCP    | Transmission Control Protocol  |
| TCP/IP | Transmission Control Protocol/Internet Protocol                              |
| TP     | Disturbance data recorded with or without trip bit                           |
| UTC    | Coordinated universal time   |
| VT     | Voltage transformer  |
| WAN    | Wide area network  |
| WHMI   | Web human-machine interface  |



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