Relion® 650 SERIES

Busbar protection REB650
Version 2.2 IEC
Application manual
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Conformity

This product complies with the directive of the Council of the European Communities on the approximation of the laws of the Member States relating to electromagnetic compatibility (EMC Directive 2004/108/EC) and concerning electrical equipment for use within specified voltage limits (Low-voltage directive 2006/95/EC). This conformity is the result of tests conducted by ABB in accordance with the product standard EN 60255-26 for the EMC directive, and with the product standards EN 60255-1 and EN 60255-27 for the low voltage directive. The product is designed in accordance with the international standards of the IEC 60255 series.
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Section 19 Glossary
Section 1  Introduction

1.1  This manual

The application manual contains application descriptions and setting guidelines sorted per function. The manual can be used to find out when and for what purpose a typical protection function can be used. The manual can also provide assistance for calculating settings.

1.1.1  Presumptions for Technical Data

The technical data stated in this document are only valid under the following circumstances:

1. Main current transformers with 1 A or 2 A secondary rating are wired to the IED 1 A rated CT inputs.
2. Main current transformer with 5 A secondary rating are wired to the IED 5 A rated CT inputs.
3. CT and VT ratios in the IED are set in accordance with the associated main instrument transformers. Note that for functions which measure an analogue signal which do not have corresponding primary quantity the 1:1 ratio shall be set for the used analogue inputs on the IED. Example of such functions are: HZPDIF, ROTIPHIZ and STTIPHIZ.
4. Parameter IBase used by the tested function is set equal to the rated CT primary current.
5. Parameter UBase used by the tested function is set equal to the rated primary phase-to-phase voltage.
6. Parameter SBase used by the tested function is set equal to:
   - $\sqrt{3} \times I_{\text{Base}} \times U_{\text{Base}}$
7. The rated secondary quantities have the following values:
   - Rated secondary phase current $I_r$ is either 1 A or 5 A depending on selected TRM.
   - Rated secondary phase-to-phase voltage $U_r$ is within the range from 100 V to 120 V.
   - Rated secondary power for three-phase system $S_r = \sqrt{3} \times U_r \times I_r$
8. For operate and reset time testing, the default setting values of the function are used if not explicitly stated otherwise.
9. During testing, signals with rated frequency have been injected if not explicitly stated otherwise.

1.2  Intended audience

This manual addresses the protection and control engineer responsible for planning, pre-engineering and engineering.

The protection and control engineer must be experienced in electrical power engineering and have knowledge of related technology, such as protection schemes and communication principles.
1.3 Product documentation

1.3.1 Product documentation set

Figure 1: The intended use of manuals throughout the product lifecycle

The engineering manual contains instructions on how to engineer the IEDs using the various tools available within the PCM600 software. The manual provides instructions on how to set up a PCM600 project and insert IEDs to the project structure. The manual also recommends a sequence for the engineering of protection and control functions, as well as communication engineering for IEC 61850.

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 the chronological order in which the IED should be installed.

The commissioning manual contains instructions on how to commission the IED. The manual can also be used by system engineers and maintenance personnel for assistance during the testing phase. The manual provides procedures for the checking of external circuitry and energizing the IED, parameter setting and configuration as well as verifying settings by secondary injection. The manual describes the process of testing an IED in a station which is not in service. The chapters are organized in the chronological order in which the IED should be commissioned. The relevant procedures may be followed also during the service and maintenance activities.

The operation manual contains instructions on how to operate the IED once it has been commissioned. The manual provides instructions for the monitoring, controlling and setting of the IED. The manual also describes how to identify disturbances and how to view calculated and measured power grid data to determine the cause of a fault.
The application manual contains application descriptions and setting guidelines sorted per function. The manual can be used to find out when and for what purpose a typical protection function can be used. The manual can also provide assistance for calculating settings.

The technical manual contains operation principle descriptions, and lists function blocks, logic diagrams, input and output signals, setting parameters and technical data, sorted per function. The manual can be used as a technical reference during the engineering phase, installation and commissioning phase, and during normal service.

The communication protocol manual describes the communication protocols supported by the IED. The manual concentrates on the vendor-specific implementations.

The point list manual describes the outlook and properties of the data points specific to the IED. The manual should be used in conjunction with the corresponding communication protocol manual.

The cyber security deployment guideline describes the process for handling cyber security when communicating with the IED. Certification, Authorization with role based access control, and product engineering for cyber security related events are described and sorted by function. The guideline can be used as a technical reference during the engineering phase, installation and commissioning phase, and during normal service.

### 1.3.2 Document revision history

<table>
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<td>-</td>
<td>2017–05</td>
<td>2.2.0</td>
<td>First release for product version 2.2</td>
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<td>A</td>
<td>2017-10</td>
<td>2.2.1</td>
<td>Ethernet ports with RJ45 connector added. Enhancements/updates made to GENPDIF, ZMFPDIS and ZMFCPDIS.</td>
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<tr>
<td>B</td>
<td>2018-03</td>
<td>2.2.1</td>
<td>Document enhancements and corrections</td>
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<tr>
<td>C</td>
<td>2019-05</td>
<td>2.2.1</td>
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### 1.3.3 Related documents

<table>
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<tr>
<th>Documents related to REB650</th>
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<tr>
<td>Application manual</td>
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<tr>
<td>Commissioning manual</td>
<td>1MRK 505 390-UEN</td>
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<tr>
<td>Product guide</td>
<td>1MRK 505 391-BEN</td>
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<td>Technical manual</td>
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<td>Engineering manual</td>
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<td>Installation manual</td>
<td>1MRK 514 027-UEN</td>
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<tr>
<td>Communication protocol manual, DNP3</td>
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<tr>
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<td>1MRK 511 416-UEN</td>
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<td>1MRK 511 414-UEN</td>
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<tr>
<td>Communication protocol manual, IEC 61850 Edition 2</td>
<td>1MRK 511 415-UEN</td>
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1.4 Document symbols and conventions

1.4.1 Symbols

⚠️ The electrical warning icon indicates the presence of a hazard which could result in electrical shock.

⚠️ The warning icon indicates the presence of a hazard which could result in personal injury.

🔥 The caution hot surface icon indicates important information or warning about the temperature of product surfaces.

‖ Class 1 Laser product. Take adequate measures to protect the eyes and do not view directly with optical instruments.

⚠️ 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.

ℹ️ 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 warning hazards are related to personal injury, it is necessary to understand that under certain operational conditions, operation of damaged equipment may result in
1.4.2 Document conventions

- Abbreviations and acronyms in this manual are spelled out in the glossary. The glossary also contains definitions of important terms.
- Push button navigation in the LHMI menu structure is presented by using the push button icons.
  
  For example, to navigate between the options, use ↑ and ↓.
- HMI menu paths are presented in bold.
  
  For example, select **Main menu/Settings**.
- LHMI messages are shown in Courier font.
  
  For example, to save the changes in non-volatile memory, select Yes and press ➔.
- Parameter names are shown in italics.
  
  For example, the function can be enabled and disabled with the *Operation* setting.
- Each function block symbol shows the available input/output signal.
  
  - the character ^ in front of an input/output signal name indicates that the signal name may be customized using the PCM600 software.
  
  - the character * after an input signal name indicates that the signal must be connected to another function block in the application configuration to achieve a valid application configuration.
- Dimensions are provided both in inches and millimeters. If it is not specifically mentioned then the dimension is in millimeters.

1.5 IEC 61850 edition 1 / edition 2 mapping

Function block names are used in **ACT** and **PST** to identify functions. Respective function block names of Edition 1 logical nodes and Edition 2 logical nodes are shown in the table below.

*Table 1: IEC 61850 edition 1 / edition 2 mapping*

<table>
<thead>
<tr>
<th>Function block name</th>
<th>Edition 1 logical nodes</th>
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<td>BRCPTOC</td>
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<td>CCRBRF</td>
<td>CCRBRF</td>
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<td>CCSPVPC</td>
<td>CCSPVPC</td>
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<td>CMSQI</td>
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</tbody>
</table>
Section 2 Application

2.1 General IED application

The numerical high impedance differential busbar protection REB650 IED provides its users with a wide variety of application opportunities. Designed primarily for the protection of single busbar with or without sectionalizers in high impedance based applications, it also offers high impedance differential protection for generators, autotransformers, shunt reactors and capacitor banks.

Its I/O capability allows you to protect up to three 3-phase high impedance differential protection zones with a single IED. A number of additional protection functions are available for the protection of the bus coupler bay. The additional protection functions include different types of phase and earth fault overcurrent protection and over voltage/under voltage protection.

One pre-configured package has been defined for the following application:

- 2 zones/1 checkzone, 3 phase high impedance (A03)

For the high impedance differential protection, the differential current process is made in the analogue current transformer circuits where the differential current is connected to the IED via a high ohmic resistor. In REB650, a current input is used for each phase and protection zone. The package is configured and ready for direct use. Analog inputs and binary input/output circuits are pre-defined.

The IED can be used in applications with the IEC/UCA 61850-9-2LE process bus with up to four Merging Units (MU). Each MU has eight analogue channels, four current and four voltages. Conventional input transformer module and Merging Unit channels can be mixed freely in your application.

The pre-configured IED can be changed and adapted to suit specific applications with the application configuration tool.

Forcing of binary inputs and outputs is a convenient way to test wiring in substations as well as testing configuration logic in the IEDs. Basically it means that all binary inputs and outputs on the IED I/O modules (BOM, BIM and IOM) can be forced to arbitrary values.

Central Account Management is an authentication infrastructure that offers a secure solution for enforcing access control to IEDs and other systems within a substation. This incorporates management of user accounts, roles and certificates and the distribution of such, a procedure completely transparent to the user.

The Flexible Product Naming allows the customer to use an IED-vendor independent IEC 61850 model of the IED. This customer model will be used as the IEC 61850 data model, but all other aspects of the IED will remain unchanged (e.g., names on the local HMI and names in the tools). This offers significant flexibility to adapt the IED to the customers' system and standard solution.

The following tables list all the functions available in the IED. Those functions that are not exposed to the user or do not need to be configured are not described in this manual.
# 2.2 Main protection functions

### Table 2: Example of quantities

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<thead>
<tr>
<th></th>
<th>Description</th>
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<tr>
<td>2</td>
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</tr>
<tr>
<td>0-3</td>
<td>option quantities</td>
</tr>
<tr>
<td>3-A03</td>
<td>optional function included in packages A03 (refer to ordering details)</td>
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</table>

<table>
<thead>
<tr>
<th>IEC 61850 or function name</th>
<th>ANSI</th>
<th>Function description</th>
<th>Busbar</th>
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<td>Differential protection</td>
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## 2.3 Back-up protection functions

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<td>Directional residual overcurrent protection, four steps</td>
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<td>Four step directional negative phase sequence overcurrent protection</td>
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1) 67 requires voltage
2) 67N requires voltage
## 2.4 Control and monitoring functions

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<td>WRNCALH</td>
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<td>INDCALH</td>
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<tr>
<td>AND, GATE, INV, LLD, OR, PULSETIMER, RSMEMORY, SRMEMORY, TIMERSET, XOR</td>
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<td>BTITGAPC</td>
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<td>Boolean to integer conversion with logical node representation, 16 bit</td>
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<td>IB16</td>
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<td>Integer to Boolean 16 conversion</td>
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<td>Integer to Boolean 16 conversion with Logic Node representation</td>
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### Table 3: Total number of instances for basic configurable logic blocks

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<td>GATE</td>
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<tr>
<td>INV</td>
<td>420</td>
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<tr>
<td>LLD</td>
<td>40</td>
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<tr>
<td>OR</td>
<td>298</td>
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<td>PULSETIMER</td>
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### Table 3: (continued)

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<td>VMMXU</td>
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<td>Voltage measurement phase-phase</td>
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<td>CMSQI</td>
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<td>Current sequence measurement</td>
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<td>VMSQI</td>
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<td>VNMMXU</td>
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<td>Voltage measurement phase-earth</td>
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<td>SSIML</td>
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<td>Circuit breaker condition monitoring</td>
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<td>MGVAPC</td>
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<td>Generic communication function for measured values</td>
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### 2.5 Communication

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<td>Operation selection between SPA and IEC 60870-5-103 for SLM</td>
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### 2.6 Basic IED functions

**Table 4: Basic IED functions**

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<td>INTERSIG</td>
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<td>TIMESYNCHGEN</td>
<td>Time synchronization module</td>
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<td>BININPUT, SYNCHCAN, SYNCHGPS, SYNCHCMPPS, SYNCHLON, SYNCHPPH, SYNCHPPS, SNTP, SYNCHSPA</td>
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<td>TIMEZONE</td>
<td>Time synchronization</td>
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<td>IIRIG-B</td>
<td>Time synchronization</td>
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<td>SETGRPS</td>
<td>Number of setting groups</td>
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<td>ACTVGRP</td>
<td>Parameter setting groups</td>
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<td>TESTMODE</td>
<td>Test mode functionality</td>
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<td>CHNGLCK</td>
<td>Change lock function</td>
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<td>SMBI</td>
<td>Signal matrix for binary inputs</td>
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<td>SMBO</td>
<td>Signal matrix for binary outputs</td>
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<td>SMAI1 - SMAI12</td>
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<td>Summation block 3 phase</td>
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<td>ATHCHCK</td>
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<td>Authority management</td>
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<td>Global base values for settings</td>
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<td>ALTMS</td>
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<td>LHMICTRL</td>
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<td>FNKEYMD1–FNKEYMD5</td>
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<td>GRP2_LED1–GRP2_LED15</td>
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<tr>
<td>GRP3_LED1–GRP3_LED15</td>
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</table>
Section 3  Configuration

3.1  Description of configuration REB650

3.1.1  Introduction

The basic delivery includes one binary input module and one binary output module, which is sufficient for the default configured I/O to trip and close circuit breaker. All IEDs can be reconfigured with the help of the application configuration tool in PCM600. The IED can be adapted to special applications and special logic can be developed, such as logic for automatic opening of disconnectors and closing of ring bays, automatic load transfer from one busbar to the other, and so on.

The basic IED configuration is provided with the signal matrix, single line diagram and the application configuration prepared for the functions included in the product by default. All parameters should be verified by the customer, since these are specific to the system, object or application. Optional functions and optional I/O ordered will not be configured at delivery. It should be noted that the standard only includes one binary input and one binary output module and only the key functions such as tripping are connected to the outputs in the signal matrix tool. The required total I/O must be calculated and specified at ordering.

The configurations are as far as found necessary provided with application comments to explain why the signals have been connected in the special way. On request, ABB is available to support the re-configuration work, either directly or to do the design checking.

3.1.1.1  Description of A03

Complete busbar protection for two busbar sections (zone 1 and 2), with the possibility for check zone.
Figure 2: Configuration diagram for configuration A03
Section 4  Analog inputs

4.1  Introduction

Analog input channels must be configured and set properly in order to get correct measurement results and correct protection operations. For power measuring, all directional and differential functions, the directions of the input currents must be defined in order to reflect the way the current transformers are installed/connected in the field (primary and secondary connections). Measuring and protection algorithms in the IED use primary system quantities. Setting values are in primary quantities as well and it is important to set the data about the connected current and voltage transformers properly.

An AISVBAS reference PhaseAngleRef can be defined to facilitate service values reading. This analog channel's phase angle will always be fixed to zero degrees and remaining analog channel's phase angle information will be shown in relation to this analog input. During testing and commissioning of the IED, the reference channel can be changed to facilitate testing and service values reading.

The IED has the ability to receive analog values from primary equipment, that are sampled by Merging units (MU) connected to a process bus, via the IEC 61850-9-2 LE protocol.

The availability of VT inputs depends on the ordered transformer input module (TRM) type.

4.2  Setting guidelines

The available setting parameters related to analog inputs are depending on the actual hardware (TRM) and the logic configuration made in PCM600.

If a second TRM is used, at least one TRM channel must be configured to get the service values. However, the MU physical channel must be configured to get service values from that channel.

4.2.1  Setting of the phase reference channel

All phase angles are calculated in relation to a defined reference. An appropriate analog input channel is selected and used as phase reference. The parameter PhaseAngleRef defines the analog channel that is used as phase angle reference.
4.2.1.1 Example

4.2.2 Setting of current channels

The direction of a current to the IED is depending on the connection of the CT. Unless indicated otherwise, the main CTs are supposed to be star connected and can be connected with the earthing point to the object or from the object. This information must be set in the IED. The convention of the directionality is defined as follows: A positive value of current, power, and so on means that the quantity has the direction into the object and a negative value means direction out from the object. For directional functions the direction into the object is defined as Forward and the direction out from the object is defined as Reverse. See Figure 3.

A positive value of current, power, and so on (forward) means that the quantity flows towards the object. A negative value of current, power, and so on (reverse) means that the quantity flows away from the object. See Figure 3.

![Diagram showing directionality](en05000456.vsd)

Figure 3: Internal convention of the directionality in the IED

With correct setting of the primary CT direction, CTStarPoint set to FromObject or ToObject, a positive quantities always flowing towards the protected object and a direction defined as Forward always is looking towards the protected object. The following examples show the principle.

4.2.2.1 Example 1

Two IEDs used for protection of two objects.
Setting of current input:
Set parameter CTStarPoint with Transformer as reference object. Correct setting is "ToObject".

Correct setting is "ToObject".

Setting of current input:
Set parameter CTStarPoint with Line as reference object. Correct setting is "FromObject".

IEC05000753=IEC05000753=1=en=Origin\[1\].vsd

Figure 4: Example how to set CTStarPoint parameters in the IED

Figure 4 shows the normal case where the objects have their own CTs. The settings for CT direction shall be done according to the figure. To protect the line, direction of the directional functions of the line protection shall be set to Forward. This means that the protection is looking towards the line.

4.2.2.2 Example 2

Two IEDs used for protection of two objects and sharing a CT.
Setting of current input:
Set parameter CTStarPoint with Transformer as reference object.
Correct setting is "ToObject"

Setting of current input:
Set parameter CTStarPoint with Transformer as reference object.
Correct setting is "ToObject"

Setting of current input:
Set parameter CTStarPoint with Line as reference object.
Correct setting is "FromObject"

Figure 5: Example how to set CTStarPoint parameters in the IED

This example is similar to example 1, but here the transformer is feeding just one line and the line protection uses the same CT as the transformer protection does. The CT direction is set with different reference objects for the two IEDs though it is the same current from the same CT that is feeding the two IEDs. With these settings, the directional functions of the line protection shall be set to Forward to look towards the line.

4.2.2.3 Example 3

One IED used to protect two objects.
In this example, one IED includes both transformer and line protections and the line protection uses the same CT as the transformer protection does. For both current input channels, the CT direction is set with the transformer as reference object. This means that the direction Forward for the line protection is towards the transformer. To look towards the line, the direction of the directional functions of the line protection must be set to Reverse. The direction Forward/Reverse is related to the reference object that is the transformer in this case.

When a function is set to Reverse and shall protect an object in reverse direction, it shall be noted that some directional functions are not symmetrical regarding the reach in forward and reverse direction. It is in first hand the reach of the directional criteria that can differ. Normally it is not any limitation but it is advisable to have it in mind and check if it is acceptable for the application in question.

If the IED has sufficient number of analog current inputs, an alternative solution is shown in Figure 7. The same currents are fed to two separate groups of inputs and the line and transformer protection functions are configured to the different inputs. The CT direction for the current channels to the line protection is set with the line as reference object and the directional functions of the line protection shall be set to Forward to protect the line.
Transformer and Line protection

Setting of current input for transformer functions:
- Set parameter CTStarPoint with Transformer as reference object.
- Correct setting is "ToObject".

Setting of current input for line functions:
- Set parameter CTStarPoint with Line as reference object.
- Correct setting is "FromObject".

Figure 7: Example how to set CTStarPoint parameters in the IED

Figure 8:

For busbar protection, it is possible to set the CTStarPoint parameters in two ways.

The first solution will be to use busbar as a reference object. In that case for all CT inputs marked with 1 in Figure 8, set CTStarPoint = ToObject, and for all CT inputs marked with 2 in Figure 8, set CTStarPoint = FromObject.

The second solution will be to use all connected bays as reference objects. In that case for all CT inputs marked with 1 in Figure 8, set CTStarPoint = FromObject, and for all CT inputs marked with 2 in Figure 8, set CTStarPoint = ToObject.

Regardless which one of the above two options is selected, busbar differential protection will behave correctly.

The main CT ratios must also be set. This is done by setting the two parameters CTprim and CTsec for each current channel. For a 1000/1 A CT, the following settings shall be used:

- $CTprim = 1000$ (value in A)
- $CTsec = 1$ (value in A).

4.2.2.4 Examples on how to connect, configure and set CT inputs for most commonly used CT connections

Figure 9 defines the marking of current transformer terminals commonly used around the world:

In the SMAI function block, you have to set if the SMAI block is measuring current or voltage. This is done with the parameter: AnalogInputType: Current/Voltage. The ConnectionType: phase-phase/phase-earth and GlobalBaseSel.
Figure 9: Commonly used markings of CT terminals

Where:

a) is symbol and terminal marking used in this document. Terminals marked with a square indicates the primary and secondary winding terminals with the same (that is, positive) polarity

b) and c) are equivalent symbols and terminal marking used by IEC (ANSI) standard for CTs. Note that for these two cases the CT polarity marking is correct!

It shall be noted that depending on national standard and utility practices, the rated secondary current of a CT has typically one of the following values:

- 1A
- 5A

However, in some cases, the following rated secondary currents are used as well:

- 2A
- 10A

The IED fully supports all of these rated secondary values.

It is recommended to:

- use 1A rated CT input into the IED in order to connect CTs with 1A and 2A secondary rating
- use 5A rated CT input into the IED in order to connect CTs with 5A and 10A secondary rating

4.2.2.5 Example on how to connect a star connected three-phase CT set to the IED

Figure 10 gives an example about the wiring of a star connected two-phase CT set to the IED. It gives an overview of the actions which are needed to make this measurement available to the built-in protection and control functions within the IED as well.
For correct terminal designations, see the connection diagrams valid for the delivered IED.

**Figure 10:** Star connected three-phase CT set with star point towards the protected object

Where:

1) The drawing shows how to connect three individual phase currents from a star connected three-phase CT set to the three CT inputs of the IED.

2) The current inputs are located in the TRM. It shall be noted that for all these current inputs the following setting values shall be entered for the example shown in Figure 10:

- \(CT_{prim}=600A\)
- \(CT_{sec}=5A\)
- \(CTStarPoint=ToObject\)

Ratio of the first two parameters is only used inside the IED. The third parameter \((CTStarPoint=ToObject)\) as set in this example causes no change on the measured currents. In other words, currents are already measured towards the protected object.

Table continues on next page
3) These three connections are the links between the three current inputs and the three input channels of the preprocessing function block 4). Depending on the type of functions, which need this current information, more than one preprocessing block might be connected in parallel to the same three physical CT inputs.

4) The preprocessing block that has the task to digitally filter the connected analog inputs and calculate:
   - fundamental frequency phasors for all three input channels
   - harmonic content for all three input channels
   - positive, negative and zero sequence quantities by using the fundamental frequency phasors for the first three input channels (channel one taken as reference for sequence quantities)

These calculated values are then available for all built-in protection and control functions within the IED, which are connected to this preprocessing function block. For this application most of the preprocessing settings can be left to the default values. If frequency tracking and compensation is required (this feature is typically required only for IEDs installed in power plants), then the setting parameters DFTReference shall be set accordingly. Section SMAI in this manual provides information on adaptive frequency tracking for the signal matrix for analogue inputs (SMAI).

5) AI3P in the SMAI function block is a grouped signal which contains all the data about the phases L1, L2, L3 and neutral quantity; in particular the data about fundamental frequency phasors, harmonic content and positive sequence quantities are available. AI1, AI2, AI3, AI4 are the output signals from the SMAI function block which contain the fundamental frequency phasors and the harmonic content of the corresponding input channels of the preprocessing function block. AIN is the signal which contains the fundamental frequency phasors and the harmonic content of the neutral quantity. In this example, GRP2N is not connected so this data is calculated by the preprocessing function block on the basis of the inputs GRPL1, GRPL2 and GRPL3. If GRP2N is connected, the data reflects the measured value of GRP2N.

Another alternative is to have the star point of the three-phase CT set as shown in Figure 11:
• $CT_{prim}=600\text{A}$
• $CT_{sec}=5\text{A}$
• $CT_{StarPoint}=\text{FromObject}$

The ratio of the first two parameters is only used inside the IED. The third parameter as set in this example will negate the measured currents in order to ensure that the currents are measured towards the protected object within the IED.

A third alternative is to have the residual/neutral current from the three-phase CT set connected to the IED as shown in Figure 11.

![Diagram](IEC06000644-4-en.vsdx)

**Figure 12:** Star connected three-phase CT set with its star point away from the protected object and the residual/neutral current connected to the IED

Where:
1) Shows how to connect three individual phase currents from a star connected three-phase CT set to the three CT inputs of the IED.
2) Shows how to connect residual/neutral current from the three-phase CT set to the fourth input in the IED. It shall be noted that if this connection is not made, the IED will still calculate this current internally by vectorial summation of the three individual phase currents.
3) Is the TRM where these current inputs are located. It shall be noted that for all these current inputs the following setting values shall be entered.
   - $CT_{prim}=800\text{A}$
   - $CT_{sec}=1\text{A}$
   - $CT_{StarPoint}=\text{FromObject}$
   - $ConnectionType=\text{Ph-N}$

The ratio of the first two parameters is only used inside the IED. The third parameter as set in this example will have no influence on measured currents (that is, currents are already measured towards the protected object).

Table continues on next page
4) Are three connections made in the Signal Matrix tool (SMT) and Application configuration tool (ACT), which connects these three current inputs to the first three input channels on the preprocessing function block 6). Depending on the type of functions, which need this current information, more than one preprocessing block might be connected in parallel to these three CT inputs.

5) Is a connection made in the Signal Matrix tool (SMT) and Application configuration tool (ACT), which connects the residual/neutral current input to the fourth input channel of the preprocessing function block 6). Note that this connection in SMT shall not be done if the residual/neutral current is not connected to the IED.

6) Is a Preprocessing block that has the task to digitally filter the connected analog inputs and calculate:
   - fundamental frequency phasors for all input channels
   - harmonic content for all input channels
   - positive, negative and zero sequence quantities by using the fundamental frequency phasors of the first three input channels (channel one taken as reference for sequence quantities)

These calculated values are then available for all built-in protection and control functions within the IED, which are connected to this preprocessing function block in the configuration tool. For this application, most of the preprocessing settings can be left to the default values. If frequency tracking and compensation is required (this feature is typically required only for IEDs installed in the generating stations), then the setting parameters DFTReference shall be set accordingly.

### 4.2.2.6 Example how to connect delta connected three-phase CT set to the IED

Figure 13 gives an example how to connect a delta connected three-phase CT set to the IED. It gives an overview of the required actions by the user in order to make this measurement available to the built-in protection and control functions in the IED as well.

For correct terminal designations, see the connection diagrams valid for the delivered IED.
Figure 13: Delta DAB connected three-phase CT set

Where:

1) shows how to connect three individual phase currents from a delta connected three-phase CT set to three CT inputs of the IED.

2) is the TRM where these current inputs are located. It shall be noted that for all these current inputs the following setting values shall be entered.

   \[ \begin{align*}
   CT_{\text{prim}} &= 600A \\
   CT_{\text{sec}} &= 5A \\
   \cdot \quad CT_{\text{StarPoint}} &= \text{ToObject} \\
   \cdot \quad \text{ConnectionType} &= \text{Ph-Ph}
   \end{align*} \]

3) are three connections made in Signal Matrix Tool (SMT), Application configuration tool (ACT), which connect these three current inputs to first three input channels of the preprocessing function block. Depending on the type of functions which need this current information, more than one preprocessing block might be connected in parallel to these three CT inputs.

4) is a Preprocessing block that has the task to digitally filter the connected analog inputs and calculate:

   \[ \begin{align*}
   \cdot \quad & \text{fundamental frequency phasors for all three input channels} \\
   \cdot \quad & \text{harmonic content for all three input channels} \\
   \cdot \quad & \text{positive, negative and zero sequence quantities by using the fundamental frequency phasors for the first three input channels (channel one taken as reference for sequence quantities)}
   \end{align*} \]

These calculated values are then available for all built-in protection and control functions within the IED, which are connected to this preprocessing function block. For this application most of the preprocessing settings can be left to the default values.

If frequency tracking and compensation is required (this feature is typically required only for IEDs installed in the generating stations) then the setting parameters \( DFTReference \) shall be set accordingly.
Another alternative is to have the delta connected CT set as shown in figure 14:

**Figure 14: Delta DAC connected three-phase CT set**

In this case, everything is done in a similar way as in the above described example, except that for all used current inputs on the TRM the following setting parameters shall be entered:

- \( CT_{\text{prim}} = 800 \text{A} \)
- \( CT_{\text{sec}} = 1 \text{A} \)
- \( CT_{\text{StarPoint}} = \text{ToObject} \)
- \( \text{ConnectionType} = \text{Ph-Ph} \)

It is important to notice the references in SMAI. As inputs at Ph-Ph are expected to be L1L2, L2L3 respectively L3L1 we need to tilt 180° by setting ToObject.

### 4.2.2.7 Example how to connect single-phase CT to the IED

Figure 15 gives an example how to connect the single-phase CT to the IED. It gives an overview of the required actions by the user in order to make this measurement available to the built-in protection and control functions within the IED as well.

For correct terminal designations, see the connection diagrams valid for the delivered IED.
Figure 15: Connections for single-phase CT input

Where:
1) shows how to connect single-phase CT input in the IED.
2) is TRM where these current inputs are located. It shall be noted that for all these current inputs the following setting values shall be entered.
   For connection (a) shown in Figure 15:
   \[ CT_{prim} = 1000 \text{ A} \]
   \[ CT_{sec} = 1 \text{ A} \]
   \[ CTStarPoint=ToObject \]

   For connection (b) shown in Figure 15:
   \[ CT_{prim} = 1000 \text{ A} \]
   \[ CT_{sec} = 1 \text{ A} \]
   \[ CTStarPoint=FromObject \]
3) shows the connection made in SMT tool, which connect this CT input to the fourth input channel of the preprocessing function block 4).
4) is a Preprocessing block that has the task to digitally filter the connected analog inputs and calculate values. The calculated values are then available for all built-in protection and control functions within the IED, which are connected to this preprocessing function block.
   If frequency tracking and compensation is required (this feature is typically required only for IEDs installed in the power plants) then the setting parameters DFTReference shall be set accordingly.

4.2.3 Relationships between setting parameter Base Current, CT rated primary current and minimum pickup of a protection IED

Note that for all line protection applications (e.g. distance protection or line differential protection) the parameter Base Current (i.e. \( I_{Base} \) setting in the IED) used by the relevant protection function, shall always be set equal to the largest rated CT primary current among all CTs involved in the protection scheme. The rated CT primary current value is set as parameter \( CT_{Prim} \) under the IED TRM settings.

For all other protection applications (e.g. generator, shunt reactor, shunt capacitor and transformer protection) it is typically desirable to set \( I_{Base} \) parameter equal to the rated current of the protected object. However this is only recommended to do if the rated current of the protected object is within the range of 40% to 120% of the selected CT rated primary current. If for any reason (e.g. high maximum short circuit current) the rated current of the
protected object is less than 40% of the rated CT primary current, it is strongly recommended
to set the parameter \( I_{\text{Base}} \) in the IED to be equal to the largest rated CT primary current
among all CTs involved in the protection scheme and installed on the same voltage level. This
will effectively make the protection scheme less sensitive; however, such measures are
necessary in order to avoid possible problems with loss of the measurement accuracy in the IED.

Regardless of the applied relationship between the \( I_{\text{Base}} \) parameter and the rated CT primary
current, the corresponding minimum pickup of the function on the CT secondary side must
always be verified. It is strongly recommended that the minimum pickup of any instantaneous
protection function (e.g. differential, restricted earth fault, distance, instantaneous
overcurrent, etc.) shall under no circumstances be less than 4% of the used IED CT input rating
(i.e. 1A or 5A). This corresponds to 40mA secondary for IED 1A rated inputs and to 200mA
secondary for IED 5A rated inputs used by the function. This shall be individually verified for all
current inputs involved in the protection scheme.

Note that exceptions from the above 4% rule may be acceptable for very special applications
(e.g. when Multipurpose filter SMAIHPAC is involved in the protection scheme).

### 4.2.4 Setting of voltage channels

As the IED uses primary system quantities, the main VT ratios must be known to the IED. This
is done by setting the two parameters \( VT_{\text{sec}} \) and \( VT_{\text{prim}} \) for each voltage channel. The phase-
to-phase value can be used even if each channel is connected to a phase-to-earth voltage from
the VT.

#### 4.2.4.1 Example

Consider a VT with the following data:

\[
\frac{132kV}{\sqrt{3}} / \frac{110V}{\sqrt{3}}
\]

(Equation 1)

The following setting should be used: \( VT_{\text{prim}} = 132 \) (value in kV) \( VT_{\text{sec}} = 110 \) (value in V)

#### 4.2.4.2 Examples how to connect, configure and set VT inputs for most
commonly used VT connections

Figure 16 defines the marking of voltage transformer terminals commonly used around the
world.
Where:

a) is the symbol and terminal marking used in this document. Terminals marked with a square indicate the primary and secondary winding terminals with the same (positive) polarity

b) is the equivalent symbol and terminal marking used by IEC (ANSI) standard for phase-to-earth connected VTs

c) is the equivalent symbol and terminal marking used by IEC (ANSI) standard for open delta connected VTs

d) is the equivalent symbol and terminal marking used by IEC (ANSI) standard for phase-to-phase connected VTs

It shall be noted that depending on national standard and utility practices the rated secondary voltage of a VT has typically one of the following values:

- 100 V
- 110 V
- 115 V
- 120 V
- 230 V

The IED fully supports all of these values and most of them will be shown in the following examples.

4.2.4.3 Examples on how to connect a three phase-to-earth connected VT to the IED

Figure 17 gives an example on how to connect a three phase-to-earth connected VT to the IED. It gives an overview of required actions by the user in order to make this measurement available to the built-in protection and control functions within the IED.

For correct terminal designations, see the connection diagrams valid for the delivered IED.
Figure 17: A Three phase-to-earth connected VT

Figure 18: A two phase-to-earth connected VT
Where:

1) shows how to connect three secondary phase-to-earth voltages to three VT inputs on the IED

2) is the TRM where these three voltage inputs are located. For these three voltage inputs, the following setting values shall be entered:
   \[ VT_{prim} = 132 \text{ kV} \]
   \[ VT_{sec} = 110 \text{ V} \]
   Inside the IED, only the ratio of these two parameters is used. It shall be noted that the ratio of the entered values exactly corresponds to ratio of one individual VT.

\[
\frac{66}{110} = \frac{\sqrt{3}}{\sqrt{3}}
\]

(Equation 2)

3) are three connections made in Signal Matrix Tool (SMT), which connect these three voltage inputs to first three input channels of the preprocessing function block 5). Depending on the type of functions which need this voltage information, more then one preprocessing block might be connected in parallel to these three VT inputs.

4) shows that in this example the fourth (that is, residual) input channel of the preprocessing block is not connected in SMT tool. Thus the preprocessing block will automatically calculate \(3U_0\) inside by vectorial sum from the three phase to earth voltages connected to the first three input channels of the same preprocessing block. Alternatively, the fourth input channel can be connected to open delta VT input, as shown in Figure 20.

5) is a Preprocessing block that has the task to digitally filter the connected analog inputs and calculate:
   - fundamental frequency phasors for all input channels
   - harmonic content for all input channels
   - positive, negative and zero sequence quantities by using the fundamental frequency phasors for the first three input channels (channel one taken as reference for sequence quantities)

These calculated values are then available for all built-in protection and control functions within the IED, which are connected to this preprocessing function block in the configuration tool. For this application most of the preprocessing settings can be left to the default values. However the following settings shall be set as shown here:
   - \(U_{Base}=66\text{ kV}\) (that is, rated Ph-Ph voltage)
   - If frequency tracking and compensation is required (this feature is typically required only for IEDs installed in the generating stations) then the setting parameters \(DFTReference\) shall be set accordingly.

### 4.2.4.4 Example on how to connect a phase-to-phase connected VT to the IED

Figure 19 gives an example how to connect a phase-to-phase connected VT to the IED. It gives an overview of the required actions by the user in order to make this measurement available to the built-in protection and control functions within the IED. It shall be noted that this VT connection is only used on lower voltage levels (that is, rated primary voltage below 40 kV).
Figure 19: A Two phase-to-phase connected VT

Where:

1) shows how to connect the secondary side of a phase-to-phase VT to the VT inputs on the IED
2) is the TRM where these three voltage inputs are located. It shall be noted that for these three voltage inputs the following setting values shall be entered:

   - $\text{VTprim}=13.8 \, \text{kV}$
   - $\text{VTsec}=120 \, \text{V}$

   Please note that inside the IED only ratio of these two parameters is used.
3) are three connections made in the Signal Matrix tool (SMT), Application configuration tool (ACT), which connects these three voltage inputs to first three input channels of the preprocessing function block 5). Depending on the type of functions, which need this voltage information, more than one preprocessing block might be connected in parallel to these three VT inputs.
4) shows that in this example the fourth (that is, residual) input channel of the preprocessing block is not connected in SMT. Note. If the parameters $U_{L1}$, $U_{L2}$, $U_{L3}$, $U_N$ should be used the open delta must be connected here.
5) Preprocessing block has a task to digitally filter the connected analog inputs and calculate:
   - fundamental frequency phasors for all four input channels
   - harmonic content for all four input channels
   - positive, negative and zero sequence quantities by using the fundamental frequency phasors for the first three input channels (channel one taken as reference for sequence quantities)

These calculated values are then available for all built-in protection and control functions within the IED, which are connected to this preprocessing function block in the configuration tool. For this application most of the preprocessing settings can be left to the default values. However the following settings shall be set as shown here:

- $\text{Connection Type}=\text{Ph-Ph}$
- $\text{UBase}=13.8 \, \text{kV}$

If frequency tracking and compensation is required (this feature is typically required only for IEDs installed in the generating stations) then the setting parameters $\text{DFTReference}$ shall be set accordingly.
### Example on how to connect an open delta VT to the IED for high impedance earthed or unearthed networks

Figure 20 gives an example about the wiring of an open delta VT to the IED for high impedance earthed or unearthed power systems. It shall be noted that this type of VT connection presents a secondary voltage proportional to 3U0 to the IED.

In case of a solid earth fault close to the VT location the primary value of 3U0 will be equal to:

$$3U_0 = \sqrt{3} \cdot U_{p_k-p_k} = 3 \cdot U_{p_k-N}$$

(Equation 3)

The primary rated voltage of an open Delta VT is always equal to $U_{Ph-E}$. Three series connected VT secondary windings gives a secondary voltage equal to three times the individual VT secondary winding rating. Thus the secondary windings of open delta VTs quite often have a secondary rated voltage equal to one third of the rated phase-to-phase VT secondary voltage (110/3V in this particular example).

Figure 20 gives overview of required actions by the user in order to make this measurement available to the built-in protection and control functions within the IED as well.

*Figure 20: Open delta connected VT in high impedance earthed power system*
Where:

1) shows how to connect the secondary side of the open delta VT to one VT input on the IED. 

   +3U₀ shall be connected to the IED

2) is the TRM where this voltage input is located. It shall be noted that for this voltage input the following setting values shall be entered:

   \[ VT_{prim} = \sqrt{3} \times 6.6 = 11.43kV \]

   (Equation 4)

   \[ VT_{sec} = \frac{3 \times 110}{3} = 110V \]

   (Equation 5)

   Inside the IED, only the ratio of these two parameters is used. It shall be noted that the ratio of the entered values exactly corresponds to ratio of one individual open delta VT.

   \[ \frac{\sqrt{3} \times 6.6}{110} = \frac{6.6/3}{110/3} \]

   (Equation 6)

3) shows that in this example the first three input channel of the preprocessing block is not connected in SMT tool or ACT tool.

4) shows the connection made in Signal Matrix Tool (SMT), Application configuration tool (ACT), which connect this voltage input to the fourth input channel of the preprocessing function block 5).

5) is a Preprocessing block that has the task to digitally filter the connected analog input and calculate:

   - fundamental frequency phasors for all four input channels
   - harmonic content for all four input channels
   - positive, negative and zero sequence quantities by using the fundamental frequency phasors for the first three input channels (channel one taken as reference for sequence quantities)

   These calculated values are then available for all built-in protection and control functions within the IED, which are connected to this preprocessing function block in the configuration tool. For this application most of the preprocessing settings can be left to the default values. If frequency tracking and compensation is required (this feature is typically required only for IEDs installed in the generating stations) then the setting parameters DFTReference shall be set accordingly.

4.2.4.6 Example how to connect the open delta VT to the IED for low impedance earthed or solidly earthed power systems

Figure 21 gives an example about the connection of an open delta VT to the IED for low impedance earthed or solidly earthed power systems. It shall be noted that this type of VT connection presents secondary voltage proportional to 3U₀ to the IED.

In case of a solid earth fault close to the VT location the primary value of 3U₀ will be equal to:
The primary rated voltage of such VT is always equal to $U_{\text{Ph-E}}$. Therefore, three series connected VT secondary windings will give the secondary voltage equal only to one individual VT secondary winding rating. Thus the secondary windings of such open delta VTs quite often has a secondary rated voltage close to rated phase-to-phase VT secondary voltage, that is, 115V or $115/\sqrt{3}$V as in this particular example. Figure 21 gives an overview of the actions which are needed to make this measurement available to the built-in protection and control functions within the IED.

Figure 21: Open delta connected VT in low impedance or solidly earthed power system
Where:

1) shows how to connect the secondary side of open delta VT to one VT input in the IED.

   +3U₀ shall be connected to the IED.

2) is TRM where this voltage input is located. It shall be noted that for this voltage input the following setting values shall be entered:

   \[ VT_{prim} = \sqrt{3} \frac{138}{\sqrt{3}} = 138kV \]

   (Equation 8)

   \[ VT_{sec} = \sqrt{3} \frac{115}{\sqrt{3}} = 115\]V

   (Equation 9)

Inside the IED, only the ratio of these two parameters is used. It shall be noted that the ratio of the entered values exactly corresponds to ratio of one individual open delta VT.

   \[ \frac{138}{115} = \frac{\sqrt[3]{138}}{\sqrt[3]{115}} \]

   (Equation 10)

3) shows that in this example the first three input channel of the preprocessing block is not connected in SMT tool.

4) shows the connection made in Signal Matrix Tool (SMT), which connect this voltage input to the fourth input channel of the preprocessing function block 4).

5) preprocessing block has a task to digitally filter the connected analog inputs and calculate:
   - fundamental frequency phasors for all four input channels
   - harmonic content for all four input channels
   - positive, negative and zero sequence quantities by using the fundamental frequency phasors for the first three input channels (channel one taken as reference for sequence quantities)

   These calculated values are then available for all built-in protection and control functions within the IED, which are connected to this preprocessing function block in the configuration tool. For this application most of the preprocessing settings can be left to the default values.

   If frequency tracking and compensation is required (this feature is typically required only for IEDs installed in the generating stations) then the setting parameters \textit{DFTReference} shall be set accordingly.

### 4.2.4.7 Example on how to connect a neutral point VT to the IED

Figure 22 gives an example on how to connect a neutral point VT to the IED. This type of VT connection presents secondary voltage proportional to U₀ to the IED.
In case of a solid earth fault in high impedance earthed or unearthed systems the primary value of $U_0$ voltage will be equal to:

$$U_0 = \frac{U_{/n} - n}{\sqrt{3}} = U_{/n} - e$$

(Equation 11)

Figure 22 gives an overview of required actions by the user in order to make this measurement available to the built-in protection and control functions within the IED.

**Figure 22: Neutral point connected VT**

Where:

1) shows how to connect the secondary side of neutral point VT to one VT input in the IED.

$U_0$ shall be connected to the IED.

2) is the TRM or AIM where this voltage input is located. For this voltage input the following setting values shall be entered:

$$VT_{prim} = \frac{6.6}{\sqrt{3}} = 3.81kV$$

(Equation 12)

$$VT_{sec} = 100V$$

(Equation 13)

Inside the IED, only the ratio of these two parameters is used. It shall be noted that the ratio of the entered values exactly corresponds to ratio of the neutral point VT.

Table continues on next page
3) shows that in this example the first three input channel of the preprocessing block is not connected in SMT tool or ACT tool.

4) shows the connection made in Signal Matrix Tool (SMT), Application configuration tool (ACT), which connects this voltage input to the fourth input channel of the preprocessing function block.

5) is a preprocessing block that has the task to digitally filter the connected analog inputs and calculate:
   - fundamental frequency phasors for all four input channels
   - harmonic content for all four input channels
   - positive, negative and zero sequence quantities by using the fundamental frequency phasors for the first three input channels (channel one taken as reference for sequence quantities)

These calculated values are then available for all built-in protection and control functions within the IED, which are connected to this preprocessing function block in the configuration tool. For this application, most of the preprocessing settings can be left to the default values. If frequency tracking and compensation is required (this feature is typically required only for IEDs installed in the generating stations) then the setting parameters $DFTReference$ shall be set accordingly.
Figure 23: Local human-machine interface

The LHMI of the IED contains the following elements

- Keypad
- Display (LCD)
- LED indicators
- Communication port for PCM600

The LHMI is used for setting, monitoring and controlling.
5.1 Display

The LHMI includes a graphical monochrome liquid crystal display (LCD) with a resolution of 320 x 240 pixels. The character size can vary. The amount of characters and rows fitting the view depends on the character size and the view that is shown.

The display view is divided into four basic areas.

Figure 24: Display layout

1 Path
2 Content
3 Status
4 Scroll bar (appears when needed)

The function key button panel shows on request what actions are possible with the function buttons. Each function button has a LED indication that can be used as a feedback signal for the function button control action. The LED is connected to the required signal with PCM600.
5.2 LEDs

The LHMI includes three status LEDs above the display: Ready, Start and Trip.

There are 15 programmable indication LEDs on the front of the LHMI. Each LED can indicate three states with the colors: green, yellow and red. The texts related to each three-color LED are divided into three panels.

There are 3 separate panels of LEDs available. The 15 physical three-color LEDs in one LED group can indicate 45 different signals. Altogether, 135 signals can be indicated since there are...
three LED groups. The LEDs are lit according to priority, with red being the highest and green the lowest priority. For example, if on one panel there is an indication that requires the green LED to be lit, and on another panel there is an indication that requires the red LED to be lit, the red LED takes priority and is lit. The LEDs can be configured with PCM600 and the operation mode can be selected with the LHMI or PCM600.

Information panels for the indication LEDs are shown by pressing the Multipage button. Pressing that button cycles through the three pages. A lit or un-acknowledged LED is indicated with a highlight. Such lines can be selected by using the Up/Down arrow buttons. Pressing the Enter key shows details about the selected LED. Pressing the ESC button exits from information pop-ups as well as from the LED panel as such.

The Multipage button has a LED. This LED is lit whenever any LED on any panel is lit. If there are un-acknowledged indication LEDs, then the Multipage LED blinks. To acknowledge LEDs, press the Clear button to enter the Reset menu (refer to description of this menu for details).

There are two additional LEDs which are next to the control buttons and . These LEDs can indicate the status of two arbitrary binary signals by configuring the OPENCLOSE_LED function block. For instance, OPENCLOSE_LED can be connected to a circuit breaker to indicate the breaker open/close status on the LEDs.

Figure 27: OPENCLOSE_LED connected to SXCBR

5.3 Keypad

The LHMI keypad contains push-buttons which are used to navigate in different views or menus. The push-buttons are also used to acknowledge alarms, reset indications, provide help and switch between local and remote control mode.

The keypad also contains programmable push-buttons that can be configured either as menu shortcut or control buttons.
Figure 28: LHMI keypad with object control, navigation and command push-buttons and RJ-45 communication port

1...5 Function button
6 Close
7 Open
8 Escape
9 Left
10 Down
11 Up
12 Right
13 Key
14 Enter
15 Remote/Local
16 Uplink LED
17 Not in use
18 Multipage
19 Menu
20 Clear
21 Help
5.4 Local HMI functionality

5.4.1 Protection and alarm indication

Protection indicators

The protection indicator LEDs are Ready, Start and Trip.

The yellow and red status LEDs are configured in the disturbance recorder function, DRPRDRE, by connecting a start or trip signal from the actual function to a BxRBDR binary input function block using the PCM600 and configure the setting to Off, Start or Trip for that particular signal.

Table 6: Ready LED (green)

<table>
<thead>
<tr>
<th>LED state</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF</td>
<td>Auxiliary supply voltage is disconnected.</td>
</tr>
<tr>
<td>ON</td>
<td>Normal operation.</td>
</tr>
<tr>
<td>Flashing</td>
<td>Internal fault has occurred.</td>
</tr>
</tbody>
</table>

Table 7: Start LED (yellow)

<table>
<thead>
<tr>
<th>LED state</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF</td>
<td>Normal operation.</td>
</tr>
<tr>
<td>ON</td>
<td>A protection function has started and an indication message is displayed. The start indication is latching and must be reset via communication, LHMI or binary input on the LEDGEN component. To open the reset menu on the LHMI, press .</td>
</tr>
<tr>
<td>Flashing</td>
<td>The IED is in test mode and protection functions are blocked, or the IEC61850 protocol is blocking one or more functions. The indication disappears when the IED is no longer in test mode and blocking is removed. The blocking of functions through the IEC61850 protocol can be reset in Main menu/Test/Reset IEC61850 Mod. The yellow LED changes to either ON or OFF state depending on the state of operation.</td>
</tr>
</tbody>
</table>

Table 8: Trip LED (red)

<table>
<thead>
<tr>
<th>LED state</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF</td>
<td>Normal operation.</td>
</tr>
<tr>
<td>ON</td>
<td>A protection function has tripped. An indication message is displayed if the auto-indication feature is enabled in the local HMI. The trip indication is latching and must be reset via communication, LHMI or binary input on the LEDGEN component. To open the reset menu on the LHMI, press .</td>
</tr>
<tr>
<td>Flashing</td>
<td>Configuration mode.</td>
</tr>
</tbody>
</table>
### Alarm indicators

The 15 programmable three-color LEDs are used for alarm indication. An individual alarm/status signal, connected to any of the LED function blocks, can be assigned to one of the three LED colors when configuring the IED.

<table>
<thead>
<tr>
<th>LED state</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF</td>
<td>Normal operation. All activation signals are OFF.</td>
</tr>
</tbody>
</table>
| ON        | • Follow-S sequence: The activation signal is ON.  
           • LatchedColl-S sequence: The activation signal is ON, or it is off but the indication has not been acknowledged.  
           • LatchedAck-F-S sequence: The indication has been acknowledged, but the activation signal is still ON.  
           • LatchedAck-S-F sequence: The activation signal is ON, or it is off but the indication has not been acknowledged.  
           • LatchedReset-S sequence: The activation signal is ON, or it is off but the indication has not been acknowledged. |
| Flashing  | • Follow-F sequence: The activation signal is ON.  
           • LatchedAck-F-S sequence: The activation signal is ON, or it is off but the indication has not been acknowledged.  
           • LatchedAck-S-F sequence: The indication has been acknowledged, but the activation signal is still ON. |

### 5.4.2 Parameter management

The LHMI is used to access the relay parameters. Three types of parameters can be read and written.

- Numerical values
- String values
- Enumerated values

Numerical values are presented either in integer or in decimal format with minimum and maximum values. Character strings can be edited character by character. Enumerated values have a predefined set of selectable values.

### 5.4.3 Front communication

The RJ-45 port in the LHMI enables front communication.

- The green uplink LED on the left is lit when the cable is successfully connected to the port.  
- The yellow LED is not used; it is always off.
The default IP address for the IED front port is 10.1.150.3 and the corresponding subnetwork mask is 255.255.254.0. It can be set through the local HMI path Main menu/Configuration/Communication/Ethernet configuration/Front port/AP_FRONT.

Ensure not to change the default IP address of the IED.

Do not connect the IED front port to a LAN. Connect only a single local PC with PCM600 to the front port. It is only intended for temporary use, such as commissioning and testing.
Section 6  Differential protection

6.1  High impedance differential protection, single phase HZPDIF

6.1.1  Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>High impedance differential protection, single phase</td>
<td>HZPDIF</td>
<td>Id</td>
<td>87</td>
</tr>
</tbody>
</table>

6.1.2  Application

The 1Ph High impedance differential protection function HZPDIF can be used as:

- Generator differential protection
- Reactor differential protection
- Busbar differential protection
- Autotransformer differential protection (for common and serial windings only)
- T-feeder differential protection
- Capacitor differential protection
- Restricted earth fault protection for transformer, generator and shunt reactor windings
- Restricted earth fault protection

Three instances of HZPDIF are used as a busbar protection for one busbar zone.
6.1.2.1 **The basics of the high impedance principle**

The high impedance differential protection principle has been used for many years and is well documented in literature publicly available. Its operating principle provides very good sensitivity and high speed operation. One main benefit offered by the principle is an absolute stability (that is, no operation) for external faults even in the presence of heavy CT saturation. The principle is based on the CT secondary current circulating between involved current transformers and not through the IED due to high impedance in the measuring branch. This stabilizing resistance is in the range of hundreds of ohms and sometimes above one kilo Ohm. When an internal fault occurs the current cannot circulate and is forced through the measuring branch causing relay operation.
It should be remembered that the whole scheme, its built-in components and wiring must be adequately maintained throughout the lifetime of the equipment in order to be able to withstand the high voltage peaks (that is, pulses) which may appear during an internal fault. Otherwise any flash-over in CT secondary circuits or any other part of the scheme may prevent correct operation of the high impedance differential relay for an actual internal fault.

Figure 32: Example for the high impedance restricted earth fault protection application

For a through fault one current transformer might saturate when the other CTs still will feed current. For such a case a voltage will be developed across the measuring branch. The calculations are made with the worst situations in mind and a minimum operating voltage $U_R$ is calculated according to equation 14

$$ UR > IF_{\text{max}} \cdot (R_{ct} + R_l) $$

(Equation 14)

where:
- $IF_{\text{max}}$ is the maximum through fault current at the secondary side of the CT
- $R_{ct}$ is the current transformer secondary winding resistance and
- $R_l$ is the maximum loop resistance of the circuit at any CT.
The minimum operating voltage has to be calculated (all loops) and the IED function is set higher than the highest achieved value (setting $U>Trip$). As the loop resistance is the value to the connection point from each CT, it is advisable to do all the CT core summations in the switchgear to have shortest possible loops. This will give lower setting values and also a better balanced scheme. The connection in to the control room can then be from the most central bay.

For an internal fault, all involved CTs will try to feed current through the measuring branch. Depending on the size of current transformer, relatively high voltages will be developed across the series resistor. Note that very high peak voltages can appear. To prevent the risk of flashover in the circuit, a voltage limiter must be included. The voltage limiter is a voltage dependent resistor (Metrosil).

The external unit with stabilizing resistor has a value of either 6800 ohms or 1800 ohms (depending on ordered alternative) with a sliding link to allow adjustment to the required value. Select a suitable value of the resistor based on the UR voltage calculated. A higher resistance value will give a higher sensitivity and a lower value a lower sensitivity of the relay.

The function has a recommended operating current range 40 mA to 1.0A for 1 A inputs and 200 mA to 5A for 5A inputs. This, together with the selected and set value, is used to calculate the required value of current at the set $U>Trip$ and SeriesResitor values.

The CT inputs used for 1Ph High impedance differential protection HZPDIF function, shall be set to have ratio 1:1. So the parameters $CT_{secx}$ and $CT_{primx}$ of the relevant channel $x$ of TRM and/or AIM shall be set equal to 1 A by PST in PCM600; The parameter $CTStarPointx$ may be set to ToObject.

The tables 10, 11 below show, the operating currents for different settings of operating voltages and selected resistances. Adjust as required based on tables 10, 11 or to values in between as required for the application.

Minimum ohms can be difficult to adjust due to the small value compared to the total value.

Normally the voltage can be increased to higher values than the calculated minimum $U>Trip$ with a minor change of total operating values as long as this is done by adjusting the resistor to a higher value. Check the sensitivity calculation below for reference.

**Table 10:** 1 A channels: input with minimum operating down to 40 mA

<table>
<thead>
<tr>
<th>Operating voltage $U&gt;Trip$</th>
<th>Stabilizing resistor R ohms</th>
<th>Operating current level 1 A</th>
<th>Stabilizing resistor R ohms</th>
<th>Operating current level 1 A</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 V</td>
<td>500</td>
<td>0.040 A</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>40 V</td>
<td>1000</td>
<td>0.040 A</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>60 V</td>
<td>1500</td>
<td>0.040 A</td>
<td>600</td>
<td>0.100 A</td>
</tr>
<tr>
<td>80 V</td>
<td>2000</td>
<td>0.040 A</td>
<td>800</td>
<td>0.100 A</td>
</tr>
<tr>
<td>100 V</td>
<td>2500</td>
<td>0.040 A</td>
<td>1000</td>
<td>0.100 A</td>
</tr>
<tr>
<td>150 V</td>
<td>3750</td>
<td>0.040 A</td>
<td>1500</td>
<td>0.100 A</td>
</tr>
<tr>
<td>200 V</td>
<td>5000</td>
<td>0.040 A</td>
<td>2000</td>
<td>0.100 A</td>
</tr>
</tbody>
</table>
Table 11: 5 A channels: input with minimum operating down to 100 mA

<table>
<thead>
<tr>
<th>Operating voltage U&gt;Trip</th>
<th>Stabilizing resistor R1 ohms</th>
<th>Operating current level 5 A</th>
<th>Stabilizing resistor R1 ohms</th>
<th>Operating current level 5 A</th>
<th>Stabilizing resistor R1 ohms</th>
<th>Operating current level 5 A</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 V</td>
<td>200</td>
<td>0.100 A</td>
<td>100</td>
<td>0.200 A</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>40 V</td>
<td>400</td>
<td>0.100 A</td>
<td>200</td>
<td>0.200 A</td>
<td>100</td>
<td>0.400 A</td>
</tr>
<tr>
<td>60 V</td>
<td>600</td>
<td>0.100 A</td>
<td>300</td>
<td>0.200 A</td>
<td>150</td>
<td>0.400 A</td>
</tr>
<tr>
<td>80 V</td>
<td>800</td>
<td>0.100 A</td>
<td>400</td>
<td>0.200 A</td>
<td>200</td>
<td>0.400 A</td>
</tr>
<tr>
<td>100 V</td>
<td>1000</td>
<td>0.100 A</td>
<td>500</td>
<td>0.200 A</td>
<td>250</td>
<td>0.400 A</td>
</tr>
<tr>
<td>150 V</td>
<td>1500</td>
<td>0.100 A</td>
<td>750</td>
<td>0.200 A</td>
<td>375</td>
<td>0.400 A</td>
</tr>
<tr>
<td>200 V</td>
<td>2000</td>
<td>0.100 A</td>
<td>1000</td>
<td>0.200 A</td>
<td>500</td>
<td>0.400 A</td>
</tr>
</tbody>
</table>

The current transformer saturation voltage must be at least $2 \cdot U>Trip$ to have sufficient operating margin. This must be checked after calculation of $U>Trip$.

When the R value has been selected and the $U>Trip$ value has been set, the sensitivity of the scheme $IP$ can be calculated. The IED sensitivity is decided by the total current in the circuit according to equation 15.

\[
IP = n \cdot (IR + Ires + \sum Imag)
\]

(Equation 15)

where:
- $n$ is the CT ratio
- $IP$ is the primary current at IED pickup,
- $IR$ is the IED pickup current ($U>Trip$/SeriesResistor)
- $Ires$ is the current through the voltage limiter and
- $\sum Imag$ is the sum of the magnetizing currents from all CTs in the circuit (for example, 4 for restricted earth fault protection, 2 for reactor differential protection, 3-5 for autotransformer differential protection).

It should be remembered that the vectorial sum of the currents must be used (IEDs, Metrosil and resistor currents are resistive). The current measurement is insensitive to DC component in fault current to allow the use of only the AC components of the fault current in the above calculations.

The voltage dependent resistor (Metrosil) characteristic is shown in Figure 38.

**Series resistor thermal capacity**

The series resistor is dimensioned for 200 W. Preferable the $U>Trip^2$/SeriesResistor should always be lower than 200 W to allow continuous activation during testing. If this value is exceeded, testing should be done with a transient faults.
Figure 33: The high impedance principle for one phase with two current transformer inputs
6.1.3 Connection examples for high impedance differential protection

WARNING! USE EXTREME CAUTION! Dangerously high voltages might be present on this equipment, especially on the plate with resistors. De-energize the primary object protected with this equipment before connecting or disconnecting wiring or performing any maintenance. The plate with resistors should be provided with a protective cover, mounted in a separate box or in a locked cubicle. National law and standards shall be followed.

6.1.3.1 Connections for three-phase high impedance differential protection

Generator, reactor or busbar differential protection is a typical application for three-phase high impedance differential protection. Typical CT connections for three-phase high impedance differential protection scheme are shown in figure 34.

Figure 34: CT connections for high impedance differential protection

<table>
<thead>
<tr>
<th>Pos</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Scheme earthing point</td>
</tr>
<tr>
<td></td>
<td>It is important to insure that only one earthing point exist in this scheme.</td>
</tr>
<tr>
<td>2</td>
<td>Three-phase plate with setting resistors and metrosils. Protective earth is a separate 4 mm screw terminal on the plate.</td>
</tr>
<tr>
<td>3</td>
<td>Necessary connection for three-phase metrosil set.</td>
</tr>
<tr>
<td>4</td>
<td>Position of optional test switch for secondary injection into the high impedance differential IED.</td>
</tr>
<tr>
<td>5</td>
<td>Necessary connection for setting resistors.</td>
</tr>
</tbody>
</table>
6 Factory-made star point on a three-phase setting resistor set.

The star point connector must be removed for installations with 650 series IEDs. This star point is required for RADHA schemes only.

7 Connections of three individual phase currents for high impedance scheme to three CT inputs in the IED.

### 6.1.3.2 Connections for 1Ph High impedance differential protection HZPDIF

Restricted earth fault protection is a typical application for 1Ph High impedance differential protection HZPDIF. Typical CT connections for the high impedance based protection scheme are shown in figure 35.

**Figure 35: CT connections for restricted earth fault protection**

<table>
<thead>
<tr>
<th>Pos</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Scheme earthing point</td>
</tr>
<tr>
<td>2</td>
<td>One-phase plate with stabilizing resistor and metrosil. Protective earth is a separate 4 mm screw terminal on the plate.</td>
</tr>
<tr>
<td>3</td>
<td>Necessary connection for the metrosil.</td>
</tr>
<tr>
<td>4</td>
<td>Position of optional test switch for secondary injection into the high impedance differential IED.</td>
</tr>
<tr>
<td>5</td>
<td>Necessary connection for stabilizing resistor.</td>
</tr>
<tr>
<td>6</td>
<td>How to connect the high impedance restricted earth fault protection scheme to one CT input in IED.</td>
</tr>
</tbody>
</table>

Ensure that only one earthing point exists in this scheme.
6.1.4 Setting guidelines

The setting calculations are individual for each application. Refer to the different application descriptions below.

6.1.4.1 Configuration

The configuration is done in the Application Configuration tool.

6.1.4.2 Settings of protection function

Operation: The operation of the high impedance differential function can be switched On or Off.

U>Alarm: Set the alarm level. The sensitivity can roughly be calculated as a certain percentage of the selected Trip level. A typical setting is 10% of U>Trip This alarm stage can be used for scheme CT supervision.

tAlarm: Set the time delay for the alarm. A typical setting is 2-3 seconds.

U>Trip: Set the trip level according to the calculations (see examples below for a guidance). The level is selected with margin to the calculated required voltage to achieve stability. Values can be within 20V - 400V range dependent on the application.

SeriesResistor: Set the value of the used stabilizing series resistor. Calculate the value according to the examples for each application. Measure the value achieved and set this value for this parameter.

The value shall always be high impedance. This means for example, for 1A circuits say bigger than 400 ohms (400 VA) and for 5 A circuits say bigger than 100 ohms (2500 VA). This ensures that the current will circulate and not go through the differential circuit at through faults.

That the settings of U>Alarm, U>Trip and SeriesResistor must be chosen such that both U>Alarm/SeriesResistor and U>Trip/SeriesResistor are >4% of IRated of the used current input. Normally the settings shall also be such that U>Alarm/SeriesResistor and U>Trip/SeriesResistor both give a value <4*IRated of the used current input. If not, the limitation in how long time the actual current is allowed to persist not to overload the current input must be considered especially during the secondary testing.

6.1.4.3 T-feeder protection

In many busbar arrangements such as one-and a half breaker, ring breaker, mesh corner, there will be a T-feeder from the current transformer at the breakers up to the current transformers in the feeder circuit (for example, in the transformer bushings). It is often required to separate the protection zones that the feeder is protected with one scheme while the T-zone is protected with a separate differential protection scheme. The 1Ph high impedance differential HZPDIF function in the IED allows this to be done efficiently, see Figure 36.
Figure 36: The protection scheme utilizing the high impedance function for the T-feeder

Normally this scheme is set to achieve a sensitivity of around 20 percent of the used CT primary rating so that a low ohmic value can be used for the series resistor.
It is strongly recommended to use the highest tap of the CT whenever high impedance protection is used. This helps in utilizing maximum CT capability, minimize the secondary fault current, thereby reducing the stability voltage limit. Another factor is that during internal faults, the voltage developed across the selected tap is limited by the non-linear resistor but in the unused taps, owing to auto-transformer action, voltages induced may be much higher than design limits.

Setting example

### Basic data:
- Current transformer ratio: 2000/1 A
- CT Class: 20 VA 5P20
- Secondary resistance: 6.2 ohms
- Cable loop resistance: <100 m 2.5 mm² (one way) gives 2 × 0.8 ohm at 75° C
- Max fault current: Equal to switchgear rated fault current 40 kA

### Calculation:

\[
UR > \frac{40000}{2000} \times (6.2+1.6) = 156V 
\]

(Equation 16)

Select a setting of \(U_{\text{Trip}}=200\) V.

The current transformer saturation voltage must be at least twice the set operating voltage \(U_{\text{Trip}}\).

\[
ESP > (20 + 6.2) \times 20 = 524V 
\]

(Equation 17)

that is, bigger than \(2 \times U_{\text{Trip}}\)

Check from the table of selected resistances the required series stabilizing resistor value to use. As this application requires to be so sensitive select \(SeriesResistor= 2000 \) ohm, which gives an IED operating current of 100 mA.

Calculate the primary sensitivity at operating voltage using the following equation.

\[
IP = \frac{2000}{1} \times (100[0°] + 20[0°] + 3 \times 10[0°]=60°) \times 10^{-3} \leq approx 275A 
\]

(Equation 18)

where
- 100 mA is the current drawn by the IED circuit
- 10 mA is the current drawn by each CT just at pickup
- 20 mA is current drawn by metrosil at pickup
The magnetizing current is taken from the magnetizing curve for the current transformer cores which should be available. The current value at $U>T_{\text{Trip}}$ is taken. For the voltage dependent resistor current the peak value of voltage $200 \times \sqrt{2}$ is used. Then the RMS current is calculated by dividing obtained current value from the metrosil curve with $\sqrt{2}$. Use the value from the maximum metrosil curve given in Figure 38.

It can clearly be seen that the sensitivity is not so much influenced by the selected voltage level so a sufficient margin should be used. The selection of the stabilizing resistor and the level of the magnetizing current (mostly dependent of the number of turns) are the most important factors.

6.1.4.4 Tertiary reactor protection

Reactive power equipment (for example shunt reactors and/or shunt capacitors) can be connected to the tertiary winding of the power transformers. The 1Ph High impedance differential protection function HZPDIF can be used to protect the tertiary reactor for phase faults as well as earth faults if the power system of the tertiary winding is direct or low impedance earthed.

Figure 37: Application of the 1Ph High impedance differential protection HZPDIF function on a reactor
Setting example

It is strongly recommended to use the highest tap of the CT whenever high impedance protection is used. This helps in utilizing maximum CT capability, minimize the secondary fault, thereby reducing the stability voltage limit. Another factor is that during internal faults, the voltage developed across the selected tap is limited by the non-linear resistor but in the unused taps, owing to auto-transformer action, voltages much higher than design limits might be induced.

Basic data:

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current transformer ratio</td>
<td>100/5 A (Note: Must be the same at all locations)</td>
</tr>
<tr>
<td>CT Class</td>
<td>10 VA 5P20</td>
</tr>
<tr>
<td>Secondary resistance</td>
<td>0.26 ohms</td>
</tr>
<tr>
<td>Cable loop resistance</td>
<td>&lt;50 m 2.5mm² (one way) gives 1 x 0.4 ohm at 75° C</td>
</tr>
<tr>
<td></td>
<td>Note! Only one way as the tertiary power system earthing is limiting the earth-fault current. If high earth-fault current exists use two way cable length.</td>
</tr>
<tr>
<td>Max fault current</td>
<td>The maximum through fault current is limited by the reactor reactance and the inrush will be the worst for a reactor for example, 800 A.</td>
</tr>
</tbody>
</table>

Calculation:

\[
UR > \frac{800}{100/5} \times (0.26 + 0.4) = 26.4
\]

(Equation 19)

Select a setting of \(U>Trip=30\ V\).

The current transformer saturation voltage must be at least, twice the set operating voltage \(U>Trip\).

\[
U_{\text{CT Saturation}} > \left(\frac{10}{25} + 0.26\right) \times 20 \times 5 = 66V
\]

(Equation 20)

that is, greater than \(2 \times U>Trip\).

Check from the table of selected resistances the required series stabilizing resistor value to use. Since this application requires good sensitivity, select \(SeriesResistor = 300\ ohm\), which gives an IED current of 100 mA.

To calculate the sensitivity at operating voltage, refer to equation 21, which gives an acceptable value. A little lower sensitivity could be selected by using a lower resistance value.

\[
IP = \frac{100}{5} \times (100\|0° + 50° + 2 \times 100\|60°) \times 10^{-3} \leq approx \ 5A
\]

(Equation 21)

The magnetizing current is taken from the magnetizing curve of the current transformer cores, which should be available. The current value at \(U>Trip\) is taken. For the voltage dependent resistor current the peak value of voltage 30° × √2 is used. Then the RMS current is calculated by
dividing obtained current value from the metrosil curve with $\sqrt{2}$. Use the maximum value from the metrosil curve given in Figure 38.

### 6.1.4.5 Alarm level operation

The 1Ph High impedance differential protection HZPDIF function has a separate alarm level, which can be used to give alarm for problems with an involved current transformer circuit. The setting level is normally selected to be around 10% of the operating voltage $U_{\text{Trip}}$.

As seen in the setting examples above the sensitivity of HZPDIF function is normally high, which means that the function will in many cases operate also for short circuits or open current transformer secondary circuits. However the stabilizing resistor can be selected to achieve sensitivity higher than normal load current and/or separate criteria can be added to the operation, like a check zone. This can be either another IED, with the same HZPDIF function, or be a check about the fault condition, which is performed by an earth overcurrent function or neutral point voltage function.

For such cases where operation is not expected during normal service the alarm output should be used to activate an external shorting of the differential circuit avoiding continuous high voltage in the circuit. A time delay of a few seconds is used before the shorting and alarm are activated. Auxiliary relays with contacts that can withstand high voltage shall be used, like RXMVB types.

The metrosil operating characteristic is given in the following figure.

![Figure 38: Current voltage characteristics for the non-linear resistors, in the range 10-200 V, the average range of current is: 0.01–10 mA](xc0680749.png)
Section 7  Current protection

7.1  Directional phase overcurrent protection, four steps OC4PTOC

7.1.1  Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directional phase overcurrent protection, four steps</td>
<td>OC4PTOC</td>
<td></td>
<td>51_67</td>
</tr>
</tbody>
</table>

7.1.2  Application

Directional phase overcurrent protection, four steps OC4PTOC is used in several applications in the power system. Some applications are:

- Short circuit protection of feeders in distribution and subtransmission systems. Normally these feeders have a radial structure.
- Back-up short circuit protection of transmission lines.
- Back-up short circuit protection of power transformers.
- Short circuit protection of different kinds of equipment connected to the power system such as; shunt capacitor banks, shunt reactors, motors and others.
- Back-up short circuit protection of power generators.

In many applications several steps with different current pickup levels and time delays are needed. OC4PTOC can have up to four different, individually settable steps. The following options are possible:

Non-directional / Directional function: In most applications the non-directional functionality is used. This is mostly the case when no fault current can be fed from the protected object itself. In order to achieve both selectivity and fast fault clearance, the directional function can be necessary.

If VT inputs are not available or not connected, the setting parameter DirModex ($x = \text{step } 1, 2, 3 \text{ or } 4$) shall be left to the default value Non-directional.

Choice of time delay characteristics: There are several types of time delay characteristics available such as definite time delay and different types of inverse time delay characteristics. The selectivity between different overcurrent protections is normally enabled by co-ordination between the function time delays of the different protections. To enable optimal co-ordination between all overcurrent protections, they should have the same time delay characteristic. Therefore, a wide range of standardized inverse time characteristics are available for IEC and ANSI. It is also possible to tailor make the inverse time characteristic.
Normally, it is required that the phase overcurrent protection shall reset as fast as possible when the current level gets lower than the operation level. In some cases some sort of delayed reset is required. Therefore, different kinds of reset characteristics can be used.

For some protection applications, there can be a need to change the current pick-up level for some time. A typical case is when the protection will measure the current to a large motor. At the start up sequence of a motor the start current can be significantly larger than the rated current of the motor. Therefore, there is a possibility to give a setting of a multiplication factor to the current pick-up level. This multiplication factor is activated from a binary input signal to the function.

Power transformers can have a large inrush current, when being energized. This phenomenon is due to saturation of the transformer magnetic core during parts of the period. There is a risk that inrush current will reach levels above the pick-up current of the phase overcurrent protection. The inrush current has a large 2\textsuperscript{nd} harmonic content. This can be used to avoid unwanted operation of the protection function. Therefore, OC4PTOC has a possibility of 2\textsuperscript{nd} harmonic restrain if the level of 2\textsuperscript{nd} harmonic current reaches a value above a set percent of the fundamental current.

The phase overcurrent protection is often used as a protection for two and three phase short circuits. In some cases, it is not wanted to detect single-phase earth faults by the phase overcurrent protection. This fault type is detected and cleared after operation of earth fault protection. Therefore, it is possible to make a choice how many phases, at minimum, that have to have current above the pick-up level, to enable operation. If set 1 of 3 it is sufficient to have high current in one phase only. If set 2 of 3 or 3 of 3 single-phase earth faults are not detected.

### 7.1.3 Setting guidelines

When inverse time overcurrent characteristic is selected, the operate time of the stage will be the sum of the inverse time delay and the set definite time delay. Thus, if only the inverse time delay is required, it is important to set the definite time delay for that stage to zero.

The parameters for the directional phase overcurrent protection, four steps OC4PTOC are set via the local HMI or PCM600.

The following settings can be done for OC4PTOC.

**Common base IED values**

- **IBase**: Primary current (I_{Base})
- **UBase**: Primary voltage (U_{Base})
- **SBase**: Primary power (S_{Base})

These values are set in global base values for settings function GBASVAL.

**GlobalBaseSel**: Selects the global base value group used by the function to define I_{Base}, U_{Base} and S_{Base}.

**MeasType**: Selection of discrete Fourier filtered (DFT) or true RMS filtered (RMS) signals. RMS is used when the harmonic contents are to be considered, for example in applications with shunt capacitors.

**Operation**: The protection can be set to On or Off.

**AngleRCA**: Protection characteristic angle set in degrees. If the angle of the fault loop current has the angle RCA, the direction to the fault is forward.

**AngleROA**: Angle value, given in degrees, to define the angle sector of the directional function, shown in Figure 39.

**StartPhSel**: Number of phases, with high current, required for operation. The setting possibilities are: 1 out of 3, 2 out of 3 and 3 out of 3. The default setting is 1 out of 3.
**IMinOpPhSel**: Minimum current setting level for releasing the directional start signals in % of \(IB\). This setting should be less than the lowest step setting. The default setting is 7% of \(IB\).

**2ndHarmonicStab**: Operate level of 2nd harmonic current restrain set in % of the fundamental current. The setting range is 5 - 100% in steps of 1%. The default setting is 20%.

---

![Diagram](IEC09000636_2_vsd)

**Figure 39**: Directional function characteristic

1. RCA = Relay characteristic angle
2. ROA = Relay operating angle
3. Reverse
4. Forward

---

### 7.1.3.1 Settings for each step

\(x\) means step 1, 2, 3 and 4.

**DirModex**: The directional mode of step \(x\). Possible settings are **Off/Non-directional/Forward/Reverse**.

**Characterisx**: Selection of time characteristic for step \(x\). Definite time delay and different types of inverse time characteristics are available according to Table 12.
Table 12: Inverse time characteristics

<table>
<thead>
<tr>
<th>Curve name</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANSI Extremely Inverse</td>
</tr>
<tr>
<td>ANSI Very Inverse</td>
</tr>
<tr>
<td>ANSI Normal Inverse</td>
</tr>
<tr>
<td>ANSI Moderately Inverse</td>
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<td>ANSI Long Time Extremely Inverse</td>
</tr>
<tr>
<td>ANSI Long Time Very Inverse</td>
</tr>
<tr>
<td>ANSI Long Time Inverse</td>
</tr>
<tr>
<td>IEC Normal Inverse</td>
</tr>
<tr>
<td>IEC Very Inverse</td>
</tr>
<tr>
<td>IEC Inverse</td>
</tr>
<tr>
<td>IEC Extremely Inverse</td>
</tr>
<tr>
<td>IEC Short Time Inverse</td>
</tr>
<tr>
<td>IEC Long Time Inverse</td>
</tr>
<tr>
<td>IEC Definite Time</td>
</tr>
<tr>
<td>User Programmable</td>
</tr>
<tr>
<td>ASEA RI</td>
</tr>
<tr>
<td>RXIDG or RD (logarithmic)</td>
</tr>
</tbody>
</table>

The different characteristics are described in *Technical manual*.

\( Ix> \): Operate phase current level for step \( x \) given in % of \( IB \).

\( Ix>\text{Max} \) and \( Ix>\text{Min} \) should only be changed if remote setting of operation current level, \( Ix> \), is used. The limits are used for decreasing the used range of the \( Ix> \) setting. If \( Ix> \) is set outside \( Ix>\text{Max} \) and \( Ix>\text{Min} \), the closest of the limits to \( Ix> \) is used by the function. If \( Ix>\text{Max} \) is smaller than \( Ix>\text{Min} \), the limits are swapped.

\( tx \): Definite time delay for step \( x \). The definite time \( tx \) is added to the inverse time when inverse time characteristic is selected. Note that the value set is the time between activation of the start and the trip outputs.

\( kx \): Time multiplier for inverse time delay for step \( x \).

\( IMinx \): Minimum operate current in % of \( IB \) for all inverse time characteristics, below which no operation takes place.

\( IMinx \): Minimum operate current for step \( x \) in % of \( IBase \). Set \( IMinx \) below \( Ix> \) for every step to achieve ANSI reset characteristic according to standard. If \( IMinx \) is set above \( Ix> \) for any step the ANSI reset works as if current is zero when current drops below \( IMinx \).

\( txMin \): Minimum operate time for all inverse time characteristics. At high currents the inverse time characteristic might give a very short operation time. By setting this parameter the operation time of the step can never be shorter than the setting. Setting range: 0.000 - 60,000s in steps of 0.001s.

\( IxMult \): Multiplier for scaling of the current setting value. If a binary input signal ENMULTx (enableMultiplier) is activated the current operation level is increased by this setting constant. Setting range: 1.0-10.0
In order to fully comply with the definition of the curve, the setting parameter $txMin$ shall be set to a value equal to the operating time of the selected inverse curve for twenty times the set current pickup value. Note that the operate time is dependent on the selected time multiplier setting $kx$.

**ResetTypeCrvx**: The reset of the delay timer can be made as shown in Table 13.

<table>
<thead>
<tr>
<th>Curve name</th>
<th>Curve index no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instantaneous</td>
<td>1</td>
</tr>
<tr>
<td>IEC Reset (constant time)</td>
<td>2</td>
</tr>
<tr>
<td>ANSI Reset (inverse time)</td>
<td>3</td>
</tr>
</tbody>
</table>

The delay characteristics are described in *Technical manual*. There are some restrictions regarding the choice of the reset delay.

For the definite time delay characteristics, the possible delay time setting instantaneous (1) and IEC (2 = set constant time reset).

For ANSI inverse time characteristics, all three types of reset time characteristics are available: instantaneous (1), IEC (2 = set constant time reset) and ANSI (3 = current dependent reset time).

For IEC inverse time characteristics, the possible delay time settings are instantaneous (1) and IEC (2 = set constant time reset).

For the customer tailor-made inverse time delay characteristics (type 17), all three types of reset time characteristics are available: instantaneous (1), IEC (2 = set constant time reset) and ANSI (3 = current dependent reset time). If the current-dependent type is used, settings $pr$, $tr$ and $cr$ must be given.

$tResetx$: Constant reset time delay in seconds for step $x$.

$tPCrvx$, $tACrvx$, $tBCrvx$, $tCCrvx$: These parameters are used by the customer to create the inverse time characteristic curve. See equation 22 for the time characteristic equation. For more information, refer to *Technical manual*.
\[ t[s] = \left( \frac{A}{i^{n}} - C \right) \cdot IxMult \]

(Equation 22)

\( tPRCrvx, tTRCrvx, tCRCrvx \): These parameters are used by the customer to create the inverse reset time characteristic curve. For more information, refer to Technical manual.

\( HarmRestrainx \): Enables the block of step \( x \) from the harmonic restrain function (2nd harmonic). This function should be used when there is a risk of an unwanted trip caused by power transformer inrush currents. It can be set to Off/On.

### 7.1.3.2 Setting example

Directional phase overcurrent protection, four steps can be used in different ways, depending on the application where the protection is used. A general description is given below.

The operating current setting of the inverse time protection, or the lowest current step of the definite time protection, must be defined so that the highest possible load current does not cause protection operation. The protection reset current must also be considered so that a short peak of overcurrent does not cause the operation of a protection even when the overcurrent has ceased. This phenomenon is described in Figure 41.

**Figure 41:** Operate and reset current for an overcurrent protection

The lowest setting value can be written according to Equation 23.
where:
1.2 is a safety factor
$k$ is the reset ratio of the protection
$Imax$ is the maximum load current

The load current up to the present situation can be found from operation statistics. The
current setting must remain valid for several years. In most cases, the setting values are
updated once every five years or less often. Investigate the maximum load current that the
equipment on the line can withstand. Study components, such as line conductors, current
transformers, circuit breakers, and disconnectors. The manufacturer of the equipment
normally gives the maximum thermal load current of the equipment.

The maximum load current on the line has to be estimated. There is also a demand that all
faults within the zone that the protection shall cover must be detected by the phase
overcurrent protection. The minimum fault current $Iscmin$ to be detected by the protection
must be calculated. Taking this value as a base, the highest pickup current setting can be
written according to Equation 24.

\[ Ipu \leq 0.7 \cdot Iscmin \]  
(Equation 24)

where:
0.7 is a safety factor
$Iscmin$ is the smallest fault current to be detected by the overcurrent protection.

As a summary, the operating current shall be chosen within the interval stated in Equation 25.

\[ 1.2 \cdot \frac{Imax}{k} \leq Ipu \leq 0.7 \cdot Iscmin \]  
(Equation 25)

The high current function of the overcurrent protection, which only has a short-delay trip time,
must be given a current setting so that the protection is selective to other protection
functions in the power system. It is desirable to have rapid tripping of faults within a large part
of the power system to be protected by the protection (primary protected zone). A fault
current calculation gives the largest current of faults, $Iscmax$, at the most remote part of the
primary protected zone. The risk of transient overreach must be considered, due to a possible
DC component of the short circuit current. The lowest current setting of the fastest stage can
be written according to
\[ I_{\text{high}} \geq 1.2 \cdot k_t \cdot I_{\text{sc max}} \]  

(Equation 26)

where:
- \(1.2\) is a safety factor
- \(k_t\) is a factor that takes care of the transient overreach due to the DC component of the fault current and can be considered to be less than 1.05
- \(I_{\text{sc max}}\) is the largest fault current at a fault at the most remote point of the primary protection zone.

The operate time of the phase overcurrent protection has to be chosen so that the fault time is short enough that the protected equipment will not be destroyed due to thermal overload while, at the same time, selectivity is assured. For overcurrent protection in a radial fed network, the time setting can be chosen in a graphical way. This is mostly used in the case of inverse time overcurrent protection. Figure 42 shows how the time-versus-current curves are plotted in a diagram. The time setting is chosen to get the shortest fault time with maintained selectivity. Selectivity is assured if the time difference between the curves is larger than a critical time difference.

**Figure 42: Fault time with maintained selectivity**

The operation time can be set individually for each overcurrent protection.

To assure selectivity between different protection functions in the radial network, there has to be a minimum time difference \(\Delta t\) between the time delays of two protections. To determine the shortest possible time difference, the operation time of the protection, the breaker opening time and the protection resetting time must be known. These time delays can vary.
significantly between different protective equipment. The following time delays can be estimated:

- Protection operation time: 15-60 ms
- Protection resetting time: 15-60 ms
- Breaker opening time: 20-120 ms

**Example for time coordination**

Assume two substations A and B directly connected to each other via one line, as shown in the Figure 43. Consider a fault located at another line from the station B. The fault current to the overcurrent protection of IED B1 has a magnitude so that the overcurrent protection will start and subsequently trip, and the overcurrent protection of IED A1 must have a delayed operation in order to avoid maloperation. The sequence of events during the fault can be described using a time axis shown in Figure 43.

![Figure 43: Sequence of events during fault](IEC05000205=2=en=Original.vsd)

where:

- t=0 is when the fault occurs
- t=t1 is when protection IED B1 and protection IED A1 start
- t=t2 is when the trip signal from the overcurrent protection at IED B1 is sent to the circuit breaker.
- t=t3 is when the circuit breaker at IED B1 opens. The circuit breaker opening time is t3 - t2
- t=t4 is when the overcurrent protection at IED A1 resets. The protection resetting time is t4 - t3.

To ensure that the overcurrent protection at IED A1 is selective to the overcurrent protection at IED B1, the minimum time difference must be larger than the time t3. There are uncertainties in the values of protection operation time, breaker opening time and protection resetting time. Therefore a safety margin has to be included. With normal values the needed time difference can be calculated according to Equation 27.
\[ \Delta t \geq 40\, ms + 100\, ms + 40\, ms + 40\, ms = 220\, ms \]  

(Equation 27)

where it is considered that:
- the operate time of overcurrent protection B1 is 40 ms
- the breaker open time is 100 ms
- the resetting time of protection A1 is 40 ms and
- the additional margin is 40 ms

7.2  Directional residual overcurrent protection, four steps EF4PTOC

7.2.1  Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directional residual overcurrent protection, four steps</td>
<td>EF4PTOC</td>
<td></td>
<td>51N_67N</td>
</tr>
</tbody>
</table>

7.2.2  Application

The directional residual overcurrent protection, four steps EF4PTOC is used in several applications in the power system. Some applications are:

- Earth-fault protection of feeders in effectively earthed distribution and subtransmission systems. Normally these feeders have radial structure.
- Back-up earth-fault protection of transmission lines.
- Sensitive earth-fault protection of transmission lines. EF4PTOC can have better sensitivity to detect resistive phase-to-earth-faults compared to distance protection.
- Back-up earth-fault protection of power transformers.
- Earth-fault protection of different kinds of equipment connected to the power system such as shunt capacitor banks, shunt reactors and others.

In many applications, several steps with different current operating levels and time delays are needed. EF4PTOC can have up to four, individual settable steps. The flexibility of each step of EF4PTOC is great. The following options are possible:

Non-directional/Directional function: In some applications the non-directional functionality is used. This is mostly the case when no fault current can be fed from the protected object itself. In order to achieve both selectivity and fast fault clearance, the directional function can be necessary. This can be the case for earth-fault protection in meshed and effectively earthed transmission systems. The directional residual overcurrent protection is also well suited to operate in teleprotection communication schemes, which enables fast clearance of earth faults on transmission lines. The directional function uses the polarizing quantity as decided by setting. Voltage polarizing is the most commonly used, but alternatively current polarizing...
where currents in transformer neutrals providing the neutral source (ZN) is used to polarize \((IN \cdot ZN)\) the function. Dual polarizing, where the sum of both voltage and current components is allowed to polarize can also be selected.

Choice of time characteristics: There are several types of time characteristics available such as definite time delay and different types of inverse time characteristics. The selectivity between different overcurrent protections is normally enabled by co-ordination between the operate time of the different protections. To enable optimal co-ordination all overcurrent protections, to be co-ordinated against each other, should have the same time characteristic. Therefore a wide range of standardized inverse time characteristics are available for IEC and ANSI.

Table 14: Time characteristics

<table>
<thead>
<tr>
<th>Curve name</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANSI Extremely Inverse</td>
</tr>
<tr>
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</tr>
<tr>
<td>ASEA RI</td>
</tr>
<tr>
<td>RXIDG or RD (logarithmic)</td>
</tr>
</tbody>
</table>

It is also possible to tailor make the inverse time characteristic.

Normally it is required that EF4PTOC shall reset as fast as possible when the current level gets lower than the operation level. In some cases some sort of delayed reset is required. Therefore different kinds of reset characteristics can be used.

For some protection applications, there can be a need to change the current operating level for some time. Therefore, there is a possibility to give a setting of a multiplication factor \(INxMult\) to the residual current pick-up level. This multiplication factor is activated from a binary input signal ENMULTx to the function.

Power transformers can have a large inrush current, when being energized. This inrush current can produce residual current component. The phenomenon is due to saturation of the transformer magnetic core during parts of the cycle. There is a risk that inrush current will give a residual current that reaches level above the operating current of the residual overcurrent protection. The inrush current has a large second harmonic content. This can be used to avoid unwanted operation of the protection. Therefore, EF4PTOC has a possibility of second harmonic restrain if the level of 2\(^{nd}\) harmonic current reaches a value above a set percent of the fundamental current.
### 7.2.3 Setting guidelines

When inverse time overcurrent characteristic is selected, the operate time of the stage will be the sum of the inverse time delay and the set definite time delay. Thus, if only the inverse time delay is required, it is important to set the definite time delay for that stage to zero.

The parameters for the four step residual overcurrent protection are set via the local HMI or PCM600. The following settings can be done for the function.

- **Common base IED values for the primary current** (IBase), primary voltage (UBase) and primary power (SBase) are set in global base values for settings function GBASVAL.

- **GlobalBaseSel**: Selects the global base value group used by the function to define IBase, UBase and SBase.

- **SeqTypeUPol**: This is used to select the type of voltage polarising quantity i.e. Zero seq or Neg seq for direction detection.

- **SeqTypeIPol**: This is used to select the type of current polarising quantity i.e. Zero seq or Neg seq for direction detection.

- **SeqTypeIDir**: This is used to select the type of operating current quantity i.e. Zero seq or Neg seq for direction detection.

### 7.2.3.1 Common settings for all steps

- **AngleRCA**: Relay characteristic angle given in degree. This angle is defined as shown in Figure 44. The angle is defined positive when the residual current lags the reference voltage (Upol = 3U₀ or U₂)

  ![Relay characteristic angle given in degree](IEC05000135-5-en.vsdx)

*Figure 44: Relay characteristic angle given in degree*

In a normal transmission network a normal value of RCA is about 65°. The setting range is -180° to +180°.
polMethod: Defines if the directional polarization is from

- Voltage \((3U_0 \text{ or } U_2)\)
- Current \((3I_0 \cdot ZNpol \text{ or } 3I_2 \cdot ZNpol \text{ where } ZNpol = RNpol + jXNpol)\), or
- both currents and voltage, Dual (dual polarizing, \((3U_0 + 3I_0 \cdot ZNpol) \text{ or } (U_2 + I_2 \cdot ZNpol)\)).

Normally voltage polarizing from the internally calculated residual sum or an external open delta is used.

Current polarizing is useful when the local source is strong and a high sensitivity is required. In such cases the polarizing voltage \((3U_0)\) can be below 1% and it is then necessary to use current polarizing or dual polarizing. Multiply the required set current (primary) with the minimum impedance \((ZNpol)\) and check that the percentage of the phase-to-earth voltage is definitely higher than 1% (minimum \(3U_0 > UPolMin\) setting) as a verification.

\(RNPol, XNPol\): The zero-sequence source is set in primary ohms as base for the current polarizing. The polarizing voltage is then achieved as \(3I_0 \cdot ZNpol\). The ZNpol can be defined as \((ZS_1 - ZS_0)/3\), that is the earth return impedance of the source behind the protection. The maximum earth-fault current at the local source can be used to calculate the value of ZN as \(U/(\sqrt{3} \cdot 3I_0)\). Typically, the minimum ZNPol (3 · zero sequence source) is set. The setting is in primary ohms.

When the dual polarizing method is used, it is important that the setting \(INx>\) or the product \(3I_0 \cdot ZNpol\) is not greater than \(3U_0\). If so, there is a risk for incorrect operation for faults in the reverse direction.

\(IPolMin\): is the minimum earth-fault current accepted for directional evaluation. For smaller currents than this value, the operation will be blocked. A typical setting is 5-10% of \(IB\).

\(UPolMin\): Minimum polarization (reference) polarizing voltage for the directional function, given in % of \(UBase/\sqrt{3}\).

\(INx>Dir\): Operate residual current release level in % of \(IB\) for directional comparison scheme. The setting is given in % of \(IB\) and must be set below the lowest \(INx>\) setting, set for the directional measurement. The output signals, STFW and STRV can be used in a teleprotection scheme. The appropriate signal should be configured to the communication scheme block.

### 2nd harmonic restrain

If a power transformer is energized there is a risk that the current transformer core will saturate during part of the period, resulting in a transformer inrush current. This will give a declining residual current in the network, as the inrush current is deviating between the phases. There is a risk that the residual overcurrent function will give an unwanted trip. The inrush current has a relatively large ratio of 2nd harmonic component. This component can be used to create a restrain signal to prevent this unwanted function.

At current transformer saturation a false residual current can be measured by the protection. Here the 2nd harmonic restrain can prevent unwanted operation as well.

\(2ndHarmStab\): The rate of 2nd harmonic current content for activation of the 2nd harmonic restrain signal. The setting is given in % of the fundamental frequency residual current.

### Parallel transformer inrush current logic

In case of parallel transformers there is a risk of sympathetic inrush current. If one of the transformers is in operation, and the parallel transformer is switched in, the asymmetric inrush current of the switched-in transformer will cause partial saturation of the transformer already in service. This is called transferred saturation. The 2nd harmonic of the inrush currents
of the two transformers will be in phase opposition. The summation of the two currents will thus give a small 2\textsuperscript{nd} harmonic current. The residual fundamental current will however be significant. The inrush current of the transformer in service before the parallel transformer energizing, will be a little delayed compared to the first transformer. Therefore, we will have high 2\textsuperscript{nd} harmonic current initially. After a short period this current will however be small and the normal 2\textsuperscript{nd} harmonic blocking will reset.

**Figure 45: Application for parallel transformer inrush current logic**

If the $BlkParTransf$ function is activated, the 2\textsuperscript{nd} harmonic restrain signal will latch as long as the residual current measured by the relay is larger than a selected step current level. Assume that step 4 is chosen to be the most sensitive step of the four step residual overcurrent protection function EF4PTOC. The harmonic restrain blocking is enabled for this step. Also the same current setting as this step is chosen for the blocking at parallel transformer energizing.

The settings for the parallel transformer logic are described below.

$BlkParTransf$: This is used to On blocking at energising of parallel transformers.

$UseStartValue$: Gives which current level should be used for the activation of the blocking signal. This is given as one of the settings of the steps: Step 1/2/3/4. Normally, the step having the lowest operation current level should be set.

### 7.2.3.4 Switch onto fault logic

In case of energizing a faulty object there is a risk of having a long fault clearance time, if the fault current is too small to give fast operation of the protection. The switch on to fault function can be activated from auxiliary signals from the circuit breaker, either the close command or the open/close position (change of position).

This logic can be used to issue a fast trip if one breaker pole does not close properly at a manual or automatic closing.

SOTF and under time are similar functions to achieve fast clearance at asymmetrical closing based on requirements from different utilities.

The function is divided into two parts. The SOTF function will give operation from step 2 or 3 during a set time after change in the position of the circuit breaker. The SOTF function has a set time delay. The under time function, which has 2\textsuperscript{nd} harmonic restrain blocking, will give operation from step 4. The 2nd harmonic restrain will prevent unwanted function in case of transformer inrush current. The under time function has a set time delay.

Below the settings for switch on to fault logics are described.

$SOTF$: This parameter can be set: Off/SOTF/Under Time/SOTF+Under Time.
ActivationSOTF: This setting will select the signal to activate SOTF function; CB position open/CB position closed/CB close command.

StepForSOTF: If this parameter is set on step 3, the step 3 start signal will be used as current set level. If set on step 2, the step 2 start signal will be used as current set level.

HarmBlkSOTF: This is used to On/Off harmonic restrain during SOTF conditions.

tSOTF: Time delay for operation of the SOTF function. The setting range is 0.000 - 60.000 s in step of 0.001 s. The default setting is 0.100 s

$t4U$: Time interval when the SOTF function is active after breaker closing. The setting range is 0.000 - 60.000 s in step of 0.001 s. The default setting is 1.000 s.

ActUnderTime: Describes the mode to activate the sensitive undertime function. The function can be activated by Circuit breaker position (change) or Circuit breaker command.

$tUnderTime$: Time delay for operation of the sensitive undertime function. The setting range is 0.000 - 60.000 s in step of 0.001 s. The default setting is 0.300 s

7.2.3.5 Settings for each step (x = 1, 2, 3 and 4)

**Operation**: Sets the protection to On or Off.

**DirModex**: The directional mode of step x. Possible settings are Off/Non-directional/Forward/Reverse.

**Characterisx**: Selection of time characteristic for step x. Definite time delay and different types of inverse time characteristics are available.

Inverse time characteristic enables fast fault clearance of high current faults at the same time as selectivity to other inverse time phase overcurrent protections can be assured. This is mainly used in radial fed networks but can also be used in meshed networks. In meshed networks, the settings must be based on network fault calculations.

To assure selectivity between different protections, in the radial network, there has to be a minimum time difference $\Delta t$ between the time delays of two protections. To determine the shortest possible time difference, the operation time of protections, breaker opening time and protection resetting time must be known. These time delays can vary significantly between different protective equipment. The following time delays can be estimated:

- Protection operate time: 15-60 ms
- Protection resetting time: 15-60 ms
- Breaker opening time: 20-120 ms

The different characteristics are described in the technical reference manual.

$t_{x}$: Definite time delay for step $x$. The definite time $t_{x}$ is added to the inverse time when inverse time characteristic is selected. Note that the value set is the time between activation of the start and the trip outputs.

$IN_{x}>$: Operate residual current level for step $x$ given in % of $IB$.

$IN_{x}>Max$ and $IN_{x}>Min$ should only be changed if remote setting of operation current level, $IN_{x}>$, is used. The limits are used for decreasing the used range of the $IN_{x}>$ setting. If $IN_{x}>$ is set outside $IN_{x}>Max$ and $IN_{x}>Min$, the closest of the limits to $IN_{x}>$ is used by the function. If $IN_{x}>Max$ is smaller than $IN_{x}>Min$, the limits are swapped.
**kx**: Time multiplier for the dependent (inverse) characteristic for step x.

**IMinx**: Minimum operate current for step x in % of IB. Set IMinx below INx> for every step to achieve ANSI reset characteristic according to standard. If IMinx is set above INx> for any step, signal will reset at current equals to zero.

**txMin**: Minimum operating time for inverse time characteristics. At high currents, the inverse time characteristic might give a very short operation time. By setting this parameter, the operation time of the step can never be shorter than the setting.

![Figure 46: Minimum operate current and operate time for inverse time characteristics](image)

In order to fully comply with the curves definition, the setting parameter txMin shall be set to the value which is equal to the operate time of the selected IEC inverse curve for measured current of twenty times the set current pickup value. Note that the operate time value is dependent on the selected setting value for time multiplier kx.

**INxMult**: Multiplier for scaling of the current setting value. If a binary input signal (ENMULTx) is activated, the current operation level is increased by this setting constant.

**ResetTypeCrvx**: The reset of the delay timer can be made in different ways. The possibilities are described in the technical reference manual.

**tResetx**: Constant reset time delay in s for step x.

**HarmBlockx**: This is used to enable block of step x from 2nd harmonic restrain function.

**tPCrvx, tACrvx, tBCrvx, tCCrvx**: Parameters for user programmable of inverse time characteristic curve. The time characteristic equation is according to equation 28:

\[ t[x] = \left( \frac{A}{\left( \frac{i}{in} \right)^p} + B \right) \cdot k \]

(Equation 28)

Further description can be found in the technical reference manual.
tPRCrvx, tTRCrvx, tCRCrvx: Parameters for user programmable of inverse reset time characteristic curve. Further description can be found in the technical reference manual.

7.3 Four step directional negative phase sequence overcurrent protection NS4PTOC

7.3.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Four step negative sequence overcurrent protection</td>
<td>NS4PTOC</td>
<td></td>
<td>4612</td>
</tr>
</tbody>
</table>

7.3.2 Application

Four step negative sequence overcurrent protection NS4PTOC is used in several applications in the power system. Some applications are:

- Earth-fault and phase-phase short circuit protection of feeders in effectively earthed distribution and subtransmission systems. Normally these feeders have radial structure.
- Back-up earth-fault and phase-phase short circuit protection of transmission lines.
- Sensitive earth-fault protection of transmission lines. NS4PTOC can have better sensitivity to detect resistive phase-to-earth-faults compared to distance protection.
- Back-up earth-fault and phase-phase short circuit protection of power transformers.
- Earth-fault and phase-phase short circuit protection of different kinds of equipment connected to the power system such as shunt capacitor banks, shunt reactors and others.

In many applications several steps with different current operating levels and time delays are needed. NS4PTOC can have up to four, individual settable steps. The flexibility of each step of NS4PTOC function is great. The following options are possible:

Non-directional/Directional function: In some applications the non-directional functionality is used. This is mostly the case when no fault current can be fed from the protected object itself. In order to achieve both selectivity and fast fault clearance, the directional function can be necessary. This can be the case for unsymmetrical fault protection in meshed and effectively earthed transmission systems. The directional negative sequence overcurrent protection is also well suited to operate in teleprotection communication schemes, which enables fast clearance of unsymmetrical faults on transmission lines. The directional function uses the voltage polarizing quantity.

Choice of time characteristics: There are several types of time characteristics available such as definite time delay and different types of inverse time characteristics. The selectivity between different overcurrent protections is normally enabled by co-ordination between the operating time of the different protections. To enable optimal co-ordination all overcurrent relays, to be co-ordinated against each other, should have the same time characteristic. Therefore a wide range of standardized inverse time characteristics are available: IEC and ANSI.
Table 15: Inverse time characteristics

<table>
<thead>
<tr>
<th>Curve name</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANSI Extremely Inverse</td>
</tr>
<tr>
<td>ANSI Very Inverse</td>
</tr>
<tr>
<td>ANSI Normal Inverse</td>
</tr>
<tr>
<td>ANSI Moderately Inverse</td>
</tr>
<tr>
<td>ANSI/IEEE Definite time</td>
</tr>
<tr>
<td>ANSI Long Time Extremely Inverse</td>
</tr>
<tr>
<td>ANSI Long Time Very Inverse</td>
</tr>
<tr>
<td>ANSI Long Time Inverse</td>
</tr>
<tr>
<td>IEC Normal Inverse</td>
</tr>
<tr>
<td>IEC Very Inverse</td>
</tr>
<tr>
<td>IEC Inverse</td>
</tr>
<tr>
<td>IEC Extremely Inverse</td>
</tr>
<tr>
<td>IEC Short Time Inverse</td>
</tr>
<tr>
<td>IEC Long Time Inverse</td>
</tr>
<tr>
<td>IEC Definite Time</td>
</tr>
<tr>
<td>User Programmable</td>
</tr>
<tr>
<td>ASEA RI</td>
</tr>
<tr>
<td>RXIDG (logarithmic)</td>
</tr>
</tbody>
</table>

There is also a user programmable inverse time characteristic.

Normally it is required that the negative sequence overcurrent function shall reset as fast as possible when the current level gets lower than the operation level. In some cases some sort of delayed reset is required. Therefore different kinds of reset characteristics can be used.

For some protection applications there can be a need to change the current operating level for some time. Therefore there is a possibility to give a setting of a multiplication factor $IxMult$ to the negative sequence current pick-up level. This multiplication factor is activated from a binary input signal $ENMULTx$ to the function.

### 7.3.3 Setting guidelines

The parameters for Four step negative sequence overcurrent protection NS4PTOC are set via the local HMI or Protection and Control Manager (PCM600).

The following settings can be done for the four step negative sequence overcurrent protection:

*Operation:* Sets the protection to *On* or *Off*.

Common base IED values for the primary current ($I_{Base}$), primary voltage ($U_{Base}$) and primary power ($S_{Base}$) are set in global base values for settings function GBASVAL.

*GlobalBaseSel:* Selects the global base value group used by the function to define $I_{Base}$, $U_{Base}$ and $S_{Base}$.
When inverse time overcurrent characteristic is selected, the operate time of the stage will be the sum of the inverse time delay and the set definite time delay. Thus, if only the inverse time delay is required, it is important to set the definite time delay for that stage to zero.

### 7.3.3.1 Settings for each step

x means step 1, 2, 3 and 4.

*DirModeSelx*: The directional mode of step x. Possible settings are off/nondirectional/forward/reverse.

*Characteristx*: Selection of time characteristic for step x. Definite time delay and different types of inverse time characteristics are available.

#### Table 16: Inverse time characteristics

<table>
<thead>
<tr>
<th>Curve name</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANSI Extremely Inverse</td>
</tr>
<tr>
<td>ANSI Very Inverse</td>
</tr>
<tr>
<td>ANSI Normal Inverse</td>
</tr>
<tr>
<td>ANSI Moderately Inverse</td>
</tr>
<tr>
<td>ANSI/IEEE Definite time</td>
</tr>
<tr>
<td>ANSI Long Time Extremely Inverse</td>
</tr>
<tr>
<td>ANSI Long Time Very Inverse</td>
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<td>ANSI Long Time Inverse</td>
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</tr>
<tr>
<td>IEC Very Inverse</td>
</tr>
<tr>
<td>IEC Inverse</td>
</tr>
<tr>
<td>IEC Extremely Inverse</td>
</tr>
<tr>
<td>IEC Short Time Inverse</td>
</tr>
<tr>
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<td>IEC Definite Time</td>
</tr>
<tr>
<td>User Programmable</td>
</tr>
<tr>
<td>ASEA RI</td>
</tr>
<tr>
<td>RXIDG (logarithmic)</td>
</tr>
</tbody>
</table>

The different characteristics are described in the Technical Reference Manual (TRM).

*lx*: Operation negative sequence current level for step x given in % of *IBase*.

*tx*: Definite time delay for step x. The definite time *tx* is added to the inverse time when inverse time characteristic is selected. Note that the value set is the time between activation of the start and the trip outputs.

*kx*: Time multiplier for the dependent (inverse) characteristic.
**IMinx**: Minimum operate current for step \( x \) in % of \( I_{\text{Base}} \). Set \( I_{\text{Min}x} \) below \( I_{x^*} \) for every step to achieve ANSI reset characteristic according to standard. If \( I_{\text{Min}x} \) is set above \( I_{x^*} \) for any step the ANSI reset works as if current is zero when current drops below \( I_{\text{Min}x} \).

**IxMult**: Multiplier for scaling of the current setting value. If a binary input signal (ENMULT\( x \)) is activated the current operation level is multiplied by this setting constant.

**txMin**: Minimum operation time for inverse time characteristics. At high currents the inverse time characteristic might give a very short operation time. By setting this parameter the operation time of the step can never be shorter than the setting.

---

**Figure 47**: Minimum operate current and operation time for inverse time characteristics

**ResetTypeCrvx**: The reset of the delay timer can be made in different ways. By choosing setting there are the following possibilities:

<table>
<thead>
<tr>
<th>Curve name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instantaneous</td>
</tr>
<tr>
<td>IEC Reset (constant time)</td>
</tr>
<tr>
<td>ANSI Reset (inverse time)</td>
</tr>
</tbody>
</table>

The different reset characteristics are described in the Technical Reference Manual (TRM). There are some restrictions regarding the choice of reset delay.

For the independent time delay characteristics the possible delay time settings are instantaneous (1) and IEC (2 = set constant time reset).

For ANSI inverse time delay characteristics all three types of reset time characteristics are available; instantaneous (1), IEC (2 = set constant time reset) and ANSI (3 = current dependent reset time).

For IEC inverse time delay characteristics the possible delay time settings are instantaneous (1) and IEC (2 = set constant time reset).

For the programmable inverse time delay characteristics all three types of reset time characteristics are available; instantaneous (1), IEC (2 = set constant time reset) and ANSI (3 = current dependent reset time). If the current dependent type is used settings \( pr \), \( tr \) and \( cr \) must be given.
$tPCrvx, tACrvx, tBCrvx, tCCrvx$: Parameters for programmable inverse time characteristic curve. The time characteristic equation is according to equation 29:

$$t[s] = \left( \frac{A}{\left( \frac{i}{in} \right)^p} + B \right) \cdot k$$

(Equation 29)

Further description can be found in the Technical reference manual (TRM).

$tPRCrvx, tTRCrvx, tCRCrvx$: Parameters for customer creation of inverse reset time characteristic curve. Further description can be found in the Technical Reference Manual.

### 7.3.3.2 Common settings for all steps

$x$ means step 1, 2, 3 and 4.

*AngleRCA*: Relay characteristic angle given in degrees. This angle is defined as shown in figure 48. The angle is defined positive when the residual current lags the reference voltage ($Upol = -U2$)

![Figure 48: Relay characteristic angle given in degree](IEC10000031-1-en.vsd)
In a transmission network a normal value of RCA is about 80°.

**UPolMin**: Minimum polarization (reference) voltage % of UBase.

**I>Dir**: Operate residual current level for directional comparison scheme. The setting is given in % of IBase. The start forward or start reverse signals can be used in a communication scheme. The appropriate signal must be configured to the communication scheme block.

### 7.4 Thermal overload protection, two time constants TRPTTR

#### 7.4.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal overload protection, two time constants</td>
<td>TRPTTR</td>
<td></td>
<td>49</td>
</tr>
</tbody>
</table>

#### 7.4.2 Application

Transformers in the power system are designed for a certain maximum load current (power) level. If the current exceeds this level the losses will be higher than expected. As a consequence the temperature of the transformer will increase. If the temperature of the transformer reaches too high a value, the equipment might be damaged;

- The insulation within the transformer experiences forced ageing. As a consequence of this, the risk of internal phase-to-phase or phase-to-earth faults increases.
- There might be hot spots within the transformer, which degrades the paper insulation. It might also cause bubbling in the transformer oil.

In stressed situations in the power system it can be required to overload transformers for a limited time. This should be done without the above mentioned 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 cooling system of the transformer. There are two main principles:

- **OA**: The air is naturally circulated to the coolers without fans and the oil is naturally circulated without pumps.
- **FOA**: The coolers have fans to force air for cooling and pumps to force the circulation of the transformer oil.

The protection can have two sets of parameters, one for non-forced cooling and one for forced cooling. Both the permissive steady state loading level as well as the thermal time constant is influenced by the cooling system of the transformer. The two parameters sets can be activated by the binary input signal COOLING. This can be used for transformers where forced cooling can be taken out of operation, for example at fan or pump faults.
The thermal overload protection estimates the internal heat content of the transformer (temperature) continuously. This estimation is made by using a thermal model of the transformer which is based on current measurement.

If the heat content of the protected transformer reaches a set alarm level a signal can be given to the operator. Two alarm levels are available. This enables preventive actions in the power system to be taken before dangerous temperatures are reached. If the temperature continues to increase to the trip value, the protection initiates a trip of the protected transformer.

After tripping by the thermal overload protection, the transformer will cool down over time. There will be a time gap before the heat content (temperature) reaches such a level so that the transformer can be taken into service again. Therefore, the function will continue to estimate the heat content using a set cooling time constant. Energizing of the transformer can be blocked until the heat content has reached a set level.

### Setting guideline

The parameters for the thermal overload protection, two time constants (TRPTTR) are set via the local HMI or Protection and Control IED Manager (PCM600).

The following settings can be done for the thermal overload protection:

**Operation:** Off/On

*Operation:* Sets the mode of operation. Off switches off the complete function.

**GlobalBaseSel:** Selects the global base value group used by the function to define $I_{\text{Base}}$, $U_{\text{Base}}$ and $S_{\text{Base}}$.

**$I_{\text{Ref}}:** Reference level of the current given in %. When the current is equal to $I_{\text{Ref}}$ the final (steady state) heat content is equal to 1. It is suggested to give a setting corresponding to the rated current of the transformer winding.

**$I_{\text{RefMult}}:** If a binary input ENMULT is activated the reference current value can be multiplied by the factor $I_{\text{RefMult}}$. The activation could be used in case of deviating ambient temperature from the reference value. In the standard for loading of a transformer an ambient temperature of 20°C is used. For lower ambient temperatures the load ability is increased and vice versa. $I_{\text{RefMult}}$ can be set within a range: 0.01 - 10.00.

**$I_{\text{Base1}}:** Base current for setting given as percentage of $I_{\text{Base}}$. This setting shall be related to the status with no COOLING input. It is suggested to give a setting corresponding to the rated current of the transformer with natural cooling (OA).

**$I_{\text{Base2}}:** Base current for setting given as percentage of $I_{\text{Base}}$. This setting shall be related to the status with activated COOLING input. It is suggested to give a setting corresponding to the rated current of the transformer with forced cooling (FOA). If the transformer has no forced cooling $I_{\text{Base2}}$ can be set equal to $I_{\text{Base1}}$.

**$\tau_1:** The thermal time constant of the protected transformer, related to $I_{\text{Base1}}$ (no cooling) given in minutes.

**$\tau_2:** The thermal time constant of the protected transformer, related to $I_{\text{Base2}}$ (with cooling) given in minutes.

The thermal time constant should be obtained from the transformer manufacturers manuals. The thermal time constant is dependent on the cooling and the amount of oil. Normal time constants for medium and large transformers (according to IEC 60076-7) are about 2.5 hours for naturally cooled transformers and 1.5 hours for forced cooled transformers.

The time constant can be estimated from measurements of the oil temperature during a cooling sequence (described in IEC 60076-7). It is assumed that the transformer is operated at
a certain load level with a constant oil temperature (steady state operation). The oil temperature above the ambient temperature is \( \Delta \theta_{o0} \). Then the transformer is disconnected from the grid (no load). After a time \( t \) of at least 30 minutes the temperature of the oil is measured again. Now the oil temperature above the ambient temperature is \( \Delta \theta_{o1} \). The thermal time constant can now be estimated as:

\[
\tau = \frac{t}{\ln \Delta \theta_{o1} - \ln \Delta \theta_{o0}}
\]

(Equation 30)

If the transformer has forced cooling (FOA) the measurement should be made both with and without the forced cooling in operation, giving \( \tau_{2} \) and \( \tau_{1} \).

The time constants can be changed if the current is higher than a set value or lower than a set value. If the current is high it is assumed that the forced cooling is activated while it is deactivated at low current. The setting of the parameters below enables automatic adjustment of the time constant.

\( \tau_{1,\text{High}} \): Multiplication factor to adjust the time constant \( \tau_{1} \) if the current is higher than the set value \( I_{\text{High} \tau_{1}} \). \( I_{\text{High} \tau_{1}} \) is set in % of \( I_{\text{Base}1} \).

\( \tau_{1,\text{Low}} \): Multiplication factor to adjust the time constant \( \tau_{1} \) if the current is lower than the set value \( I_{\text{Low} \tau_{1}} \). \( I_{\text{Low} \tau_{1}} \) is set in % of \( I_{\text{Base}1} \).

\( \tau_{2,\text{High}} \): Multiplication factor to adjust the time constant \( \tau_{2} \) if the current is higher than the set value \( I_{\text{High} \tau_{2}} \). \( I_{\text{High} \tau_{2}} \) is set in % of \( I_{\text{Base}2} \).

\( \tau_{2,\text{Low}} \): Multiplication factor to adjust the time constant \( \tau_{2} \) if the current is lower than the set value \( I_{\text{Low} \tau_{2}} \). \( I_{\text{Low} \tau_{2}} \) is set in % of \( I_{\text{Base}2} \).

The possibility to change time constant with the current value as the base can be useful in different applications. Below some examples are given:

- In case a total interruption (low current) of the protected transformer all cooling possibilities will be inactive. This can result in a changed value of the time constant.
- If other components (motors) are included in the thermal protection, there is a risk of overheating of that equipment in case of very high current. The thermal time constant is often smaller for a motor than for the transformer.

\( IT_{\text{Trip}} \): The steady state current that the transformer can withstand. The setting is given in % of \( I_{\text{Base}1} \) or \( I_{\text{Base}2} \).

\( \text{Alarm1} \): Heat content level for activation of the signal ALARM1. ALARM1 is set in % of the trip heat content level.

\( \text{Alarm2} \): Heat content level for activation of the output signal ALARM2. ALARM2 is set in % of the trip heat content level.

\( \text{ResLo} \): Lockout release level of heat content to release the lockout signal. When the thermal overload protection trips a lock-out signal is activated. This signal is intended to block switching on of the protected circuit transformer as long as the transformer temperature is high. The signal is released when the estimated heat content is below the set value. This temperature value should be chosen below the alarm temperature. \( \text{ResLo} \) is set in % of the trip heat content level.

\( \text{ThetaInit} \): Heat content before activation of the function. This setting can be set a little below the alarm level. If the transformer is loaded before the activation of the protection function, its temperature can be higher than the ambient temperature. The start point given in the setting
will prevent risk of no trip at overtemperature during the first moments after activation.  
\( \Theta_{\text{Init}} \): is set in \% of the trip heat content level.

Warning: If the calculated time to trip factor is below the setting Warning a warning signal is activated. The setting is given in minutes.

### 7.4.3.1 Setting example

Calculation of the operate time with the available current is performed only if the calculated final temperature is greater than the operate level temperature.

\[
I_{\text{operate}} = -\tau \cdot \ln \left( \frac{\Theta_{\text{final}} - \Theta_{\text{operate}}}{\Theta_{\text{final}} - \Theta_{n}} \right)
\]

(Equation 31)

where:

- \( t_{\text{operate}} \) is the time to operate
- \( \tau \) is the time constant

\[
\theta_{\text{final}} = \left( \frac{I_{\text{final}}}{I_{\text{ref}}} \right)^{\frac{2}{3}}
\]

- \( \theta_{\text{final}} \) is the steady state heat content
- \( I_{\text{final}} \) is the largest phase load current
- \( I_{\text{ref}} \) is the given reference load current

\[
\theta_{\text{operate}} = \left( I_{\text{operate}} \times I_{\text{ref}} \times I_{\text{Trip}} \right)^{\frac{2}{3}}
\]

- \( \theta_{\text{operate}} \) is the operate level heat content
- \( I_{\text{operate}} \) is the operate level load current
- \( I_{\text{Trip}} \) is the selected base current based cooling system \( \text{ON/OFF} \)
- \( I_{\text{ref}} \) is the current heat content

Consider that the given system has \( I_{\text{Base}} \) of 1000 A and the cooling system is \( \text{ON} \). The following settings are used to calculate the operate time:

- \( I_{\text{Ref}} \) 110% of \( I_{\text{Base}} \)
- \( I_{\text{Base}1} \) 110% of \( I_{\text{B}} \)
- \( I_{\text{Base}2} \) 120% of \( I_{\text{B}} \)
- \( \tau_{1} \) 150 min
- \( \tau_{2} \) 90 min
- \( I_{\text{HighTau}1} \) 110% of \( I_{\text{B}1} \)
- \( I_{\text{HighTau}2} \) 125% of \( t_{C1} \)
- \( I_{\text{LowTau}1} \) 90% of \( I_{\text{B}1} \)
- \( I_{\text{LowTau}2} \) 75% of \( t_{C1} \)
- \( I_{\text{HighTau}2} \) 110% of \( I_{\text{B}2} \)
- \( I_{\text{LowTau}2} \) 115% of \( t_{C2} \)
- \( I_{\text{LowTau}2} \) 90% of \( I_{\text{B}2} \)
- \( I_{\text{LowTau}2} \) 85% of \( t_{C2} \)
As the cooling system is ON, \(I_{Base2}\) is selected as the base current and \(Tau2\) setting is selected as the time constant.

For example, the largest phase load current is taken as 1800 A, then:

\[
\theta_{\text{final}} = \left(\frac{1800}{1.1}\right)^2 = 2677685.95
\]

\[
\theta_{\text{operate}} = (1.2 \times 1000 \times 1.1 \times 1.2)^2 = 2509056
\]

Here

\[
\theta_{\text{final}} > \Theta_n
\]

At \(t=0\)

\[
\theta_n = \theta_{\text{init}} = ThetaInit \times \theta_{\text{operate}} = 0.5 \times 2509056 = 1254528
\]

At next execution, \(\theta_{n-1}=1254528\) and \(\theta_n=1254555.04\).

Therefore, \(t_{\text{operate}} = -90 \times \ln((2677685.95 - 2509056) / (2677685.95 - 1254555.04)) = 192\) min

After the trip, a lockout is released to inhibit reconnecting the tripped circuit. The output lockout signal LOCKOUT is activated when the temperature of the object is greater than the set lockout release temperature setting \(ResLo\).

\[
t_{\text{lockout-release}} = -\tau \cdot \ln \left(\frac{\Theta_{\text{final}} - \Theta_{\text{lockout-release}}}{\Theta_{\text{final}} - \Theta_n}\right)
\]

(Equation 32)

where:

\(t_{\text{lockout-release}}\) is the time to lockout release

\(\Theta_{\text{lockout-release}}\) is the lockout release level heat content = \(ResLo \times \theta_{\text{operate}}\)

Consider that the current heat content \(\theta_n\) is 2700000 and the cooling system is still ON, then:

\[
\theta_{\text{lockout-release}} = 0.6 \times 2509056 = 1505433.6
\]

\[
t_{\text{lockout-release}} = -90 \times \ln((2677685.95 - 1505433.6) / (2677685.95 - 2700000)) = 244\) min

7.5 Breaker failure protection CCRBRF
### 7.5.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breaker failure protection, 3-phase activation and output</td>
<td>CCRBF</td>
<td></td>
<td>50BF</td>
</tr>
</tbody>
</table>

### 7.5.2 Application

In the design of the fault clearance system the N-1 criterion is often used. This means that a fault needs to be cleared even if any component in the fault clearance system is faulty. One necessary component in the fault clearance system is the circuit breaker.

It is from practical and economical reason not feasible to duplicate the circuit breaker for the protected object. Instead a breaker failure protection is used.

Breaker failure protection CCRBRF will issue a backup trip command to adjacent circuit breakers in case of failure to trip of the “normal” circuit breaker for the protected object. The detection of failure to break the current through the breaker is made either by means of current measurement or as detection of closed status using auxiliary contact.

CCRBRF can also give a retrip command. This means that a second trip signal is sent to the protected object circuit breaker. The retrip function can be used to increase the probability of operation of the breaker, or it can be used to avoid backup trip of many breakers in case of mistakes during relay maintenance and testing.

### 7.5.3 Setting guidelines

The parameters for Breaker failure protection CCRBRF are set via the local HMI or PCM600.

The following settings can be done for the breaker failure protection.

- **GlobalBaseSel**: Selects the global base value group used by the function to define IBase, UBase and SBase.

- **Operation**: Off/On to enable/disable the complete function.

- **FunctionMode**: This parameter can be set Current or Contact. This states the way the detection of failure of the breaker is performed. In the mode current the current measurement is used for the detection. In the mode Contact the long duration of breaker position signal is used as indicator of failure of the breaker. The mode Current/Contact means that both ways of detections are activated. Contact mode can be usable in applications where the fault current through the circuit breaker is small. This can be the case for some generator protection application (for example reverse power protection) or in case of line ends with weak end infeed.

- **RetripMode**: This setting states how the retrip function shall operate. Retrip Off means that the retrip function is not activated. CB Pos Check (circuit breaker position check) and Current means that a phase current must be larger than the operate level to allow retrip. CB Pos Check (circuit breaker position check) and Contact means retrip is done when circuit breaker is closed (breaker position is used). No CBPos Check means retrip is done without any check of breaker position.
Table 17: Dependencies between parameters RetripMode and FunctionMode

<table>
<thead>
<tr>
<th>RetripMode</th>
<th>FunctionMode</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retrip Off</td>
<td>N/A</td>
<td>The retrip function is not activated</td>
</tr>
<tr>
<td>CB Pos Check</td>
<td>Current</td>
<td>Retrip is done if the phase current is larger than the operate level after retrip time has elapsed</td>
</tr>
<tr>
<td></td>
<td>Contact</td>
<td>Retrip is done when auxiliary contact position indicates that breaker is still closed after retrip time has elapsed</td>
</tr>
<tr>
<td></td>
<td>Current/Contact</td>
<td>Both methods according to above are used but taken into account also I&gt;BlkCont</td>
</tr>
<tr>
<td>No CBPos Check</td>
<td>Current</td>
<td>Retrip is done without check of current level</td>
</tr>
<tr>
<td></td>
<td>Contact</td>
<td>Retrip is done without check of auxiliary contact position</td>
</tr>
<tr>
<td></td>
<td>Current/Contact</td>
<td>Retrip is done without check of current level or auxiliary contact position</td>
</tr>
</tbody>
</table>

**BuTripMode**: backup trip mode is given to state sufficient current criteria to detect failure to break. For **Current** operation **2 out of 4** means that at least two currents, of the three-phase currents and the residual current, shall be high to indicate breaker failure. **1 out of 3** means that at least one current of the three-phase currents shall be high to indicate breaker failure. **1 out of 4** means that at least one current of the three-phase currents or the residual current shall be high to indicate breaker failure. In most applications **1 out of 3** is sufficient. For **Contact** operation means backup trip is done when circuit breaker is closed (breaker position is used).

**IP>**: Current level for detection of breaker failure, set in % of IBase. This parameter should be set so that faults with small fault current can be detected. The setting can be chosen in accordance with the most sensitive protection function to start the breaker failure protection. Default setting is 10% of IBase.

**I>BlkCont**: If any contact based detection of breaker failure is used, this function can be blocked if any phase current is larger than this setting level. If the **FunctionMode** is set **Current/Contact** breaker failure for high current faults are safely detected by the current measurement function. To increase security the contact based function should be disabled for high currents. The setting can be given within the range 5 – 200% of IBase.

**IN>**: Residual current level for detection of breaker failure set in % of IBase. In high impedance earthed systems the residual current at phase- to-earth faults are normally much smaller than the short circuit currents. In order to detect breaker failure at single phase-to-earth faults in such systems it is necessary to measure the residual current separately. Also in effectively earthed systems the setting of the earth-fault current protection can be chosen to relatively low current level. The **BuTripMode** shall be set **1 out of 4** in such systems. The current setting should be chosen in accordance to the setting of the sensitive earth-fault protection. The setting can be given within the range 2 – 200% of IBase.

**t1**: Time delay of the retrip. The setting can be given within the range 0 – 60s in steps of 0.001s. Typical setting is within range 0 – 50ms.

**t2**: Time delay of the backup trip. The choice of this setting is made as short as possible at the same time as unwanted operation must be avoided. Typical setting is within range 90 – 200ms (also dependent of retrip timer).
Timer $t_2$ is used when function is started in one phase only (i.e. for single-phase to ground fault on an OHL (Over Head Lines) when single-pole auto-reclosing is used).

The minimum time delay for the backup trip can be estimated as:

$$t_2 \geq t_1 + t_{CB\_open} + t_{BFP\_reset} + t_{margin}$$

(Equation 33)

where:

- $t_{CB\_open}$ is the maximum opening time for the circuit breaker
- $t_{BFP\_reset}$ is the maximum time for breaker failure protection to detect correct breaker function (the current criteria reset)
- $t_{margin}$ is a safety margin

It is often required that the total fault clearance time shall be less than a given critical time. This time is often dependent of the ability of the power system to maintain transient stability in case of a fault close to a power plant.

![Figure 49: Time sequence](IEC05000479_2_en.vsd)

**Figure 49: Time sequence**

$t_{2\text{MPH}}$: Time delay of the backup trip at multi-phase start. The critical fault clearance time is often shorter in case of multi-phase faults, compared to single phase-to-earth faults. Therefore there is a possibility to reduce the backup trip delay for multi-phase faults. Typical setting is 90 – 150 ms.

Note that for a protected object which are always tripped three-phase (e.g. transformers, generators, reactors, cables, etc.) this timer shall always be set to the same value as $t_2$ timer.

$t_{3}$ Additional time delay to $t_2$ for a second backup trip TRBU2. In some applications there might be a requirement to have separated backup trip functions, tripping different backup circuit breakers.
**tCBAlarm**: Time delay for alarm in case of indication of faulty circuit breaker. There is a binary input CBFLT from the circuit breaker. This signal is activated when internal supervision in the circuit breaker detect that the circuit breaker is unable to clear fault. This could be the case when gas pressure is low in a SF6 circuit breaker, of others. After the set time an alarm is given, so that actions can be done to repair the circuit breaker. Note that the time delay for backup trip $t_2$ is bypassed when the CBFLT is active. Typical setting is 2.0 seconds.

**tPulse**: Trip pulse duration. This setting must be larger than the opening time of circuit breakers to be tripped from the breaker failure protection. Typical setting is 200 ms.

**Table 18**: Setting summary for FunctionMode, StartMode, RetripMode and BuTripMode

<table>
<thead>
<tr>
<th>No.</th>
<th>StartMode</th>
<th>RetripMode</th>
<th>t1 and t2 initiated with</th>
<th>When t1 has elapsed, TRRET will</th>
<th>When t2 or t2MPH has elapsed, TRBU will be given if</th>
<th>t1 and t2 and t2MPH will be stopped (reset) if</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LatchedStart</td>
<td>Off</td>
<td>external START</td>
<td>never be given</td>
<td>current is above set level (*)</td>
<td>t1 and (t2 or t2MPH) and 150ms expires and current is below set level (*)</td>
</tr>
<tr>
<td>2</td>
<td>LatchedStart</td>
<td>UseFunction Mode</td>
<td>external START</td>
<td>be given if current is above set level of IPh&gt;</td>
<td>current is above set level (*)</td>
<td>t1 and (t2 or t2MPH) and 150ms expires and current is below set level (*)</td>
</tr>
<tr>
<td>3</td>
<td>LatchedStart</td>
<td>Always</td>
<td>external START</td>
<td>always be given</td>
<td>current is above set level (*)</td>
<td>t1 and (t2 or t2MPH) and 150ms expires and current is below set level (*)</td>
</tr>
<tr>
<td>4</td>
<td>FollowStart</td>
<td>Off</td>
<td>external START</td>
<td>never be given</td>
<td>current is above set level (*)</td>
<td>external START disappears</td>
</tr>
<tr>
<td>5</td>
<td>FollowStart</td>
<td>UseFunction Mode</td>
<td>external START</td>
<td>be given if current is above set level of IPh&gt;</td>
<td>current is above set level (*)</td>
<td>external START disappears</td>
</tr>
<tr>
<td>6</td>
<td>FollowStart</td>
<td>Always</td>
<td>external START</td>
<td>be given if external START is present</td>
<td>current is above set level (*)</td>
<td>external START disappears</td>
</tr>
<tr>
<td>7</td>
<td>FollowStart&amp; Mode</td>
<td>Off</td>
<td>external START and current above set level</td>
<td>never be given</td>
<td>current is above set level (*) and external START present</td>
<td>current is below set level (*) or external START disappears</td>
</tr>
<tr>
<td>8</td>
<td>FollowStart&amp; Mode</td>
<td>UseFunction Mode</td>
<td>external START and current above set level</td>
<td>be given if current is above set level of IPh&gt; and external START is present</td>
<td>current is above set level (*) and external START present</td>
<td>current is below set level (*) or external START disappears</td>
</tr>
<tr>
<td>9</td>
<td>FollowStart&amp; Mode</td>
<td>Always</td>
<td>external START and current above set level</td>
<td>be given if external START is present</td>
<td>current is above set level (*) and external START present</td>
<td>current is below set level (*) or external START disappears</td>
</tr>
</tbody>
</table>

*) Set level depends on selected BuTripMode, that is, set level can be either IPh> or IN> or both.
<table>
<thead>
<tr>
<th>No.</th>
<th>StartMode</th>
<th>RetripMode</th>
<th>t1 and t2 initiated with</th>
<th>When t1 has elapsed, TRRET will</th>
<th>When t2 or t2MPH has elapsed, TRBU will be given if</th>
<th>t1 and t2 and t2MPH will be stopped (reset) if</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>LatchedStart</td>
<td>Off</td>
<td>external START</td>
<td>never be given</td>
<td>CBCLDLx input has logical value one</td>
<td>t1 and (t2 or t2MPH) and 150ms expires and CBCLDLx input has logical value zero</td>
</tr>
<tr>
<td>11</td>
<td>LatchedStart</td>
<td>UseFunction Mode</td>
<td>external START</td>
<td>be given if CBCLDLx input has logical value one</td>
<td>CBCLDLx input has logical value one</td>
<td>t1 and (t2 or t2MPH) and 150ms expires and CBCLDLx input has logical value zero</td>
</tr>
<tr>
<td>12</td>
<td>LatchedStart</td>
<td>Always</td>
<td>external START</td>
<td>always be given</td>
<td>CBCLDLx input has logical value one</td>
<td>t1 and (t2 or t2MPH) and 150ms expires and CBCLDLx input has logical value zero</td>
</tr>
<tr>
<td>13</td>
<td>FollowStart</td>
<td>Off</td>
<td>external START</td>
<td>never be given</td>
<td>CBCLDLx input has logical value one</td>
<td>external START disappears</td>
</tr>
<tr>
<td>14</td>
<td>FollowStart</td>
<td>UseFunction Mode</td>
<td>external START</td>
<td>be given if CBCLDLx input has logical value one</td>
<td>CBCLDLx input has logical value one</td>
<td>external START disappears</td>
</tr>
<tr>
<td>15</td>
<td>FollowStart</td>
<td>Always</td>
<td>external START</td>
<td>if external START is present</td>
<td>CBCLDLx input has logical value one</td>
<td>external START disappears</td>
</tr>
<tr>
<td>16</td>
<td>FollowStart&amp; Mode</td>
<td>Off</td>
<td>external START and CBCLDLx input has logical value one</td>
<td>never be given</td>
<td>be given if CBCLDLx input has logical value one and external START is present</td>
<td>CBCLDLx input has logical value zero or external START disappears</td>
</tr>
<tr>
<td>17</td>
<td>FollowStart&amp; Mode</td>
<td>UseFunction Mode</td>
<td>external START and CBCLDLx input has logical value one</td>
<td>be given if CBCLDLx input has logical value one and external START is present</td>
<td>be given if CBCLDLx input has logical value one and external START is present</td>
<td>CBCLDLx input has logical value zero or external START disappears</td>
</tr>
<tr>
<td>18</td>
<td>FollowStart&amp; Mode</td>
<td>Always</td>
<td>external START and CBCLDLx input has logical value one</td>
<td>be given if external START is present</td>
<td>be given if CBCLDLx input has logical value one and external START is present</td>
<td>CBCLDLx input has logical value zero or external START disappears</td>
</tr>
<tr>
<td>No.</td>
<td>StartMode</td>
<td>RetripMode</td>
<td>t1 and t2 initiated with</td>
<td>When t1 has elapsed, TRRET will be given if</td>
<td>When t2 or t2MPh has elapsed, TRBU will be given if</td>
<td>t1 and t2 and t2MPh will be stopped (reset) if</td>
</tr>
<tr>
<td>-----</td>
<td>----------------------</td>
<td>------------</td>
<td>--------------------------</td>
<td>---------------------------------------------</td>
<td>-------------------------------------------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>19</td>
<td>LatchedStart</td>
<td>Off</td>
<td>external START</td>
<td>never be given</td>
<td>current is above set level *) and higher than I&gt;BlkCBPos or CBCLDLx input has logical value one when current is smaller than I&gt;BlkCBPos</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>t1 and (t2 or t2MPh) and 150ms expires and current is below set level *) or CBCLDLx input has logical value zero</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>LatchedStart</td>
<td>UseFunction Mode</td>
<td>external START</td>
<td>be given if current is above set level of IPh&gt; and higher than I&gt;BlkCBPos or CBCLDLx input has logical value one when current is smaller than I&gt;BlkCBPos</td>
<td>current is above set level *) and higher than I&gt;BlkCBPos or CBCLDLx input has logical value one when current is smaller than I&gt;BlkCBPos</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>t1 and (t2 or t2MPh) and 150ms expires and current is below set level *) or CBCLDLx input has logical value zero</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>LatchedStart</td>
<td>Always</td>
<td>external START</td>
<td>always be given</td>
<td>current is above set level *) and higher than I&gt;BlkCBPos or CBCLDLx input has logical value one when current is smaller than I&gt;BlkCBPos</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>t1 and (t2 or t2MPh) and 150ms expires and current is below set level *) or CBCLDLx input has logical value zero</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>FollowStart</td>
<td>Off</td>
<td>external START</td>
<td>never be given</td>
<td>current is above set level *) and higher than I&gt;BlkCBPos or CBCLDLx input has logical value one when current is smaller than I&gt;BlkCBPos</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>external START disappears</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>FollowStart</td>
<td>UseFunction Mode</td>
<td>external START</td>
<td>be given if current is above set level of IPh&gt; and higher than I&gt;BlkCBPos or CBCLDLx input has logical value one when current is smaller than I&gt;BlkCBPos</td>
<td>current is above set level *) and higher than I&gt;BlkCBPos or CBCLDLx input has logical value one when current is smaller than I&gt;BlkCBPos</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>external START disappears</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>FollowStart</td>
<td>Always</td>
<td>external START</td>
<td>be given if external START is present</td>
<td>current is above set level *) and higher than I&gt;BlkCBPos or CBCLDLx input has logical value one when current is smaller than I&gt;BlkCBPos</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>external START disappears</td>
<td></td>
</tr>
</tbody>
</table>

Table continues on next page
<table>
<thead>
<tr>
<th>No.</th>
<th>StartMode</th>
<th>RetripMode</th>
<th>t1 and t2 initiated with</th>
<th>When t1 has elapsed, TRRET will</th>
<th>When t2 or t2MPh has elapsed, TRBU will be given if</th>
<th>t1 and t2 and t2MPh will be stopped (reset) if</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>FollowStart&amp; Mode</td>
<td>Off</td>
<td>external START and current above set level</td>
<td>never be given</td>
<td>current is above set level *) and higher than I&gt;BlkBPos or CBCLDLx input has logical value one when current is smaller than I&gt;BlkBPos</td>
<td>current is below set level *) or external START disappears</td>
</tr>
<tr>
<td>26</td>
<td>FollowStart&amp; Mode</td>
<td>UseFunction Mode</td>
<td>external START and current above set level</td>
<td>be given if current is above set level of IPh&gt; and higher than I&gt;BlkBPos or CBCLDLx input has logical value one when current is smaller than I&gt;BlkBPos</td>
<td>current is above set level *) and higher than I&gt;BlkBPos or CBCLDLx input has logical value one when current is smaller than I&gt;BlkBPos</td>
<td>current is below set level *) or external START disappears</td>
</tr>
<tr>
<td>27</td>
<td>FollowStart&amp; Mode</td>
<td>Always</td>
<td>external START and current above set level</td>
<td>be given if external START is present</td>
<td>current is above set level *) and higher than I&gt;BlkBPos or CBCLDLx input has logical value one when current is smaller than I&gt;BlkBPos</td>
<td>current is below set level *) or external START disappears</td>
</tr>
</tbody>
</table>

*) Set level depends on selected BuTripMode, that is, set level can be either IPh> or IN> or both.

### 7.6 Pole discordance protection CCPDSC

#### 7.6.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pole discordance protection</td>
<td>CCPDSC</td>
<td>PD</td>
<td>52PD</td>
</tr>
</tbody>
</table>

#### 7.6.2 Application

There is a risk that a circuit breaker will get discordance between the poles at circuit breaker operation: closing or opening. One pole can be open and the other two closed, or two poles can be open and one closed. Pole discordance of a circuit breaker will cause unsymmetrical currents in the power system. The consequence of this can be:

- Negative sequence currents that will give stress on rotating machines
- Zero sequence currents that might give unwanted operation of sensitive earth-fault protections in the power system.
It is therefore important to detect situations with pole discordance of circuit breakers. When this is detected the breaker should be tripped directly.

Pole discordance protection CCPDSC will detect situation with deviating positions of the poles of the protected circuit breaker. The protection has two different options to make this detection:

- By connecting the auxiliary contacts in the circuit breaker so that logic is created, a signal can be sent to the protection, indicating pole discordance. This logic can also be realized within the protection itself, by using opened and close signals for each circuit breaker pole, connected to the protection.
- Each phase current through the circuit breaker is measured. If the difference between the phase currents is larger than a \( \text{CurrUnsymLevel} \) this is an indication of pole discordance, and the protection will operate.

### 7.6.3 Setting guidelines

The parameters for the Pole discordance protection CCPDSC are set via the local HMI or PCM600.

The following settings can be done for the pole discordance protection.

- **GlobalBaseSel**: Selects the global base value group used by the function to define \( I_{\text{Base}} \), \( U_{\text{Base}} \) and \( S_{\text{Base}} \).
- **Operation**: Off or On
- **tTrip**: Time delay of the operation.
- **ContSel**: Operation of the contact based pole discordance protection. Can be set: Off/ PD signal from CB. If PD signal from CB is chosen the logic to detect pole discordance is made in the vicinity to the breaker auxiliary contacts and only one signal is connected to the pole discordance function. If the Pole pos aux cont. alternative is chosen each open close signal is connected to the IED and the logic to detect pole discordance is realized within the function itself.
- **CurrSel**: Operation of the current based pole discordance protection. Can be set: Off/ CB oper monitor/ Continuous monitor. In the alternative CB oper monitor the function is activated only directly in connection to breaker open or close command (during 200 ms). In the alternative Continuous monitor function is continuously activated.
- **CurrUnsymLevel**: Unsymmetrical magnitude of lowest phase current compared to the highest, set in % of the highest phase current. Natural difference between phase currents in 1 1/2 breaker installations must be considered. For circuit breakers in 1 1/2 breaker configured switch yards there might be natural unbalance currents through the breaker. This is due to the existence of low impedance current paths in the switch yard. This phenomenon must be considered in the setting of the parameter.
- **CurrRelLevel**: Current magnitude for release of the function in % of \( I_{\text{Base}} \).
Section 8 Voltage protection

8.1 Two step undervoltage protection UV2PTUV

8.1.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
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<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
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<tr>
<td>Two step undervoltage protection</td>
<td>UV2PTUV</td>
<td></td>
<td>3U&lt;</td>
</tr>
</tbody>
</table>

8.1.2 Application

Two-step undervoltage protection function (UV2PTUV) is applied to power system elements, such as generators, transformers, motors and power lines in order to detect low voltage conditions. It is used as a supervision and fault detection function for other protection functions as well, to increase the security of a complete protection system. Low voltage conditions are caused by abnormal operation or faults in the power system, such as:

- Malfunctioning of a voltage regulator or wrong settings under manual control (symmetrical voltage decrease)
- Overload (symmetrical voltage decrease)
- Short circuits, often as phase-to-earth faults (unsymmetrical voltage decrease)

UV2PTUV is used in combination with overcurrent protections, either as restraint or in logic “and gates” of the trip signals issued by the two functions. It can also be used to:

- Detect no voltage conditions, for example, before the energization of a HV line or for automatic breaker trip in case of a blackout
- Initiate voltage correction measures, like insertion of shunt capacitor banks to compensate for reactive load and thereby increasing the voltage
- Disconnect apparatuses, like electric motors, which will be damaged when subject to service under low voltage conditions.

The function has a high measuring accuracy and a settable hysteresis to allow applications to control reactive load.

In many cases, UV2PTUV is a useful function in circuits for local or remote automation processes in the power system.

8.1.3 Setting guidelines

All the voltage conditions in the system where UV2PTUV performs its functions should be considered. The same also applies to the associated equipment, its voltage and time characteristic.
There is a very wide application area where general undervoltage functions are used. All voltage-related settings are made as a percentage of the global base value $U_{\text{Base}}$, which normally is set to the primary rated voltage level (phase-to-phase) of the power system or the high voltage equipment under consideration.

The trip time setting for UV2PTUV is normally not critical, since there must be enough time available for the main protection to clear short circuits and earth faults.

Some applications and related setting guidelines for the voltage level are described in the following sections.

8.1.3.1 **Equipment protection, such as for motors and generators**

The setting must be below the lowest occurring "normal" voltage and above the lowest acceptable voltage for the equipment.

8.1.3.2 **Disconnected equipment detection**

The setting must be below the lowest occurring "normal" voltage and above the highest occurring voltage, caused by inductive or capacitive coupling, when the equipment is disconnected.

8.1.3.3 **Power supply quality**

The setting must be below the lowest occurring "normal" voltage and above the lowest acceptable voltage, due to regulation, good practice or other agreements.

8.1.3.4 **Voltage instability mitigation**

This setting is very much dependent on the power system characteristics, and thorough studies have to be made to find the suitable levels.

8.1.3.5 **Backup protection for power system faults**

The setting must be below the lowest occurring "normal" voltage and above the highest occurring voltage during the fault conditions under consideration.

8.1.3.6 **Settings for two step undervoltage protection**

The following settings can be done for Two step undervoltage protection UV2PTUV:

$ConnType$: Sets whether the measurement shall be phase-to-earth fundamental value, phase-to-phase fundamental value, phase-to-earth RMS value or phase-to-phase RMS value.

$Operation$: Off or On.

$U_{\text{Base}}$ (given in $GlobalBaseSel$): Base voltage phase-to-phase in primary kV. This voltage is used as reference for voltage setting. UV2PTUV will operate if the voltage becomes lower than the set percentage of $U_{\text{Base}}$. This setting is used when $ConnType$ is set to $PhPh\ DFT$ or $PhPh\ RMS$. Therefore, always set $U_{\text{Base}}$ as rated primary phase-to-phase voltage of the protected object. For more information, refer to the Technical manual.

The setting parameters described below are identical for the two steps ($n = 1$ or $2$). Therefore, the setting parameters are described only once.
**Characteristic**: This parameter gives the type of time delay to be used. The setting can be *Definite time*, *Inverse Curve A*, *Inverse Curve B*, *Prog. inv. curve*. The selection is dependent on the protection application.

**OpModen**: This parameter describes how many of the three measured voltages should be below the set level to give operation for step n. The setting can be *1 out of 3*, *2 out of 3* or *3 out of 3*. In most applications, it is sufficient that one phase voltage is low to give operation. If UV2PTUV shall be insensitive for single phase-to-earth faults, *2 out of 3* can be chosen. In subtransmission and transmission networks the undervoltage function is mainly a system supervision function and *3 out of 3* is selected.

**Un<**: Set operate undervoltage operation value for step n, given as % of the parameter *UBase*. The setting is highly dependent on the protection application. It is essential to consider the minimum voltage at non-faulted situations. Normally, this non-faulted voltage is larger than 90% of the nominal voltage.

**tn**: Time delay of step n, given in s. This setting is dependent on the protection application. In many applications the protection function shall not directly trip when there is a short circuit or earth faults in the system. The time delay must be coordinated to the other short circuit protections.

**tResetn**: Reset time for step n if definite time delay is used, given in s. The default value is 25 ms.

**tnMin**: Minimum operation time for inverse time characteristic for step n, given in s. When using inverse time characteristic for the undervoltage function during very low voltages can give a short operation time. This might lead to unselective tripping. By setting *t1Min* longer than the operation time for other protections, such unselective tripping can be avoided.

**ResetTypeCrvn**: This parameter for inverse time characteristic can be set to *Instantaneous*, *Frozen time*, *Linearly decreased*. The default setting is *Instantaneous*.

**tIResetn**: Reset time for step n if inverse time delay is used, given in s. The default value is 25 ms.

**kn**: Time multiplier for inverse time characteristic. This parameter is used for coordination between different inverse time delayed undervoltage protections.

**ACrvn, BCrvn, CCrvn, DCrvn, PCrvn**: Parameters to create a programmable undervoltage inverse time characteristic. Description of this can be found in the *Technical manual*.

**CrvSatn**: Tuning parameter that is used to compensate for the undesired discontinuity created when the denominator in the equation for the customer programmable curve is equal to zero. For more information, see the *Technical manual*.

**IntBlkSeln**: This parameter can be set to *Off*, *Block of trip*, *Block all*. In case of a low voltage the undervoltage function can be blocked. This function can be used to prevent function when the protected object is switched off. If the parameter is set *Block of trip* or *Block all* unwanted trip is prevented.

**IntBlkStValn**: Voltage level under which the blocking is activated set in % of *UBase*. This setting must be lower than the setting *Un<*. As switch of shall be detected the setting can be very low, that is, about 10%.

**tBlkUVn**: Time delay to block the undervoltage step n when the voltage level is below *IntBlkStValn*, given in s. It is important that this delay is shorter than the operate time delay of the undervoltage protection step.

### 8.2 Two step overvoltage protection OV2PTOV
8.2.1 Identification

<table>
<thead>
<tr>
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<td>Two step overvoltage protection</td>
<td>OV2PTOV</td>
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8.2.2 Application

Two step overvoltage protection OV2PTOV is applicable in all situations, where reliable detection of high voltage is necessary. OV2PTOV is used for supervision and detection of abnormal conditions, which, in combination with other protection functions, increase the security of a complete protection system.

High overvoltage conditions are caused by abnormal situations in the power system. OV2PTOV is applied to power system elements, such as generators, transformers, motors and power lines in order to detect high voltage conditions. OV2PTOV is used in combination with low current signals, to identify a transmission line, open in the remote end. In addition to that, OV2PTOV is also used to initiate voltage correction measures, like insertion of shunt reactors, to compensate for low load, and thereby decreasing the voltage. The function has a high measuring accuracy and hysteresis setting to allow applications to control reactive load.

OV2PTOV is used to disconnect apparatuses, like electric motors, which will be damaged when subject to service under high voltage conditions. It deals with high voltage conditions at power system frequency, which can be caused by:

1. Different kinds of faults, where a too high voltage appears in a certain power system, like metallic connection to a higher voltage level (broken conductor falling down to a crossing overhead line, transformer flash over fault from the high voltage winding to the low voltage winding and so on).
2. Malfunctioning of a voltage regulator or wrong settings under manual control (symmetrical voltage decrease).
3. Low load compared to the reactive power generation (symmetrical voltage decrease).
4. Earth-faults in high impedance earthed systems causes, beside the high voltage in the neutral, high voltages in the two non-faulted phases, (unsymmetrical voltage increase).

OV2PTOV prevents sensitive equipment from running under conditions that could cause their overheating or stress of insulation material, and, thus, shorten their life time expectancy. In many cases, it is a useful function in circuits for local or remote automation processes in the power system.

8.2.3 Setting guidelines

The parameters for Two step overvoltage protection (OV2PTOV) are set via the local HMI or PCM600.

All the voltage conditions in the system where OV2PTOV performs its functions should be considered. The same also applies to the associated equipment, its voltage and time characteristic.

There are wide applications where general overvoltage functions are used. All voltage related settings are made as a percentage of a settable base primary voltage, which is normally set to
the nominal voltage level (phase-to-phase) of the power system or the high voltage equipment under consideration.

The time delay for the OV2PTOV can sometimes be critical and related to the size of the overvoltage - a power system or a high voltage component can withstand smaller overvoltages for some time, but in case of large overvoltages the related equipment should be disconnected more rapidly.

Some applications and related setting guidelines for the voltage level are given below:

The hysteresis is for overvoltage functions very important to prevent that a transient voltage over set level is not “sealed-in” due to a high hysteresis. Typical values should be ≤ 0.5%.

8.2.3.1 Equipment protection, such as for motors, generators, reactors and transformers

High voltage will cause overexcitation of the core and deteriorate the winding insulation. The setting has to be well above the highest occurring "normal" voltage and well below the highest acceptable voltage for the equipment.

8.2.3.2 Equipment protection, capacitors

High voltage will deteriorate the dielectricum and the insulation. The setting has to be well above the highest occurring "normal" voltage and well below the highest acceptable voltage for the capacitor.

8.2.3.3 Power supply quality

The setting has to be well above the highest occurring "normal" voltage and below the highest acceptable voltage, due to regulation, good practice or other agreements.

8.2.3.4 High impedance earthed systems

In high impedance earthed systems, earth-faults cause a voltage increase in the non-faulty phases. Two step overvoltage protection (OV2PTOV) is used to detect such faults. The setting must be above the highest occurring "normal" voltage and below the lowest occurring voltage during faults. A metallic single-phase earth-fault causes the non-faulted phase voltages to increase a factor of $\sqrt{3}$.

8.2.3.5 The following settings can be done for the two step overvoltage protection

ConnType: Sets whether the measurement shall be phase-to-earth fundamental value, phase-to-phase fundamental value, phase-to-earth RMS value or phase-to-phase RMS value.

Operation: Off/On.

UBase (given in GlobalBaseSel): Base voltage phase to phase in primary kV. This voltage is used as reference for voltage setting. OV2PTOV measures selectively phase-to-earth voltages, or phase-to-phase voltage chosen by the setting ConnType. The function will operate if the voltage gets lower than the set percentage of UBase. When ConnType is set to PhN DFT or PhN RMS then the IED automatically divides set value for UBase by $\sqrt{3}$. When ConnType is set to PhPh DFT or PhPh RMS then set value for UBase is used. Therefore, always set UBase as rated primary phase-to-phase voltage of the protected object. If phase to neutral (PhN) measurement is selected as setting, the operation of phase-to-earth over voltage is automatically divided by $\sqrt{3}$. This means operation for phase-to-earth voltage over:
and operation for phase-to-phase voltage over:

\[ U > (\%) \cdot \text{UBase}(kV) / \sqrt{3} \]

(Equation 35)

The below described setting parameters are identical for the two steps \((n = 1 \text{ or } 2)\). Therefore the setting parameters are described only once.

**Characteristic**: This parameter gives the type of time delay to be used. The setting can be *Definite time, Inverse Curve A, Inverse Curve B, Inverse Curve C* or *I/Prog. inv. curve*. The choice is highly dependent of the protection application.

**OpModen**: This parameter describes how many of the three measured voltages that should be above the set level to give operation. The setting can be *1 out of 3, 2 out of 3, 3 out of 3*. In most applications it is sufficient that one phase voltage is high to give operation. If the function shall be insensitive for single phase-to-earth faults *1 out of 3* can be chosen, because the voltage will normally rise in the non-faulted phases at single phase-to-earth faults. In subtransmission and transmission networks the UV function is mainly a system supervision function and *3 out of 3* is selected.

**Un>**: Set operate overvoltage operation value for step \(n\), given as % of *UBase*. The setting is highly dependent of the protection application. Here it is essential to consider the maximum voltage at non-faulted situations. Normally this voltage is less than 110% of nominal voltage.

**tn**: time delay of step \(n\), given in s. The setting is highly dependent of the protection application. In many applications the protection function is used to prevent damages to the protected object. The speed might be important for example in case of protection of transformer that might be overexcited. The time delay must be co-ordinated with other automated actions in the system.

**tResetn**: Reset time for step \(n\) if definite time delay is used, given in s. The default value is 25 ms.

**tnMin**: Minimum operation time for inverse time characteristic for step \(n\), given in s. For very high voltages the overvoltage function, using inverse time characteristic, can give very short operation time. This might lead to unselective trip. By setting \(t1\text{Min}\) longer than the operation time for other protections such unselective tripping can be avoided.

**ResetTypeCrvn**: This parameter for inverse time characteristic can be set: *Instantaneous, Frozen time, Linearly decreased*. The default setting is *Instantaneous*.

**tIResetn**: Reset time for step \(n\) if inverse time delay is used, given in s. The default value is 25 ms.

**kn**: Time multiplier for inverse time characteristic. This parameter is used for co-ordination between different inverse time delayed undervoltage protections.

**ACrvn, BCrvn, CCrvn, DCrvn, PCrvn**: Parameters to set to create programmable under voltage inverse time characteristic. Description of this can be found in the technical reference manual.

**CrvSatn**: When the denominator in the expression of the programmable curve is equal to zero the time delay will be infinity. There will be an undesired discontinuity. Therefore a tuning parameter *CrvSatn* is set to compensate for this phenomenon. In the voltage interval \(Un>\) up to \(Un> \cdot (1.0 + \text{CrvSatn}/100)\) the used voltage will be: \(Un> \cdot (1.0 + \text{CrvSatn}/100)\). If the programmable curve is used, this parameter must be calculated so that:
\[ B \cdot \frac{CrvSatn}{100} - C > 0 \]

(Equation 36)

\(HystAbsn\): Absolute hysteresis set in \% of \(U_{Base}\). The setting of this parameter is highly dependent of the application. If the function is used as control for automatic switching of reactive compensation devices the hysteresis must be set smaller than the voltage change after switching of the compensation device.

### 8.3 Two step residual overvoltage protection ROV2PTOV

#### 8.3.1 Identification

<table>
<thead>
<tr>
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<td>2(U0&gt;)</td>
<td>59N</td>
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#### 8.3.2 Application

Two step residual overvoltage protection ROV2PTOV is primarily used in high impedance earthed distribution networks, mainly as a backup for the primary earth-fault protection of the feeders and the transformer. To increase the security for different earth-fault related functions, the residual overvoltage signal can be used as a release signal. The residual voltage can be measured either at the transformer neutral or from a voltage transformer open delta connection. The residual voltage can also be calculated internally, based on the measurement of the three phase-to-earth voltages.

In high impedance earthed systems the residual voltage will increase in case of any fault connected to earth. Depending on the type of fault and fault resistance the residual voltage will reach different values. The highest residual voltage, equal to three times the phase-to-earth voltage, is achieved for a single phase-to-earth fault. The residual voltage increases approximately to the same level in the whole system and does not provide any guidance in finding the faulted component. Therefore, ROV2PTOV is often used as a backup protection or as a release signal for the feeder earth-fault protection.

#### 8.3.3 Setting guidelines

All the voltage conditions in the system where ROV2PTOV performs its functions should be considered. The same also applies to the associated equipment, its voltage withstand capability and time characteristic.

All voltage-related settings are made as a percentage of a settable base voltage, which shall be set to the primary nominal voltage (phase-phase) level of the power system or the high-voltage equipment under consideration.

The time delay for ROV2PTOV is seldom critical, since residual voltage is related to earth faults in a high-impedance earthed system, and enough time must normally be given for the primary protection to clear the fault. In some more specific situations, where the residual overvoltage protection is used to protect some specific equipment, the time delay is shorter.
Some applications and related setting guidelines for the residual voltage level are given below.

8.3.3.1 Equipment protection, such as for motors, generators, reactors and transformers

Equipment protection for transformers

High residual voltage indicates earth-fault in the system, perhaps in the component to which two step residual overvoltage protection (ROV2PTOV) is connected. For selectivity reasons to the primary protection for the faulted device, ROV2PTOV must trip the component with some time delay. The setting must be above the highest occurring "normal" residual voltage and below the highest acceptable residual voltage for the equipment.

8.3.3.2 Equipment protection, capacitors

High voltage will deteriorate the dielectric and the insulation. Two step residual overvoltage protection (ROV2PTOV) has to be connected to a neutral or open delta winding. The setting must be above the highest occurring “normal” residual voltage and below the highest acceptable residual voltage for the capacitor.

8.3.3.3 Power supply quality

The setting must be above the highest occurring “normal” residual voltage and below the highest acceptable residual voltage, due to regulation, good practice or other agreements.

8.3.3.4 High impedance earthed systems

In high impedance earthed systems, earth faults cause a neutral voltage in the feeding transformer neutral. Two step residual overvoltage protection ROV2PTOV is used to trip the transformer, as a backup protection for the feeder earth-fault protection, and as a backup for the transformer primary earth-fault protection. The setting must be above the highest occurring “normal” residual voltage, and below the lowest occurring residual voltage during the faults under consideration. A metallic single-phase earth fault causes a transformer neutral to reach a voltage equal to the nominal phase-to-earth voltage.

The voltage transformers measuring the phase-to-earth voltages measure zero voltage in the faulty phase. The two healthy phases will measure full phase-to-phase voltage, as the faulty phase will be connected to earth. The residual overvoltage will be three times the phase-to-earth voltage. See figure 50.
8.3.3.5 Direct earthed system

In direct earthed systems, an earth fault on one phase is indicated by voltage collapse in that phase. The other healthy phase will still have normal phase-to-earth voltage. The residual sum will have the same value as the remaining phase-to-earth voltage, which is shown in Figure 51.

Figure 51: Earth fault in Direct earthed system

8.3.3.6 Settings for two step residual overvoltage protection

*Operation: Off or On*

*UBase* (given in *GlobalBaseSel*) is used as voltage reference for the set pickup values. The voltage can be fed to the IED in different ways:
1. The IED is fed from a normal voltage transformer group where the residual voltage is calculated internally from the phase-to-earth voltages within the protection. The setting of the analog input is given as $U_{\text{Base}} = U_{\text{ph-ph}}$.

2. The IED is fed from a broken delta connection normal voltage transformer group. In an open delta connection the protection is fed by the voltage $3U_0$ (single input). Section Analog inputs in the Application manual explains how the analog input needs to be set.

3. The IED is fed from a single voltage transformer connected to the neutral point of a power transformer in the power system. In this connection the protection is fed by the voltage $U_N = U_0$ (single input). Section Analog inputs in the Application manual explains how the analog input needs to be set.

ROV2PTOV will measure the residual voltage corresponding to the nominal phase-to-earth voltage for a high-impedance earthed system. The measurement will be based on the neutral voltage displacement.

The setting parameters described below are identical for the two steps ($n = \text{step 1 and 2}$). Therefore the setting parameters are described only once.

**OperationStep**: This is to enable/disable operation of step $n$.

**Characteristic**: Selected inverse time characteristic for step $n$. This parameter gives the type of time delay to be used. The setting can be, Definite time or Inverse curve A or Inverse curve B or Inverse curve C or Prog. inv. curve. The choice is highly dependent of the protection application.

**Un**: Set operate overvoltage operation value for step $n$, given as % of residual voltage corresponding to $U_{\text{Base}}$:

\[
U > (\%) \cdot U_{\text{Base}} (kV)/\sqrt{3}
\]

(Equation 37)

The setting depends on the required sensitivity of the protection and the type of system earthing. In non-effectively earthed systems, the residual voltage cannot be higher than three times the rated phase-to-earth voltage, which should correspond to 100%.

In effectively earthed systems, this value depends on the ratio $Z_0/Z_1$. The required setting to detect high resistive earth faults must be based on network calculations.

**tn**: time delay of step $n$, given in s. The setting is highly dependent on the protection application. In many applications, the protection function has the task to prevent damage to the protected object. The speed might be important, for example, in the case of the protection of a transformer that might be overexcited. The time delay must be co-ordinated with other automated actions in the system.

**tResetn**: Reset time for step $n$ if definite time delay is used, given in s. The default value is 25 ms.

**tnMin**: Minimum operation time for inverse time characteristic for step $n$, given in s. For very high voltages the overvoltage function, using inverse time characteristic, can give very short operation time. This might lead to unselective trip. By setting $t_{\text{tMin}}$ longer than the operation time for other protections such unselective tripping can be avoided.

**ResetTypeCrvn**: Set reset type curve for step $n$. This parameter can be set: Instantaneous, Frozen time, Linearly decreased. The default setting is Instantaneous.

**tlResetn**: Reset time for step $n$ if inverse time delay is used, given in s. The default value is 25 ms.

**kn**: Time multiplier for inverse time characteristic. This parameter is used for co-ordination between different inverse time delayed undervoltage protections.
$ACrvn, BCrvn, CCrvn, DCrvn, PCrvn$: Parameters for step $n$, to set to create programmable undervoltage inverse time characteristic. Description of this can be found in the technical reference manual.

$CrvSatn$: Set tuning parameter for step $n$. When the denominator in the expression of the programmable curve is equal to zero, the time delay will be infinite. There will be an undesired discontinuity. Therefore, a tuning parameter $CrvSatn$ is set to compensate for this phenomenon. In the voltage interval $U > \cdot (1.0 + CrvSatn/100)$ the used voltage will be: $U > \cdot (1.0 + CrvSatn/100)$. If the programmable curve is used this parameter must be calculated so that:

$$B \cdot \frac{CrvSatn}{100} - C > 0$$

(Equation 38)

$HystAbsn$: Absolute hysteresis for step $n$, set in % of $U_{Base}$. The setting of this parameter is highly dependent of the application. The hysteresis is used to avoid oscillations of the START output signal. This signal resets when the measured voltage drops below the setting level and leaves the hysteresis area. Make sure that the set value for parameter $HystABSn$ is somewhat smaller than the set pickup value. Otherwise there is a risk that step $n$ will not reset properly.
## Section 9  Secondary system supervision

### 9.1  Fuse failure supervision FUFSPVC

#### 9.1.1  Identification

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<tbody>
<tr>
<td>Fuse failure supervision</td>
<td>FUFSPVC</td>
<td>-</td>
<td>-</td>
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</tbody>
</table>

#### 9.1.2  Application

Different protection functions within the protection IED, operates on the basis of the measured voltage in the relay point. Examples are:

- impedance protection functions
- undervoltage function
- energizing check function and voltage check for the weak infeed logic

These functions can operate unintentionally if a fault occurs in the secondary circuits between the voltage instrument transformers and the IED.

It is possible to use different measures to prevent such unwanted operations. Miniature circuit breakers in the voltage measuring circuits should be located as close as possible to the voltage instrument transformers, and shall be equipped with auxiliary contacts that are wired to the IEDs. Separate fuse-failure monitoring IEDs or elements within the protection and monitoring devices are another possibilities. These solutions are combined to get the best possible effect in the fuse failure supervision function (FUFSVPVC).

FUFSVPVC function built into the IED products can operate on the basis of external binary signals from the miniature circuit breaker or from the line disconnector. The first case influences the operation of all voltage-dependent functions while the second one does not affect the impedance measuring functions.

The negative sequence detection algorithm, based on the negative-sequence measuring quantities is recommended for use in isolated or high-impedance earthed networks: a high value of voltage $3U_2$ without the presence of the negative-sequence current $3I_2$ is a condition that is related to a fuse failure event.

The zero sequence detection algorithm, based on the zero sequence measuring quantities is recommended for use in directly or low impedance earthed networks: a high value of voltage $3U_0$ without the presence of the residual current $3I_0$ is a condition that is related to a fuse failure event. In cases where the line can have a weak-infeed of zero sequence current this function shall be avoided.

A criterion based on delta current and delta voltage measurements can be added to the fuse failure supervision function in order to detect a three phase fuse failure. This is beneficial for example during three phase transformer switching.
9.1.3 Setting guidelines

9.1.3.1 General

The negative and zero sequence voltages and currents always exist due to different non-symmetries in the primary system and differences in the current and voltage instrument transformers. The minimum value for the operation of the current and voltage measuring elements must always be set with a safety margin of 10 to 20%, depending on the system operating conditions.

Pay special attention to the dissymmetry of the measuring quantities when the function is used on long untransposed lines, on multicircuit lines and so on.

The settings of negative sequence, zero sequence and delta algorithm are in percent of the base voltage and base current for the function. Common base IED values for primary current (IBase), primary voltage (UBase) and primary power (SBase) are set in Global Base Values GBASVAL. The setting GlobalBaseSel is used to select a particular GBASVAL and used its base values.

9.1.3.2 Setting of common parameters

Set the operation mode selector Operation to On to release the fuse failure function.

The voltage threshold USealIn< is used to identify low voltage condition in the system. Set USealIn< below the minimum operating voltage that might occur during emergency conditions. We propose a setting of approximately 70% of UBase.

The drop off time of 200 ms for dead phase detection makes it recommended to always set SealIn to On since this will secure a fuse failure indication at persistent fuse fail when closing the local breaker when the line is already energized from the other end. When the remote breaker closes the voltage will return except in the phase that has a persistent fuse fail. Since the local breaker is open there is no current and the dead phase indication will persist in the phase with the blown fuse. When the local breaker closes the current will start to flow and the function detects the fuse failure situation. But due to the 200 ms drop off timer the output BLKZ will not be activated until after 200 ms. This means that distance functions are not blocked and due to the “no voltage but current” situation might issue a trip.

The operation mode selector OpMode has been introduced for better adaptation to system requirements. The mode selector enables selecting interactions between the negative sequence and zero sequence algorithm. In normal applications, the OpMode is set to either UNSlns for selecting negative sequence algorithm or UZslIZs for zero sequence based algorithm. If system studies or field experiences shows that there is a risk that the fuse failure function will not be activated due to the system conditions, the dependability of the fuse failure function can be increased if the OpMode is set to UZslIZs OR UNSlns or OptimIZsNs. In mode UZslIZs OR UNSlns both negative and zero sequence based algorithms are activated and working in an OR-condition. Also in mode OptimIZsNs both negative and zero sequence algorithms are activated and the one that has the highest magnitude of measured negative or zero sequence current will operate. If there is a requirement to increase the security of the fuse failure function OpMode can be selected to UZslIZs AND UNSlns which gives that both negative and zero sequence algorithms are activated and working in an AND-condition, that is, both algorithms must give condition for block in order to activate the output signals BLKU or BLKZ.

9.1.3.3 Negative sequence based

The relay setting value 3U2> is given in percentage of the base voltage UBase and should not be set lower than the value that is calculated according to equation 39.
\[ 3U_2 \geq \frac{U^2}{UBase/\sqrt{3}} \times 100 \]  
(Equation 39)

where:
- \( U_2 \) is the maximal negative sequence voltage during normal operation conditions, plus a margin of 10...20%.
- \( UBase \) is the base voltage for the function according to the setting \( GlobalBaseSel \).

The setting of the current limit \( 3I_2 \leq \) is in percentage of parameter \( IBase \). The setting of \( 3I_2 \leq \) must be higher than the normal unbalance current that might exist in the system and can be calculated according to equation 40.

\[ 3I_2 \leq \frac{I_2}{IBase} \times 100 \]  
(Equation 40)

where:
- \( I_2 \) is the maximal negative sequence current during normal operating conditions, plus a margin of 10...20%.
- \( IBase \) is the base current for the function according to the setting \( GlobalBaseSel \).

### 9.1.3.4 Zero sequence based

The IED setting value \( 3U_0 \geq \) is given in percentage of the base voltage \( UBase \). The setting of \( 3U_0 \geq \) should not be set lower than the value that is calculated according to equation 41.

\[ 3U_0 \geq \frac{3U_0}{UBase/\sqrt{3}} \times 100 \]  
(Equation 41)

where:
- \( 3U_0 \) is the maximal zero sequence voltage during normal operation conditions, plus a margin of 10...20%.
- \( UBase \) is the base voltage for the function according to the setting \( GlobalBaseSel \).

The setting of the current limit \( 3I_0 \leq \) is done in percentage of \( IBase \). The setting of \( 3I_0 \leq \) must be higher than the normal unbalance current that might exist in the system. The setting can be calculated according to equation 42.

\[ 3I_0 \leq \frac{3I_0}{IBase} \times 100 \]  
(Equation 42)

where:
- \( 3I_0 \) is the maximal zero sequence current during normal operating conditions, plus a margin of 10...20%.
- \( IBase \) is the base current for the function according to the setting \( GlobalBaseSel \).
9.1.3.5 Delta U and delta I

Set the operation mode selector OpDUDI to On if the delta function shall be in operation.

The setting of DU> should be set high (approximately 60% of UBase) and the current threshold DI< low (approximately 10% of IBase) to avoid unwanted operation due to normal switching conditions in the network. The delta current and delta voltage function shall always be used together with either the negative or zero sequence algorithm. If USet\textsubscript{prim} is the primary voltage for operation of dU/dt and ISet\textsubscript{prim} the primary current for operation of dI/dt, the setting of DU> and DI< will be given according to equation 43 and equation 44.

\[
DU> = \frac{USet\textsubscript{prim}}{UBase} \times 100
\]  
(Equation 43)

\[
DI< = \frac{ISet\textsubscript{prim}}{IBase} \times 100
\]  
(Equation 44)

The voltage thresholds UPh> is used to identify low voltage condition in the system. Set UPh> below the minimum operating voltage that might occur during emergency conditions. A setting of approximately 70% of UBase is recommended.

The current threshold IPh> shall be set lower than the IMinOp for the distance protection function. A 5...10% lower value is recommended.

9.1.3.6 Dead line detection

The condition for operation of the dead line detection is set by the parameters IDLD< for the current threshold and UDLD< for the voltage threshold.

Set the IDLD< with a sufficient margin below the minimum expected load current. A safety margin of at least 15-20% is recommended. The operate value must however exceed the maximum charging current of an overhead line, when only one phase is disconnected (mutual coupling to the other phases).

Set the UDLD< with a sufficient margin below the minimum expected operating voltage. A safety margin of at least 15% is recommended.
Section 10  Control

10.1  Apparatus control

10.1.1  Application

The apparatus control is a functionality for control and supervising of circuit breakers, disconnectors, and earthing switches within a bay. Permission to operate is given after evaluation of conditions from other functions such as interlocking, synchrocheck, operator place selection and external or internal blockings.

The complete apparatus control function is not included in this product, and the information below is included for understanding of the principle for the use of QCBAY, LOCREM, LOCREMCTRL, SCILO, SCSWI, SXCBR.

Figure 52 shows from which places the apparatus control function receives commands. The commands to an apparatus can be initiated from the Control Centre (CC), the station HMI or the local HMI on the IED front.

Figure 52: Overview of the apparatus control functions

Features in the apparatus control function:

- Operation of primary apparatuses
- Select-Execute principle to give high security
- Selection and supervision of operator place
- Command supervision
- Block/deblock of operation
- Block/deblock of updating of position indications
- Substitution of position indications
- Overriding of interlocking functions
- Overriding of synchrocheck
- Pole discordance supervision
- Operation counter
- Suppression of mid position

The apparatus control function is realized by means of a number of function blocks designated:

- Switch controller SCSWI
- Circuit breaker SXCBR
- Bay control QCBAY
- Local remote LOCREM
- Local remote control LOCREMCTRL

The signal flow between the function blocks is shown in Figure 53. The application description for all these functions can be found below. The function SCILO in the Figure below is the logical node for interlocking.

When the circuit breaker or switch is located in a breaker IED, two more functions are added:

- GOOSE receive for switching device GOOSEXLNRCV
- Proxy for signals from switching device via GOOSE XLNPROXY

The extension of the signal flow and the usage of the GOOSE communication are shown in Figure 54.

Figure 53: Signal flow between apparatus control function blocks when all functions are situated within the IED
Control operation can be performed from the local IED HMI. If users are defined in the IED, then the local/remote switch is under authority control, otherwise the default user can perform control operations from the local IED HMI without logging in. The default position of the local/remote switch is on remote.

**Accepted originator categories for PSTO**

If the requested command is accepted by the authority control, the value will change. Otherwise the attribute `blocked-by-switching-hierarchy` is set in the cause signal. If the PSTO value is changed during a command, then the command is aborted.
The accepted originator categories for each PSTO value are shown in Table 19.

Table 19: Accepted originator categories for each PSTO

<table>
<thead>
<tr>
<th>Permitted Source To Operate</th>
<th>Originator (orCat)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 = Off</td>
<td>4,5,6</td>
</tr>
<tr>
<td>1 = Local</td>
<td>1,4,5,6</td>
</tr>
<tr>
<td>2 = Remote</td>
<td>2,3,4,5,6</td>
</tr>
<tr>
<td>3 = Faulty</td>
<td>4,5,6</td>
</tr>
<tr>
<td>4 = Not in use</td>
<td>4,5,6</td>
</tr>
<tr>
<td>5 = All</td>
<td>1,2,3,4,5,6</td>
</tr>
<tr>
<td>6 = Station</td>
<td>2,4,5,6</td>
</tr>
<tr>
<td>7 = Remote</td>
<td>3,4,5,6</td>
</tr>
</tbody>
</table>

PSTO = All, then it is no priority between operator places. All operator places are allowed to operate.

According to IEC 61850 standard the orCat attribute in originator category are defined in Table 20

Table 20: orCat attribute according to IEC 61850

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>not-supported</td>
</tr>
<tr>
<td>1</td>
<td>bay-control</td>
</tr>
<tr>
<td>2</td>
<td>station-control</td>
</tr>
<tr>
<td>3</td>
<td>remote-control</td>
</tr>
<tr>
<td>4</td>
<td>automatic-bay</td>
</tr>
<tr>
<td>5</td>
<td>automatic-station</td>
</tr>
<tr>
<td>6</td>
<td>automatic-remote</td>
</tr>
<tr>
<td>7</td>
<td>maintenance</td>
</tr>
<tr>
<td>8</td>
<td>process</td>
</tr>
</tbody>
</table>

10.1.2 Bay control QCBAY

The Bay control (QCBAY) is used to handle the selection of the operator place per bay. The function gives permission to operate from two main types of locations either from Remote (for example, control centre or station HMI) or from Local (local HMI on the IED) or from all (Local and Remote). The Local/Remote switch position can also be set to Off, which means no operator place selected that is, operation is not possible either from local or from remote.

For IEC 61850-8-1 communication, the Bay Control function can be set to discriminate between commands with orCat station and remote (2 and 3). The selection is then done through the IEC 61850-8-1 edition 2 command LocSta.

QCBAY also provides blocking functions that can be distributed to different apparatuses within the bay. There are two different blocking alternatives:

- Blocking of update of positions
- Blocking of commands
10.1.3 Switch controller SCSWI

SCSWI may handle and operate on one three-phase device or three one-phase switching devices.

After the selection of an apparatus and before the execution, the switch controller performs the following checks and actions:

- A request initiates to reserve other bays to prevent simultaneous operation.
- Actual position inputs for interlocking information are read and evaluated if the operation is permitted.
- The synchrocheck/synchronizing conditions are read and checked, and performs operation upon positive response.
- The blocking conditions are evaluated
- The position indications are evaluated according to given command and its requested direction (open or closed).

The command sequence is supervised regarding the time between:

- Select and execute.
- Select and until the reservation is granted.
- Execute and the final end position of the apparatus.
- Execute and valid close conditions from the synchrocheck.

At error the command sequence is cancelled.
In the case when there are three one-phase switches (SXCBR) connected to the switch controller function, the switch controller will "merge" the position of the three switches to the resulting three-phase position. In case of a pole discordance situation, that is, the positions of the one-phase switches are not equal for a time longer than a settable time; an error signal will be given.

The switch controller represents the content of the SCSWI logical node (according to IEC 61850) with mandatory functionality.

10.1.4 **Switches SXCBR**

Switches are functions used to close and interrupt an ac power circuit under normal conditions, or to interrupt the circuit under fault, or emergency conditions. The intention with these functions is to represent the lowest level of a power-switching device with or without short circuit breaking capability, for example, circuit breakers, disconnectors, earthing switches etc.

The purpose of these functions is to provide the actual status of positions and to perform the control operations, that is, pass all the commands to the primary apparatus via output boards and to supervise the switching operation and position.

Switches have the following functionalities:

- Local/Remote switch intended for the switchyard
- Block/deblock for open/close command respectively
- Update block/deblock of position indication
- Substitution of position indication
- Supervision timer that the primary device starts moving after a command
- Supervision of allowed time for intermediate position
- Definition of pulse duration for open/close command respectively

The realizations of these functions are done with SXCBR representing a circuit breaker.

Circuit breaker (SXCBR) can be realized either as three one-phase switches or as one three-phase switch.

The content of this function is represented by the IEC 61850 definitions for the logical node Circuit breaker (SXCBR) with mandatory functionality.

10.1.5 **Proxy for signals from switching device via GOOSE XLNPROXY**

The purpose of the proxy for signals from switching device via GOOSE (XLNPROXY) is to give the same internal representation of the position status and control response for a switch modeled in a breaker IED as if represented by a SXCBR or SXSWI function.

The command response functionality is dependent on the connection of the execution information, XIN, from the SCSWI function controlling the represented switch. Otherwise, the function only reflects the current status of the switch, such as blocking, selection, position, operating capability and operation counter.

Since different switches are represented differently on IEC 61850, the data that is mandatory to model in IEC 61850 is mandatory inputs and the other useful data for the command and status following is optional. To make it easy to choose which data to use for the XLNPROXY function, their usage is controlled by the connection of each data's signal input and valid input. These connections are usually from the GOOSEXLNRVC function (see Figure 56 and Figure 57).
Figure 56: Configuration with XLNPROXY and GOOSEXLNRCV where all the IEC 61850 modelled data is used, including selection.

Figure 57: Configuration with XLNPROXY and GOOSEXLNRCV where only the mandatory data in the IEC 61850 modelling is used.

All the information from the XLNPROXY to the SCSWI about command following status, causes for failed command and selection status is transferred in the output XPOS. The other outputs...
may be used by other functions in the same way as the corresponding outputs of the SXCBR and SXSWI function.

When a command has been issued from the connected SCSWI function, the XLNPROXY function awaits the response on it from the represented switch through the inputs POSVAL and OPOK. While waiting for the switch to start moving, it checks if the switch is blocked for the operation. When the switch has started moving and no blocking condition has been detected, XLNPROXY issues a response to the SCSWI function that the command has started. If OPOK is used, this response is given when XLNPROXY receives the signal.

If no movement of the switch is registered within the limit tStartMove, the command is considered failed, and the cause of the failure is evaluated. In the evaluation, the function checks if the state of the represented switch is indicating that the command is blocked in any way during the command, and gives the appropriate cause to the SCSWI function. This cause is also shown on the output L_CAUSE as indicated in the following table:

<table>
<thead>
<tr>
<th>Cause No</th>
<th>Cause Description</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Blocked-by-Mode</td>
<td>The BEH input is 5.</td>
</tr>
<tr>
<td>2</td>
<td>Blocked-by-switching-hierarchy</td>
<td>The LOC input indicates that only local commands are allowed for the breaker IED function.</td>
</tr>
<tr>
<td>-24</td>
<td>Blocked-for-open-cmd</td>
<td>The BLKOPN is active indicating that the switch is blocked for open commands.</td>
</tr>
<tr>
<td>-25</td>
<td>Blocked-for-close-cmd</td>
<td>The BLKCLS is active indicating that the switch is blocked for close commands.</td>
</tr>
<tr>
<td>9</td>
<td>Blocked-by-process</td>
<td>If the Blk input is connected and active indicating that the switch is dynamically blocked. Or if the OPCAP input is connected, it indicates that the operation capability of the switch is not enough to perform the command.</td>
</tr>
<tr>
<td>5</td>
<td>Position-reached</td>
<td>Switch is already in the intended position.</td>
</tr>
<tr>
<td>-31</td>
<td>Switch-not-start-moving</td>
<td>Switch did not start moving within tStartMove.</td>
</tr>
<tr>
<td>-32</td>
<td>Persistent-intermediate-state</td>
<td>The switch stopped in intermediate state for longer than tIntermediate.</td>
</tr>
<tr>
<td>-33</td>
<td>Switch-returned-to-init-pos</td>
<td>Switch returned to the initial position.</td>
</tr>
<tr>
<td>-34</td>
<td>Switch-in-bad-state</td>
<td>Switch is in a bad position.</td>
</tr>
<tr>
<td>-35</td>
<td>Not-expected-final-position</td>
<td>Switch did not reach the expected final position.</td>
</tr>
</tbody>
</table>

The OPCAP input and output are used for the CBopCap data of a XCBR respectively SwOpCap for a XSWI. The interpretation for the command following is controlled through the setting SwitchType.

### 10.1.6 Interaction between modules

A typical bay with apparatus control function consists of a combination of logical nodes or functions that are described here:

- The Switch controller (SCSWI) initializes all operations for one apparatus. It is the command interface of the apparatus. It includes the position reporting as well as the control of the position.
- The Circuit breaker (SXCBR) is the process interface to the circuit breaker for the apparatus control function.
- The Bay control (QCBAY) fulfils the bay-level functions for the apparatuses, such as operator place selection and blockings for the complete bay.
• The Protection trip logic (SMPPTRC) connects the “trip” outputs of one or more protection functions to a common “trip” to be transmitted to SXCBR.
• The Autorecloser (SMBRREC) consists of the facilities to automatically close a tripped breaker with respect to a number of configurable conditions.
• The logical node Interlocking (SCIL0) provides the information to SCSWI whether it is permitted to operate due to the switchyard topology. The interlocking conditions are evaluated with separate logic and connected to SCIL0.
• The Synchrocheck, energizing check, and synchronizing (SESRSYN) calculates and compares the voltage phasor difference from both sides of an open breaker with predefined switching conditions (synchrocheck). Also the case that one side is dead (energizing-check) is included.
• The Generic Automatic Process Control function, GAPC, handles generic commands from the operator to the system.

The overview of the interaction between these functions is shown in Figure 58 below.

Figure 58: Example overview of the interactions between functions in a typical bay
10.1.7 Setting guidelines

The setting parameters for the apparatus control function are set via the local HMI or PCM600.

10.1.7.1 Bay control (QCBAY)

If the parameter AllPSTOValid is set to No priority, all originators from local and remote are accepted without any priority.

If the parameter RemoteIncStation is set to Yes, commands from IEC 61850-8-1 clients at both station and remote level are accepted, when the QCBAY function is in Remote. If set to No, the command LocSta controls which operator place is accepted when QCBAY is in Remote. If LocSta is true, only commands from station level are accepted, otherwise only commands from remote level are accepted.

The parameter RemoteIncStation has only effect on the IEC 61850-8-1 communication. Further, when using IEC 61850 edition 1 communication, the parameter should be set to Yes, since the command LocSta is not defined in IEC 61850-8-1 edition 1.

10.1.7.2 Switch controller (SCSWI)

The parameter CtlModel specifies the type of control model according to IEC 61850. The default for control of circuit breakers, disconnectors and earthing switches the control model is set to SBO Enh (Select-Before-Operate) with enhanced security.

When the operation shall be performed in one step, and no monitoring of the result of the command is desired, the model direct control with normal security is used.

At control with enhanced security there is an additional supervision of the status value by the control object, which means that each command sequence must be terminated by a termination command.

The parameter PosDependent gives permission to operate depending on the position indication, that is, at Always permitted it is always permitted to operate independent of the value of the position. At Not perm at 00/11 it is not permitted to operate if the position is in bad or intermediate state.

tSelect is the maximum allowed time between the select and the execute command signal, that is, the time the operator has to perform the command execution after the selection of the object to operate. When the time has expired, the selected output signal is set to false and a cause-code is given.

The time parameter tResResponse is the allowed time from reservation request to the feedback reservation granted from all bays involved in the reservation function. When the time has expired, the control function is reset, and a cause-code is given.

tSynchrocheck is the allowed time for the synchrocheck function to fulfill the close conditions. When the time has expired, the function tries to start the synchronizing function. If tSynchrocheck is set to 0, no synchrocheck is done, before starting the synchronizing function.

The timer tSynchronizing supervises that the signal synchronizing in progress is obtained in SCSWI after start of the synchronizing function. The start signal for the synchronizing is set if the synchrocheck conditions are not fulfilled. When the time has expired, the control function is reset, and a cause-code is given. If no synchronizing function is included, the time is set to 0, which means no start of the synchronizing function is done, and when tSynchrocheck has expired, the control function is reset and a cause-code is given.
tExecutionFB is the maximum time between the execute command signal and the command termination. When the time has expired, the control function is reset and a cause-code is given.

tPoleDiscord is the allowed time to have discrepancy between the poles at control of three one-phase breakers. At discrepancy an output signal is activated to be used for trip or alarm, and during a command, the control function is reset, and a cause-code is given.

SuppressMidPos when On suppresses the mid-position during the time tIntermediate of the connected switches.

The parameter InterlockCheck decides if interlock check should be done at both select and operate, Sel & Op phase, or only at operate, Op phase.

10.1.7.3 Switch (SXCBR)

tStartMove is the supervision time for the apparatus to start moving after a command execution is done from the SCSWI function. When the time has expired, the command supervision is reset, and a cause-code is given.

During the tIntermediate time, the position indication is allowed to be in an intermediate (00) state. When the time has expired, the command supervision is reset, and a cause-code is given. The indication of the mid-position at SCSWI is suppressed during this time period when the position changes from open to close or vice-versa if the parameter SuppressMidPos is set to On in the SCSWI function.

If the parameter AdaptivePulse is set to Adaptive the command output pulse resets when a new correct end position is reached. If the parameter is set to Not adaptive the command output pulse remains active until the timer tOpenPulseClosePulse has elapsed.

tOpenPulse is the output pulse length for an open command. If AdaptivePulse is set to Adaptive, it is the maximum length of the output pulse for an open command. The default length is set to 200 ms for a circuit breaker (SXCBR).

tClosePulse is the output pulse length for a close command. If AdaptivePulse is set to Adaptive, it is the maximum length of the output pulse for an open command. The default length is set to 200 ms for a circuit breaker (SXCBR).

10.1.7.4 Proxy for signals from switching device via GOOSE XLNPROXY

The SwitchType setting controls the evaluation of the operating capability. If SwitchType is set to Circuit Breaker, the input OPCAP is interpreted as a breaker operating capability, otherwise it is interpreted as a switch operating capability.

<table>
<thead>
<tr>
<th>Value</th>
<th>Breaker operating capability, CbOpCap</th>
<th>Switch operating capability, SwOpCap</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>Open</td>
<td>Open</td>
</tr>
<tr>
<td>3</td>
<td>Close – Open</td>
<td>Close</td>
</tr>
<tr>
<td>4</td>
<td>Open – Close – Open</td>
<td>Close and Open</td>
</tr>
<tr>
<td>5</td>
<td>Close – Open – Close – Open</td>
<td>Larger values handled as 4, both Close and Open</td>
</tr>
<tr>
<td>6</td>
<td>Open – Close – Open – Close – Open</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>more</td>
<td></td>
</tr>
</tbody>
</table>
tStartMove is the supervision time for the apparatus to start moving after a command execution is done from the SCSWI function. When the time has expired, the command supervision is reset, and a cause-code is given.

During the tIntermediate time, the position indication is allowed to be in an intermediate (00) state. When the time has expired, the command supervision is reset, and a cause-code is given. The indication of the mid-position at SCSWI is suppressed during this time period when the position changes from open to close or vice-versa if the parameter SuppressMidPos is set to On in the SCSWI function.

In most cases, the same value can be used for both tStartMove and tIntermediate as in the source function. However, tStartMove may need to be increased to accommodate for the communication delays, mainly when representing a circuit breaker.

10.2 Logic rotating switch for function selection and LHMI presentation SLGAPC

10.2.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logic rotating switch for function selection and LHMI presentation</td>
<td>SLGAPC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

10.2.2 Application

The logic rotating switch for function selection and LHMI presentation function (SLGAPC) (or the selector switch function block, as it is also known) is used to get a selector switch functionality similar with the one provided by a hardware multi-position selector switch. Hardware selector switches are used extensively by utilities, in order to have different functions operating on pre-set values. Hardware switches are however sources for maintenance issues, lower system reliability and extended purchase portfolio. The virtual selector switches eliminate all these problems.

SLGAPC function block has two operating inputs (UP and DOWN), one blocking input (BLOCK) and one operator position input (PSTO).

SLGAPC can be activated both from the local HMI and from external sources (switches) via the IED binary inputs. It also allows the operation from remote (like the station computer). SWPOSN is an integer value output, giving the actual output number. Since the number of positions of the switch can be established by settings (see below), one must be careful in coordinating the settings with the configuration (if one sets the number of positions to x in settings – for example, there will be only the first x outputs available from the block in the configuration). Also the frequency of the (UP or DOWN) pulses should be lower than the setting tPulse.

From the local HMI, the selector switch can be operated from Single-line diagram (SLD).

10.2.3 Setting guidelines

The following settings are available for the Logic rotating switch for function selection and LHMI presentation (SLGAPC) function:
Operation: Sets the operation of the function On or Off.

NrPos: Sets the number of positions in the switch (max. 32).

OutType: Steady or Pulsed.

tPulse: In case of a pulsed output, it gives the length of the pulse (in seconds).

tDelay: The delay between the UP or DOWN activation signal positive front and the output activation.

StopAtExtremes: Sets the behavior of the switch at the end positions – if set to Disabled, when pressing UP while on first position, the switch will jump to the last position; when pressing DOWN at the last position, the switch will jump to the first position; when set to Enabled, no jump will be allowed.

10.3 Selector mini switch VSGAPC

10.3.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selector mini switch</td>
<td>VSGAPC</td>
<td>-</td>
<td>43</td>
</tr>
</tbody>
</table>

10.3.2 Application

Selector mini switch (VSGAPC) function is a multipurpose function used in the configuration tool in PCM600 for a variety of applications, as a general purpose switch. VSGAPC can be used for both acquiring an external switch position (through the IPOS1 and the IPOS2 inputs) and represent it through the single line diagram symbols (or use it in the configuration through the outputs POS1 and POS2) as well as, a command function (controlled by the PSTO input), giving switching commands through the CMDPOS12 and CMDPOS21 outputs.

The output POSITION is an integer output, showing the actual position as an integer number 0 – 3, where 0 = MidPos, 1 = Open, 2 = Closed and 3 = Error.

An example where VSGAPC is configured to switch Autorecloser on–off from a button symbol on the local HMI is shown in figure 59. The I and O buttons on the local HMI are normally used for on–off operations of the circuit breaker.

Figure 59: Control of Autorecloser from local HMI through Selector mini switch
VSGAPC is also provided with IEC 61850 communication so it can be controlled from SA system as well.

### 10.3.3 Setting guidelines

Selector mini switch (VSGAPC) function can generate pulsed or steady commands (by setting the *Mode* parameter). When pulsed commands are generated, the length of the pulse can be set using the *tPulse* parameter. Also, being accessible on the single line diagram (SLD), this function block has two control modes (settable through *CtlModel*): *Dir Norm* and *SBO Enh*.

### 10.4 Generic communication function for Double Point indication DPGAPC

#### 10.4.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generic communication function for Double Point indication</td>
<td>DPGAPC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 10.4.2 Application

Generic communication function for Double Point indication (DPGAPC) function block is used to send double point position indication to other systems, equipment or functions in the substation through IEC 61850-8-1 or other communication protocols. It is especially intended to be used in the interlocking station-wide logics. To be able to get the signals into other systems, equipment or functions, one must use other tools, described in the Engineering manual, and define which function block in which systems, equipment or functions should receive this information.

More specifically, DPGAPC function reports a combined double point position indication output POSITION, by evaluating the value and the timestamp attributes of the inputs OPEN and CLOSE, together with the logical input signal VALID.

When the input signal VALID is active, the values of the OPEN and CLOSE inputs determine the two-bit integer value of the output POSITION. The timestamp of the output POSITION will have the latest updated timestamp of the inputs OPEN and CLOSE.

When the input signal VALID is inactive, DPGAPC function forces the position to intermediated state.

When the value of the input signal VALID changes, the timestamp of the output POSITION will be updated as the time when DPGAPC function detects the change.

Refer to Table 23 for the description of the input-output relationship in terms of the value and the quality attributes.
### Table 23: Description of the input-output relationship

<table>
<thead>
<tr>
<th>VALID</th>
<th>OPEN</th>
<th>CLOSE</th>
<th>POSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Value</td>
</tr>
<tr>
<td>0</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

#### 10.4.3 Setting guidelines

The function does not have any parameters available in the local HMI or PCM600.

#### 10.5 Single point generic control 8 signals SPC8GAPC

##### 10.5.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single point generic control 8 signals</td>
<td>SPC8GAPC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

##### 10.5.2 Application

The Single point generic control 8 signals (SPC8GAPC) function block is a collection of 8 single point commands that can be used for direct commands for example reset of LED’s or putting IED in "ChangeLock" state from remote. In this way, simple commands can be sent directly to the IED outputs, without confirmation. Confirmation (status) of the result of the commands is supposed to be achieved by other means, such as binary inputs and SPGAPC function blocks.

PSTO is the universal operator place selector for all control functions. Even if PSTO can be configured to allow LOCAL or ALL operator positions, the only functional position usable with the SPC8GAPC function block is REMOTE.

##### 10.5.3 Setting guidelines

The parameters for the single point generic control 8 signals (SPC8GAPC) function are set via the local HMI or PCM600.

*Operation:* turning the function operation **On/ Off**.

There are two settings for every command output (totally 8):

- **PulseModex:** decides if the command signal for output $x$ is **Latched** (steady) or **Pulsed**.
- **tPulsex:** if **PulseModex** is set to **Pulsed**, then **tPulsex** will set the length of the pulse (in seconds).
### 10.6 AutomationBits, command function for DNP3.0

#### 10.6.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>AutomationBits, command function for DNP3</td>
<td>AUTOBITS</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 10.6.2 Application

AutomationBits, command function for DNP3 (AUTOBITS) is used within PCM600 in order to get into the configuration the commands coming through the DNP3.0 protocol. The AUTOBITS function plays the same role as functions GOOSEBINRCV (for IEC 61850) and MULTICMDRCV (for LON). AUTOBITS function block have 32 individual outputs which each can be mapped as a Binary Output point in DNP3. The output is operated by a "Object 12" in DNP3. This object contains parameters for control-code, count, on-time and off-time. To operate an AUTOBITS output point, send a control-code of latch-On, latch-Off, pulse-On, pulse-Off, Trip or Close. The remaining parameters are regarded as appropriate. For example, pulse-On, on-time=100, off-time=300, count=5 would give 5 positive 100 ms pulses, 300 ms apart.

For description of the DNP3 protocol implementation, refer to the Communication manual.

#### 10.6.3 Setting guidelines

AUTOBITS function block has one setting, *(Operation: On/Off)* enabling or disabling the function. These names will be seen in the DNP3 communication management tool in PCM600.

### 10.7 Single command, 16 signals SINGLECMD

#### 10.7.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single command, 16 signals</td>
<td>SINGLECMD</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 10.7.2 Application

Single command, 16 signals (SINGLECMD) is a common function and always included in the IED.

The IEDs may be provided with a function to receive commands either from a substation automation system or from the local HMI. That receiving function block has outputs that can be used, for example, to control high voltage apparatuses in switchyards. For local control functions, the local HMI can also be used. Together with the configuration logic circuits, the
user can govern pulses or steady output signals for control purposes within the IED or via binary outputs.

Figure 60 shows an application example of how the user can connect SINGLECMD via configuration logic circuit to control a high-voltage apparatus. This type of command control is normally carried out by sending a pulse to the binary outputs of the IED. Figure 60 shows a close operation. An open breaker operation is performed in a similar way but without the synchro-check condition.

![Diagram of single command function](en04000206.vsd)

**Figure 60:** Application example showing a logic diagram for control of a circuit breaker via configuration logic circuits

Figure 61 and figure 62 show other ways to control functions, which require steady On/Off signals. Here, the output is used to control built-in functions or external devices.

![Diagram of single command function](en04000207.vsd)

**Figure 61:** Application example showing a logic diagram for control of built-in functions
10.7.3 Setting guidelines

The parameters for Single command, 16 signals (SINGLECMD) are set via the local HMI or PCM600.

Parameters to be set are MODE, common for the whole block, and CMDOUTy which includes the user defined name for each output signal. The MODE input sets the outputs to be one of the types Off, Steady, or Pulse.

- Off, sets all outputs to 0, independent of the values sent from the station level, that is, the operator station or remote-control gateway.
- Steady, sets the outputs to a steady signal 0 or 1, depending on the values sent from the station level.
- Pulse, gives a pulse with 100 ms duration, if a value sent from the station level is changed from 0 to 1. That means the configured logic connected to the command function block may not have a cycle time longer than the cycle time for the command function block.
Section 11 Logic

11.1 Tripping logic SMPPTRC

11.1.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tripping logic</td>
<td>SMPPTRC</td>
<td>1 \rightarrow 0</td>
<td>94</td>
</tr>
</tbody>
</table>

11.1.2 Application

All trip signals from the different protection functions shall be routed through the trip logic. All start signals and directional information can be routed through the trip logic as well. In its simplest form, the trip logic will only link the TRIP signal to a binary output and make sure that the pulse time is long enough.

Tripping logic SMPPTRC offers three different operating modes:

- Three-phase tripping for all fault types (3ph operating mode)
- Single-phase tripping for single-phase faults and three-phase tripping for multi-phase and evolving faults (1ph/3ph operating mode).
- Single-phase tripping for single-phase faults, two-phase tripping for two-phase faults and three-phase tripping for three-phase faults (1ph/2ph/3ph operating mode).

If the OHL is connected to the substation via more than one breaker, one SMPPTRC function block should be used for each breaker. For example when single-phase tripping and autoreclosing is used on the line, both breakers are normally set up for 1/3-phase tripping and 1/3-phase autoreclosing. Alternatively, the breaker chosen as master can have single-phase tripping, while the slave breaker could have three-phase tripping and autoreclosing. In the case of a permanent fault, only one of the breakers has to be operated when the fault is energized a second time. In the event of a transient fault the slave breaker performs a three-phase reclosing onto the non-faulted line.

The same philosophy can be used for two-phase tripping and autoreclosing.

To prevent closing of a circuit breaker after a trip, the function offers a lockout function.

11.1.2.1 Three-phase tripping

Connect the inputs from the protection functions to the input TRIN. The TMGAPC function block is used to combine up to 32 inputs into one output. Connect the output TRIP to the binary outputs on the IO board.

This signal can also be used for other purposes internally in the IED. An example could be the starting of breaker failure protection. The three outputs TRL1, TRL2, TRL3 will always be activated at every trip and can be utilized on individual trip outputs if single-phase operating
devices are available on the circuit breaker even when a three-phase tripping scheme is selected.

Set the function block to Program = 3 phase and set the required length of the trip pulse to for example, \( t_{TripMin} = 150\text{ms} \).

The typical connection is shown below in figure 63.

**Figure 63:** Tripping logic SMPPTRC is used for a simple three-phase tripping application

### 11.1.2.2 Single- and/or three-phase tripping

The single-/three-phase tripping operation mode will give single-phase tripping for single-phase faults and three-phase tripping for multi-phase fault. This operating mode is always used together with a single-phase autoreclosing scheme.

The single-phase tripping operation mode can include different options and the use of the different inputs in the function block. Inputs TRINL1, TRINL2 and TRINL3 shall be used for trip signals from functions with built-in phase selection logic such as distance or line differential protection functions.

The inputs 1PTRZ and 1PTREF are used for single-phase tripping from functions which do not have built-in phase selection logic:

- 1PTRZ can be connected to the carrier aided trip signal from the distance protection scheme (it means that another distance protection function has seen or detected the fault)
- 1PTREF can be connected to an earth fault function such as EF4PTOC or a carrier aided trip signal from the earth fault protection scheme

These two inputs are combined with the external phase selection logic. Phase selection signals from the external phase selector must be connected to the inputs PSL1, PSL2 and PSL3 to achieve the tripping on the respective single-phase trip outputs TRL1, TRL2 and TRL3. The output TRIP is a general trip and is always activated independent of which phase is involved. Depending on which phases are involved the outputs TR1P, TR2P and TR3P will be activated as well.

When single-phase tripping schemes are used, a single-phase autoreclosing attempt is expected to follow. For cases where the autoreclosing is not in service or will not follow for some reason, the input prepare three-phase trip P3PTR must be activated. This input is
normally connected to the output PREP3P on the autorecloser function SMBRREC but can also be connected to other signals, for example, an external logic signal. If two circuit breakers are involved, one SMPPTRC block instance and one SMBRREC instance are used for each circuit breaker. This will ensure correct operation and behavior of each circuit breaker.

The output TR3P must be connected to the input TR3P on the SMBRREC function in order to switch SMBRREC to perform a three-phase reclosing. If this signal is not activated, SMBRREC will use single-phase dead time.

If a second line protection is utilizing the same SMBRREC, the three-phase trip signal must be generated as OR conditions from both line protections.

Other back-up functions are connected to the input TRIN as described above for three-phase tripping. A typical connection for a single-phase tripping scheme is shown in figure 64.

**Figure 64: The trip logic function SMPPTRC used for single-phase tripping application**

### 11.1.2.3 Single-, two- or three-phase tripping

The single-/two-/three-phase tripping mode provides single-phase tripping for single-phase faults, two-phase tripping for two-phase faults and three-phase tripping for three-phase faults. The operating mode is always used together with an autoreclosing scheme with setting $\text{ARMode} = 1/2/3 \text{ ph}$ or $\text{ARMode} = 1/2 \text{ ph}$. 

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The functionality is very similar to the single-phase scheme described above. However, in addition to the connections for single phase SMBRREC must also be informed that the trip is two phases by connecting the output TR2P to the input TR2P in the SMBRREC function.

### 11.1.2.4 Lock-out

The SMPPTRC function block is provided with possibilities to initiate lock-out. The lock-out can be set to only activate the block closing output CLLKOUT or initiate the block closing output and also maintain the trip signal output TR3P (latched trip).

The lock-out can then be manually reset after checking the primary fault by activating the input reset lock-out RSTLKOUT.

If external conditions are required to initiate a closing circuit lock-out but not to lockout trip, this can be achieved by activating input SETLKOUT. The setting AutoLock = Off means that the internal trip will not activate lock-out so only initiation of the input SETLKOUT will result in lock-out. This is normally the case for overhead line protection where most faults are transient. Unsuccessful autoreclose and back-up zone tripping can in such cases be connected to initiate lock-out by activating the input SETLKOUT.

### 11.1.2.5 Example of directional data

An example how to connect the directional data from different application functions to the trip function is given below, see Figure 65:
Figure 65: Example of the connection of directional start logic

The Start Matrix (SMAGAPC) merges start and directional output signals from different application functions and creates a common directional output signal (STDIR) to be connected to the Trip function (SMPPTRC). Protection functions connect their directional data via the STARTCOMB function to SMAGAPC and then to the SMPPTRC, or directly to SMAGAPC and then to the SMPPTRC.

The trip function (SMPPTRC) splits up the directional data as general output data for START, STL1, STL2, STL3, STN, FW and REV.

All start and directional outputs are mapped to the logical node data model of the trip function and provided via the IEC 61850 attributes dirGeneral, DIRL1, DIRL2, DIRL3 and DIRN.
11.1.2.6 Blocking of the function block

Total block of the trip function is done by activating the input BLOCK and can be used to disable the outputs of the trip logic in the event of internal failures. Block of lock-out output is achieved by activating the input BLKLKOUT.

11.1.3 Setting guidelines

The parameters for tripping logic SMPPTRC are set via the local HMI or PCM600.

*Operation*: Sets the mode of operation. *Off* switches the tripping off. The normal selection is *On*.

*Program*: Sets the required tripping scheme. Normally 3 phase or 1ph/3ph is used.

*TripLockout*: Sets the scheme for lock-out. *Off* only activates the closing circuit lock-out output. *On* activates the closing circuit lock-out output and latches the TRIP related outputs. The normal selection is *Off*.

*AutoLock*: Sets the scheme for lock-out. *Off* only activates lock-out through the input SETLKOUT. *On* additionally allows lock-out activation via the trip inputs. The normal selection is *Off*.

*tTripMin*: Sets the required minimum duration of the trip pulse. It should be set to ensure that the circuit breaker is opened correctly. The normal setting is 0.150s.

*tWaitForPHS*: Sets a duration during which external phase selection must operate in order to get a single phase trip, after any of the inputs 1PTRZ or 1PTREF has been activated. If no phase selection has been achieved, a three-phase trip will be issued after this time has elapsed.

*tEvolvingFault*: Secures two- or three-pole tripping depending on *Program* selection during evolving faults.

11.2 Trip matrix logic TMAGAPC

11.2.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trip matrix logic</td>
<td>TMAGAPC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

11.2.2 Application

The trip matrix logic (TMAGAPC) function is used to route trip signals and other logical output signals to different output contacts on the IED.

The trip matrix logic function has 3 output signals and these outputs can be connected to physical tripping outputs according to the specific application needs for settable pulse or steady output.
11.2.3 Setting guidelines

**Operation:** Operation of function **On/Off**.

**PulseTime:** Defines the pulse time when in **Pulsed** mode. When used for direct tripping of circuit breaker(s) the pulse time delay shall be set to approximately 0.150 seconds in order to obtain satisfactory minimum duration of the trip pulse to the circuit breaker trip coils.

**OnDelay:** Used to prevent output signals to be given for spurious inputs. Normally set to 0 or a low value.

**OffDelay:** Defines a delay of the reset of the outputs after the activation conditions no longer are fulfilled. It is only used in **Steady** mode. When used for direct tripping of circuit breaker(s) the off delay time shall be set to at least 0.150 seconds in order to obtain a satisfactory minimum duration of the trip pulse to the circuit breaker trip coils.

**ModeOutputx:** Defines if output signal **OUTPUTx** (where x=1-3) is **Steady** or **Pulsed**.

11.3 Logic for group alarm ALMCALH

11.3.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logic for group alarm</td>
<td>ALMCALH</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

11.3.2 Application

Group alarm logic function ALMCALH is used to route alarm signals to different LEDs and/or output contacts on the IED.

ALMCALH output signal and the physical outputs allows the user to adapt the alarm signal to physical tripping outputs according to the specific application needs.

11.3.3 Setting guidelines

**Operation:** **On** or **Off**

11.4 Logic for group alarm WRNCALH

11.4.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logic for group warning</td>
<td>WRNCALH</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

11.4.1.1 Application

Group warning logic function WRNCALH is used to route warning signals to LEDs and/or output contacts on the IED.
WRNCALH output signal WARNING and the physical outputs allows the user to adapt the warning signal to physical tripping outputs according to the specific application needs.

### Setting guidelines

**Operation**: On or Off

### Logic for group indication INDCALH

#### Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logic for group indication</td>
<td>INDCALH</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### Application

Group indication logic function INDCALH is used to route indication signals to different LEDs and/or output contacts on the IED.

INDCALH output signal IND and the physical outputs allows the user to adapt the indication signal to physical outputs according to the specific application needs.

#### Setting guidelines

**Operation**: On or Off

### Configurable logic blocks

The configurable logic blocks are available in two categories:

- Configurable logic blocks that do not propagate the time stamp and the quality of signals. They do not have the suffix QT at the end of their function block name, for example, SRMEMORY. These logic blocks are also available as part of an extension logic package with the same number of instances.
- Configurable logic blocks that propagate the time stamp and the quality of signals. They have the suffix QT at the end of their function block name, for example, SRMEMORYQT.

#### Application

A set of standard logic blocks, like AND, OR etc, and timers are available for adapting the IED configuration to the specific application needs.

#### Setting guidelines

There are no settings for AND gates, OR gates, inverters or XOR gates.

For normal On/Off delay and pulse timers the time delays and pulse lengths are set from the local HMI or via the PST tool.
Both timers in the same logic block (the one delayed on pick-up and the one delayed on drop-out) always have a common setting value.

For controllable gates, settable timers and SR flip-flops with memory, the setting parameters are accessible via the local HMI or via the PST tool.

### 11.6.2.1 Configuration

Logic is configured using the ACT configuration tool in PCM600.

Execution of functions as defined by the configurable logic blocks runs according to a fixed sequence with different cycle times.

For each cycle time, the function block is given an serial execution number. This is shown when using the ACT configuration tool with the designation of the function block and the cycle time, see example below.

![Function Block Instance](image)

*Figure 66: Example designation, serial execution number and cycle time for logic function*

The execution of different function blocks within the same cycle is determined by the order of their serial execution numbers. Always remember this when connecting two or more logical function blocks in series.

Always be careful when connecting function blocks with a fast cycle time to function blocks with a slow cycle time. Remember to design the logic circuits carefully and always check the execution sequence for different functions. In other cases, additional time delays must be introduced into the logic schemes to prevent errors, for example, race between functions.

### 11.7 Fixed signal function block FXDSIGN

#### 11.7.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed signals</td>
<td>FXDSIGN</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
11.7.2 Application

The Fixed signals function (FXDSIGN) has nine pre-set (fixed) signals that can be used in the configuration of an IED, either for forcing the unused inputs in other function blocks to a certain level/value, or for creating certain logic. Boolean, integer, floating point, string types of signals are available.

One FXDSIGN function block is included in all IEDs.

**Example for use of GRP_OFF signal in FXDSIGN**

The Restricted earth fault function (REFPDIF) can be used both for auto-transformers and normal transformers.

When used for auto-transformers, information from both windings parts, together with the neutral point current, needs to be available to the function. This means that three inputs are needed.

**Figure 67: REFPDIF function inputs for autotransformer application**

For normal transformers only one winding and the neutral point is available. This means that only two inputs are used. Since all group connections are mandatory to be connected, the third input needs to be connected to something, which is the GRP_OFF signal in FXDSIGN function block.

**Figure 68: REFPDIF function inputs for normal transformer application**
11.8  Boolean 16 to Integer conversion B16I

11.8.1  Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boolean 16 to integer conversion</td>
<td>B16I</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

11.8.2  Application

Boolean 16 to integer conversion function B16I is used to transform a set of 16 binary (logical) signals into an integer. It can be used – for example, to connect logical output signals from a function (like distance protection) to integer inputs from another function (like line differential protection). B16I does not have a logical node mapping.

The Boolean 16 to integer conversion function (B16I) will transfer a combination of up to 16 binary inputs INx where 1≤x≤16 to an integer. Each INx represents a value according to the table below from 0 to 32768. This follows the general formula: \( \text{INx} = 2^{x-1} \) where 1≤x≤16. The sum of all the values on the activated INx will be available on the output OUT as a sum of the values of all the inputs INx that are activated. OUT is an integer. When all INx where 1≤x≤16 are activated that is = Boolean 1 it corresponds to that integer 65535 is available on the output OUT. B16I function is designed for receiving up to 16 booleans input locally. If the BLOCK input is activated, it will freeze the output at the last value.

Values of each of the different OUTx from function block B16I for 1≤x≤16.

The sum of the value on each INx corresponds to the integer presented on the output OUT on the function block B16I.

<table>
<thead>
<tr>
<th>Name of input</th>
<th>Type</th>
<th>Default</th>
<th>Description</th>
<th>Value when activated</th>
<th>Value when deactivated</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN1</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>IN2</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>IN3</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 3</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>IN4</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 4</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>IN5</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 5</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>IN6</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 6</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td>IN7</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 7</td>
<td>64</td>
<td>0</td>
</tr>
<tr>
<td>IN8</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 8</td>
<td>128</td>
<td>0</td>
</tr>
<tr>
<td>IN9</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 9</td>
<td>256</td>
<td>0</td>
</tr>
<tr>
<td>IN10</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 10</td>
<td>512</td>
<td>0</td>
</tr>
<tr>
<td>IN11</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 11</td>
<td>1024</td>
<td>0</td>
</tr>
<tr>
<td>IN12</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 12</td>
<td>2048</td>
<td>0</td>
</tr>
<tr>
<td>IN13</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 13</td>
<td>4096</td>
<td>0</td>
</tr>
<tr>
<td>IN14</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 14</td>
<td>8192</td>
<td>0</td>
</tr>
<tr>
<td>IN15</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 15</td>
<td>16384</td>
<td>0</td>
</tr>
<tr>
<td>IN16</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 16</td>
<td>32768</td>
<td>0</td>
</tr>
</tbody>
</table>
The sum of the numbers in column "Value when activated" when all INx (where 1≤x≤16) are active that is=1; is 65535. 65535 is the highest boolean value that can be converted to an integer by the B16I function block.

## 11.9 Boolean to integer conversion with logical node representation, 16 bit BTIGAPC

### 11.9.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boolean to integer conversion with logical node representation, 16 bit</td>
<td>BTIGAPC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

### 11.9.2 Application

Boolean to integer conversion with logical node representation, 16 bit (BTIGAPC) is used to transform a set of 16 binary (logical) signals into an integer. BTIGAPC has a logical node mapping in IEC 61850.

The BTIGAPC function will transfer a combination of up to 16 binary inputs INx where 1≤x≤16 to an integer. Each INx represents a value according to the table below from 0 to 32768. This follows the general formula: INx = 2^{x-1} where 1≤x≤16. The sum of all the values on the activated INx will be available on the output OUT as a sum of the values of all the inputs INx that are activated. OUT is an integer. When all INx where 1≤x≤16 are activated that is = Boolean 1 it corresponds to that integer 65535 is available on the output OUT. BTIGAPC function is designed for receiving up to 16 booleans input locally. If the BLOCK input is activated, it will freeze the output at the last value.

Values of each of the different OUTx from function block BTIGAPC for 1≤x≤16.

The sum of the value on each INx corresponds to the integer presented on the output OUT on the function block BTIGAPC.

<table>
<thead>
<tr>
<th>Name of input</th>
<th>Type</th>
<th>Default</th>
<th>Description</th>
<th>Value when activated</th>
<th>Value when deactivated</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN1</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>IN2</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>IN3</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 3</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>IN4</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 4</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>IN5</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 5</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>IN6</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 6</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td>IN7</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 7</td>
<td>64</td>
<td>0</td>
</tr>
<tr>
<td>IN8</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 8</td>
<td>128</td>
<td>0</td>
</tr>
<tr>
<td>IN9</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 9</td>
<td>256</td>
<td>0</td>
</tr>
<tr>
<td>IN10</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 10</td>
<td>512</td>
<td>0</td>
</tr>
<tr>
<td>IN11</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 11</td>
<td>1024</td>
<td>0</td>
</tr>
<tr>
<td>IN12</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 12</td>
<td>2048</td>
<td>0</td>
</tr>
</tbody>
</table>

Table continues on next page

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<table>
<thead>
<tr>
<th>Name of input</th>
<th>Type</th>
<th>Default</th>
<th>Description</th>
<th>Value when activated</th>
<th>Value when deactivated</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN13</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 13</td>
<td>4096</td>
<td>0</td>
</tr>
<tr>
<td>IN14</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 14</td>
<td>8192</td>
<td>0</td>
</tr>
<tr>
<td>IN15</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 15</td>
<td>16384</td>
<td>0</td>
</tr>
<tr>
<td>IN16</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 16</td>
<td>32768</td>
<td>0</td>
</tr>
</tbody>
</table>

The sum of the numbers in column “Value when activated” when all INx (where 1≤x≤16) are active that is=1; is 65535. 65535 is the highest boolean value that can be converted to an integer by the BTIGAPC function block.

### 11.10 Integer to Boolean 16 conversion IB16

#### 11.10.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integer to boolean 16 conversion</td>
<td>IB16</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 11.10.2 Application

Integer to boolean 16 conversion function (IB16) is used to transform an integer into a set of 16 binary (logical) signals. It can be used – for example, to connect integer output signals from one function to binary (logical) inputs to another function. IB16 function does not have a logical node mapping.

The Boolean 16 to integer conversion function (IB16) will transfer a combination of up to 16 binary inputs INx where 1≤x≤16 to an integer. Each INx represents a value according to the table below from 0 to 32768. This follows the general formula: INx = 2^{x-1} where 1≤x≤16. The sum of all the values on the activated INx will be available on the output OUT as a sum of the values of all the inputs INx that are activated. OUT is an integer. When all INx where 1≤x≤16 are activated that is = Boolean 1 it corresponds to that integer 65535 is available on the output OUT. IB16 function is designed for receiving up to 16 booleans input locally. If the BLOCK input is activated, it will freeze the output at the last value.

Values of each of the different OUTx from function block IB16 for 1≤x≤16.

The sum of the value on each INx corresponds to the integer presented on the output OUT on the function block IB16.

<table>
<thead>
<tr>
<th>Name of input</th>
<th>Type</th>
<th>Default</th>
<th>Description</th>
<th>Value when activated</th>
<th>Value when deactivated</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN1</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>IN2</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>IN3</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 3</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>IN4</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 4</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>IN5</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 5</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>IN6</td>
<td>BOOLEAN</td>
<td>0</td>
<td>Input 6</td>
<td>32</td>
<td>0</td>
</tr>
</tbody>
</table>

Table continues on next page
### Name of input | Type | Default | Description | Value when activated | Value when deactivated
---|---|---|---|---|---
IN7 | BOOLEAN | 0 | Input 7 | 64 | 0
IN8 | BOOLEAN | 0 | Input 8 | 128 | 0
IN9 | BOOLEAN | 0 | Input 9 | 256 | 0
IN10 | BOOLEAN | 0 | Input 10 | 512 | 0
IN11 | BOOLEAN | 0 | Input 11 | 1024 | 0
IN12 | BOOLEAN | 0 | Input 12 | 2048 | 0
IN13 | BOOLEAN | 0 | Input 13 | 4096 | 0
IN14 | BOOLEAN | 0 | Input 14 | 8192 | 0
IN15 | BOOLEAN | 0 | Input 15 | 16384 | 0
IN16 | BOOLEAN | 0 | Input 16 | 32768 | 0

The sum of the numbers in column “Value when activated” when all INx (where 1≤x≤16) are active that is = 1, is 65535. 65535 is the highest boolean value that can be converted to an integer by the IB16 function block.

### 11.11 Integer to Boolean 16 conversion with logic node representation ITBGAPC

#### 11.11.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integer to boolean 16 conversion with logic node representation</td>
<td>ITBGAPC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 11.11.2 Application

Integer to boolean 16 conversion with logic node representation function (ITBGAPC) is used to transform an integer into a set of 16 boolean signals. ITBGAPC function can receive an integer from a station computer – for example, over IEC 61850–8–1. This function is very useful when the user wants to generate logical commands (for selector switches or voltage controllers) by inputting an integer number. ITBGAPC function has a logical node mapping in IEC 61850.

The Integer to Boolean 16 conversion with logic node representation function (ITBGAPC) will transfer an integer with a value between 0 to 65535 communicated via IEC 61850 and connected to the ITBGAPC function block to a combination of activated outputs OUTx where 1≤x≤16.

The values of the different OUTx are according to the Table 24.

If the BLOCK input is activated, it freezes the logical outputs at the last value.
### Table 24: Output signals

<table>
<thead>
<tr>
<th>Name of OUTx</th>
<th>Type</th>
<th>Description</th>
<th>Value when activated</th>
<th>Value when deactivated</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUT1</td>
<td>BOOLEAN</td>
<td>Output 1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>OUT2</td>
<td>BOOLEAN</td>
<td>Output 2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>OUT3</td>
<td>BOOLEAN</td>
<td>Output 3</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>OUT4</td>
<td>BOOLEAN</td>
<td>Output 4</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>OUT5</td>
<td>BOOLEAN</td>
<td>Output 5</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>OUT6</td>
<td>BOOLEAN</td>
<td>Output 6</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td>OUT7</td>
<td>BOOLEAN</td>
<td>Output 7</td>
<td>64</td>
<td>0</td>
</tr>
<tr>
<td>OUT8</td>
<td>BOOLEAN</td>
<td>Output 8</td>
<td>128</td>
<td>0</td>
</tr>
<tr>
<td>OUT9</td>
<td>BOOLEAN</td>
<td>Output 9</td>
<td>256</td>
<td>0</td>
</tr>
<tr>
<td>OUT10</td>
<td>BOOLEAN</td>
<td>Output 10</td>
<td>512</td>
<td>0</td>
</tr>
<tr>
<td>OUT11</td>
<td>BOOLEAN</td>
<td>Output 11</td>
<td>1024</td>
<td>0</td>
</tr>
<tr>
<td>OUT12</td>
<td>BOOLEAN</td>
<td>Output 12</td>
<td>2048</td>
<td>0</td>
</tr>
<tr>
<td>OUT13</td>
<td>BOOLEAN</td>
<td>Output 13</td>
<td>4096</td>
<td>0</td>
</tr>
<tr>
<td>OUT14</td>
<td>BOOLEAN</td>
<td>Output 14</td>
<td>8192</td>
<td>0</td>
</tr>
<tr>
<td>OUT15</td>
<td>BOOLEAN</td>
<td>Output 15</td>
<td>16384</td>
<td>0</td>
</tr>
<tr>
<td>OUT16</td>
<td>BOOLEAN</td>
<td>Output 16</td>
<td>32768</td>
<td>0</td>
</tr>
</tbody>
</table>

The sum of the numbers in column “Value when activated” when all OUTx (1≤x≤16) are active equals 65535. This is the highest integer that can be converted by the ITBGAPC function block.

11.12 Elapsed time integrator with limit transgression and overflow supervision TEIGAPC

11.12.1 Identification

<table>
<thead>
<tr>
<th>Function Description</th>
<th>IEC 61850 identification</th>
<th>IEC 60817 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elapsed time integrator</td>
<td>TEIGAPC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

11.12.2 Application

The function TEIGAPC is used for user-defined logics and it can also be used for different purposes internally in the IED. An application example is the integration of elapsed time during the measurement of neutral point voltage or neutral current at earth-fault conditions.

Settable time limits for warning and alarm are provided. The time limit for overflow indication is fixed to 999999.9 seconds.

11.12.3 Setting guidelines

The settings tAlarm and tWarning are user settable limits defined in seconds. The achievable resolution of the settings depends on the level of the values defined.
A resolution of 10 ms can be achieved when the settings are defined within the range

\[ 1.00 \text{ second} \leq t_{\text{Alarm}} \leq 99 \ 999.99 \text{ seconds} \]

\[ 1.00 \text{ second} \leq t_{\text{Warning}} \leq 99 \ 999.99 \text{ seconds} \]

If the values are above this range, the resolution becomes lower due to the 32 bit float representation

\[ 99 \ 999.99 \text{ seconds} < t_{\text{Alarm}} \leq 999 \ 999.0 \text{ seconds} \]

\[ 99 \ 999.99 \text{ seconds} < t_{\text{Warning}} \leq 999 \ 999.0 \text{ seconds} \]

Note that \( t_{\text{Alarm}} \) and \( t_{\text{Warning}} \) are independent settings, that is, there is no check if \( t_{\text{Alarm}} > t_{\text{Warning}} \).

The limit for the overflow supervision is fixed at 999999.9 seconds.

### 11.13 Comparator for integer inputs - INTCOMP

#### 11.13.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparison of integer values</td>
<td>INTCOMP</td>
<td>Int&lt;=</td>
<td></td>
</tr>
</tbody>
</table>

#### 11.13.2 Application

The function gives the possibility to monitor the level of integer values in the system relative to each other or to a fixed value. It is a basic arithmetic function that can be used for monitoring, supervision, interlocking and other logics.

#### 11.13.3 Setting guidelines

For proper operation of comparison the set value should be set within the range of \( \pm 2 \times 10^9 \).

Setting procedure on the IED:

**EnaAbs**: This setting is used to select the comparison type between signed and absolute values.

- **Absolute**: Comparison is performed on absolute values of input and reference values
- **Signed**: Comparison is performed on signed values of input and reference values.

**RefSource**: This setting is used to select the reference source between input and setting for comparison.

- **Input REF**: The function will take reference value from input REF
- **Set Value**: The function will take reference value from setting **SetValue**

**SetValue**: This setting is used to set the reference value for comparison when setting **RefSource** is selected as **SetValue**.
11.13.4 Setting example

For absolute comparison between inputs:
Set the EnaAbs = Absolute
Set the RefSource = Input REF

Similarly for Signed comparison between inputs
Set the EnaAbs = Signed
Set the RefSource = Input REF

For absolute comparison between input and setting
Set the EnaAbs = Absolute
Set the RefSource = Set Value

SetValue shall be set between -2000000000 to 2000000000

Similarly for signed comparison between input and setting
Set the EnaAbs = Signed
Set the RefSource = Set Value

SetValue shall be set between -2000000000 to 2000000000

11.14 Comparator for real inputs - REALCOMP

11.14.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparator for real inputs</td>
<td>REALCOMP</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

11.14.2 Application

The function gives the possibility to monitor the level of real values in the system relative to each other or to a fixed value. It is a basic arithmetic function that can be used for monitoring, supervision, interlocking and other logics.

11.14.3 Setting guidelines

Setting procedure on the IED:

EnaAbs: This setting is used to select the comparison type between signed and absolute values.
- Absolute: Comparison is performed with absolute values of input and reference.
- Signed: Comparison is performed with signed values of input and reference.
RefSource: This setting is used to select the reference source between input and setting for comparison.

- Input REF: The function will take reference value from input REF
- Set Value: The function will take reference value from setting SetValue

SetValue: This setting is used to set the reference value for comparison when setting RefSource is selected as Set Value. If this setting value is less than 0.2% of the set unit then the output INLOW will never pickup.

RefPrefix: This setting is used to set the unit of the reference value for comparison when setting RefSource is selected as Set Value. It has 5 unit selections and they are Milli, Unity, Kilo, Mega and Giga.

EqualBandHigh: This setting is used to set the equal condition high band limit in % of reference value. This high band limit will act as reset limit for INHIGH output when INHIGH.

EqualBandLow: This setting is used to set the equal condition low band limit in % of reference value. This low band limit will act as reset limit for INLOW output when INLOW.

11.14.4 Setting example

Let us consider a comparison is to be done between current magnitudes in the range of 90 to 110 with nominal rating is 100 and the order is kA.

For the above condition the comparator can be designed with settings as follows,

- EnaAbs = Absolute
- RefSource = Set Value
- SetValue = 100
- RefPrefix = Kilo
- EqualBandHigh = 5.0 % of reference value
- EqualBandLow = 5.0 % of reference value

Operation

The function will set the outputs for the following conditions,

INEQUAL will set when the INPUT is between the ranges of 95 to 105 kA.

INHIGH will set when the INPUT crosses above 105 kA.

INLOW will set when the INPUT crosses below 95 kA.

If the comparison should be done between two current magnitudes then those current signals need to be connected to function inputs, INPUT and REF. Then the settings should be adjusted as below,

- EnaAbs = Absolute
- RefSource = Input REF
- EqualBandHigh = 5.0 % of reference value
EqualBandLow = 5.0 % of reference value.
Section 12  Monitoring

12.1  Measurement

12.1.1  Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power system measurements</td>
<td>CVMMXN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase current measurement</td>
<td>CMMXU</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>Phase-phase voltage measurement</td>
<td>VMMXU</td>
<td>U</td>
<td></td>
</tr>
<tr>
<td>Current sequence component measurement</td>
<td>CMSQI</td>
<td>I1, I2, I0</td>
<td></td>
</tr>
<tr>
<td>Voltage sequence component measurement</td>
<td>VMSQI</td>
<td>U1, U2, U0</td>
<td></td>
</tr>
<tr>
<td>Phase-neutral voltage measurement</td>
<td>VNMMXU</td>
<td>U</td>
<td></td>
</tr>
</tbody>
</table>

12.1.2  Application

Measurement functions are used for power system measurement, supervision and reporting to the local HMI, monitoring tool within PCM600 or to station level for example, via IEC 61850. The possibility to continuously monitor measured values of active power, reactive power, currents, voltages, frequency, power factor etc. is vital for efficient production, transmission and distribution of electrical energy. It provides to the system operator fast and easy overview of the present status of the power system. Additionally, it can be used during testing and commissioning of protection and control IEDs in order to verify proper operation and connection of instrument transformers (CTs and VTs). During normal service by periodic comparison of the measured value from the IED with other independent meters the proper operation of the IED analog measurement chain can be verified. Finally, it can be used to verify proper direction orientation for distance or directional overcurrent protection function.
The available measured values from an IED are depending on the actual hardware (TRM) and the logic configuration made in PCM600.

All measured values can be supervised with four settable limits that is, low-low limit, low limit, high limit and high-high limit. A zero clamping reduction is also supported, that is, the measured value below a settable limit is forced to zero which reduces the impact of noise in the inputs.

Dead-band supervision can be used to report measured signal value to station level when change in measured value is above set threshold limit or time integral of all changes since the last time value updating exceeds the threshold limit. Measure value can also be based on periodic reporting.

**Main menu/Measurement/Monitoring/Service values/CVMMXN**

The measurement function, CVMMXN, provides the following power system quantities:

- P, Q and S: three phase active, reactive and apparent power
- PF: power factor
- U: phase-to-phase voltage amplitude
- I: phase current amplitude
- F: power system frequency

The measuring functions CMMXU, VMMXU and VNMMXU provide physical quantities:

- I: phase currents (amplitude and angle) (CMMXU)
- U: voltages (phase-to-earth and phase-to-phase voltage, amplitude and angle) (VMMXU, VNMMXU)

The CVMMXN function calculates three-phase power quantities by using fundamental frequency phasors (DFT values) of the measured current and voltage signals. The measured power quantities are available either, as instantaneously calculated quantities or, averaged values over a period of time (low pass filtered) depending on the selected settings.

It is possible to calibrate the measuring function above to get better then class 0.5 presentation. This is accomplished by angle and amplitude compensation at 5, 30 and 100% of rated current and at 100% of rated voltage.

The power system quantities provided, depends on the actual hardware, (TRM) and the logic configuration made in PCM600.

The measuring functions CMSQI and VMSQI provide sequence component quantities:

- I: sequence currents (positive, zero, negative sequence, amplitude and angle)
- U: sequence voltages (positive, zero and negative sequence, amplitude and angle).

### 12.1.3 Zero clamping

Measuring functions CVMMXN, CMMXU, VMMXU and VNMMXU have no interconnections regarding any settings or parameters.

Zero clampings are also handled entirely by ZeroDb separately for each function's every output signal. For example, zero clamping of U12 is handled by UL12ZeroDb in VMMXU, zero clamping of I1 is handled by IL1ZeroDb in CMMXU, and so on.
Example of CVMMXN operation

Outputs seen on the local HMI under Main menu/Measurements/Monitoring/Servicevalues(P_Q)/CVMMXN(P_Q):

<table>
<thead>
<tr>
<th>S</th>
<th>Apparent three-phase power</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>Active three-phase power</td>
</tr>
<tr>
<td>Q</td>
<td>Reactive three-phase power</td>
</tr>
<tr>
<td>PF</td>
<td>Power factor</td>
</tr>
<tr>
<td>ILAG</td>
<td>I lagging U</td>
</tr>
<tr>
<td>ILEAD</td>
<td>I leading U</td>
</tr>
<tr>
<td>U</td>
<td>System mean voltage, calculated according to selected mode</td>
</tr>
<tr>
<td>I</td>
<td>System mean current, calculated according to selected mode</td>
</tr>
<tr>
<td>F</td>
<td>Frequency</td>
</tr>
</tbody>
</table>

Relevant settings and their values on the local HMI under Main menu/Settings/IED settings/Monitoring/Servicevalues(P_Q)/CVMMXN(P_Q):

- When system voltage falls below UGenZeroDb, values for S, P, Q, PF, ILAG, ILEAD, U and F are forced to zero.
- When system current falls below IGenZeroDb, values for S, P, Q, PF, ILAG, ILEAD, U and F are forced to zero.
- When the value of a single signal falls below its set deadband, the value is forced to zero. For example, if the apparent three-phase power falls below SZeroDb, the value for S is forced to zero.

12.1.4 Setting guidelines

The available setting parameters of the measurement function CVMMXN, CMMXU, VMMXU, CMSQI, VMSQI, VNMMXU are depending on the actual hardware (TRM) and the logic configuration made in PCM600.

The parameters for the Measurement functions CVMMXN, CMMXU, VMMXU, CMSQI, VMSQI, VNMMXU are set via the local HMI or PCM600.

GlobalBaseSel: Selects the global base value group used by the function to define IBase, UBase and SBase.

Operation: Off/On. Every function instance (CVMMXN, CMMXU, VMMXU, CMSQI, VMSQI, VNMMXU) can be taken in operation (On) or out of operation (Off).

The following general settings can be set for the Measurement function (CVMMXN).

PowAmpFact: Amplitude factor to scale power calculations.

PowAngComp: Angle compensation for phase shift between measured I & U.

Mode: Selection of measured current and voltage. There are 9 different ways of calculating monitored three-phase values depending on the available VT inputs connected to the IED. See parameter group setting table.

k: Low pass filter coefficient for power measurement, U and I.

UGenZeroDb: Minimum level of voltage in % of UBase, used as indication of zero voltage (zero point clamping). If measured value is below UGenZeroDb calculated S, P, Q and PF will be zero.
IGenZeroDb: Minimum level of current in % of IBase, used as indication of zero current (zero point clamping). If measured value is below IGenZeroDb calculated S, P, Q and PF will be zero.

UAmpCompY: Amplitude compensation to calibrate voltage measurements at Y% of Ur, where Y is equal to 5, 30 or 100.

IAmpCompY: Amplitude compensation to calibrate current measurements at Y% of Ir, where Y is equal to 5, 30 or 100.

IAngCompY: Angle compensation to calibrate angle measurements at Y% of Ir, where Y is equal to 5, 30 or 100.

The following general settings can be set for the **Phase current measurement** (CMMXU).

IAmpCompY: Amplitude compensation to calibrate current measurements at Y% of Ir, where Y is equal to 5, 30 or 100.

IAngCompY: Angle compensation to calibrate angle measurements at Y% of Ir, where Y is equal to 5, 30 or 100.

The following general settings can be set for the **Phase-phase voltage measurement** (VMMXU).

UAmpCompY: Amplitude compensation to calibrate voltage measurements at Y% of Ur, where Y is equal to 5, 30 or 100.

UAngCompY: Angle compensation to calibrate angle measurements at Y% of Ur, where Y is equal to 5, 30 or 100.

The following general settings can be set for all monitored quantities included in the functions (CVMMXN, CMMXU, VMMXU, CMSQI, VMSQI, VNMMXU) X in setting names below equals S, P, Q, PF, U, I, F, IL1-3, UL1-3UL12-31, I1, I2, 3I0, U1, U2 or 3U0.

Xmin: Minimum value for analog signal X set directly in applicable measuring unit. This forms the minimum limit of the range.

Xmax: Maximum value for analog signal X. This forms the maximum limit of the range.

XZeroDb: Zero point clamping. A signal value less than XZeroDb is forced to zero.

Observe the related zero point clamping settings in Setting group N for CVMMXN (UGenZeroDb and IGenZeroDb). If measured value is below UGenZeroDb and/or IGenZeroDb calculated S, P, Q and PF will be zero and these settings will override XZeroDb.

XRepTyp: Reporting type. Cyclic (Cyclic), amplitude deadband (Dead band), integral deadband (Int deadband) or Deadband and xx se cyclic (xx: 5 sec, 30 sec, 1 min). The reporting interval is controlled by the parameter XDbReplnt.

XDbReplnt: This setting handles all the reporting types. If setting is deadband in XRepTyp, XDbReplnt defines the deadband in m% of the measuring range. For cyclic reporting type (XRepTyp : cyclic), the setting value reporting interval is in seconds. Amplitude deadband is the setting value in m% of measuring range. Integral deadband setting is the integral area, that is, measured value in m% of measuring range multiplied by the time between two measured values.

XHIHILim: High-high limit. Set as % of YBase (Y is SBase for S,P,Q UBase for Voltage measurement and IBase for current measurement).

XHILim: High limit. Set as % of YBase (Y is SBase for S,P,Q UBase for Voltage measurement and IBase for current measurement).
**XLowLim**: Low limit. Set as % of YBase (Y is SBase for S, P, Q UBase for Voltage measurement and IBase for current measurement).

**XLowLowLim**: Low-low limit. Set as % of YBase (Y is SBase for S, P, Q UBase for Voltage measurement and IBase for current measurement).

**XLimHyst**: Hysteresis value in % of range and is common for all limits.

All phase angles are presented in relation to defined reference channel. The parameter PhaseAngleRef defines the reference.

**Calibration curves**

It is possible to calibrate the functions (CVMMXN, CMMXU, VMMXU and VNMMXU) to get class 0.5 presentations of currents, voltages and powers. This is accomplished by amplitude and angle compensation at 5, 30 and 100% of rated current and voltage. The compensation curve will have the characteristic for amplitude and angle compensation of currents as shown in figure 69 (example). The first phase will be used as reference channel and compared with the curve for calculation of factors. The factors will then be used for all related channels.

![Calibration curves](en09000052.vsd)

**Figure 69: Calibration curves**

### 12.1.4.1 Setting examples

Three setting examples, in connection to Measurement function (CVMMXN), are provided:

- Measurement function (CVMMXN) application for a OHL
- Measurement function (CVMMXN) application on the secondary side of a transformer
- Measurement function (CVMMXN) application for a generator

For each of them detail explanation and final list of selected setting parameters values will be provided.
The available measured values of an IED are depending on the actual hardware (TRM) and the logic configuration made in PCM600.

**Measurement function application for a 400kV OHL**

Single line diagram for this application is given in figure 70:

![Single line diagram for 400kV OHL application](image)

**Figure 70:** Single line diagram for 400kV OHL application

In order to monitor, supervise and calibrate the active and reactive power as indicated in figure 70 it is necessary to do the following:

1. Set correctly CT and VT data and phase angle reference channel `PhaseAngleRef` using PCM600 for analog input channels
2. Connect, in PCM600, measurement function to three-phase CT and VT inputs
3. Set under General settings parameters for the Measurement function:
   - general settings as shown in table 25.
   - level supervision of active power as shown in table 26.
   - calibration parameters as shown in table 27.

**Table 25: General settings parameters for the Measurement function**

<table>
<thead>
<tr>
<th>Setting</th>
<th>Short Description</th>
<th>Selected value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td>Operation Off/On</td>
<td>On</td>
<td>Function must be On</td>
</tr>
<tr>
<td>PowAmpFact</td>
<td>Amplitude factor to scale power calculations</td>
<td>1.000</td>
<td>It can be used during commissioning to achieve higher measurement accuracy. Typically no scaling is required</td>
</tr>
<tr>
<td>PowAngComp</td>
<td>Angle compensation for phase shift between measured I &amp; U</td>
<td>0.0</td>
<td>It can be used during commissioning to achieve higher measurement accuracy. Typically no angle compensation is required. As well here required direction of P &amp; Q measurement is towards protected object (as per IED internal default direction)</td>
</tr>
<tr>
<td>Mode</td>
<td>Selection of measured current and voltage</td>
<td>L1, L2, L3</td>
<td>All three phase-to-earth VT inputs are available</td>
</tr>
<tr>
<td>k</td>
<td>Low pass filter coefficient for power measurement, U and I</td>
<td>0.00</td>
<td>Typically no additional filtering is required</td>
</tr>
</tbody>
</table>

Table continues on next page
### Table 26: Settings parameters for level supervision

<table>
<thead>
<tr>
<th>Setting</th>
<th>Short Description</th>
<th>Selected value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>UGenZeroDb</td>
<td>Zero point clamping in % of Ubase</td>
<td>25</td>
<td>Set minimum voltage level to 25%. Voltage below 25% will force S, P and Q to zero.</td>
</tr>
<tr>
<td>IGenZeroDb</td>
<td>Zero point clamping in % of Ibase</td>
<td>3</td>
<td>Set minimum current level to 3%. Current below 3% will force S, P and Q to zero.</td>
</tr>
<tr>
<td>UBase (set in Global base)</td>
<td>Base setting for voltage level in kV</td>
<td>400.00</td>
<td>Set rated OHL phase-to-phase voltage</td>
</tr>
<tr>
<td>IBase (set in Global base)</td>
<td>Base setting for current level in A</td>
<td>1000</td>
<td>Set rated primary CT current used for OHL</td>
</tr>
<tr>
<td>SBase (set in Global base)</td>
<td>Base Setting for power base in MVA</td>
<td>1000</td>
<td>Set based on rated Power</td>
</tr>
</tbody>
</table>

### Table 27: Settings for calibration parameters

<table>
<thead>
<tr>
<th>Setting</th>
<th>Short Description</th>
<th>Selected value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAmpComp5</td>
<td>Amplitude factor to calibrate current at 5% of Ir</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>IAmpComp30</td>
<td>Amplitude factor to calibrate current at 30% of Ir</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>IAmpComp100</td>
<td>Amplitude factor to calibrate current at 100% of Ir</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>UAmpComp5</td>
<td>Amplitude factor to calibrate voltage at 5% of Ur</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>UAmpComp30</td>
<td>Amplitude factor to calibrate voltage at 30% of Ur</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>UAmpComp100</td>
<td>Amplitude factor to calibrate voltage at 100% of Ur</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>
### Measurement function application for a power transformer

Single line diagram for this application is given in figure 71.

![Single line diagram for transformer application](IEC09000040-1-en.vsd)

**Figure 71:** Single line diagram for transformer application

In order to measure the active and reactive power as indicated in figure 71, it is necessary to do the following:
1. Set correctly all CT and VT and phase angle reference channel PhaseAngleRef data using PCM600 for analog input channels
2. Connect, in PCM600, measurement function to LV side CT & VT inputs
3. Set the setting parameters for relevant Measurement function as shown in the following table 28:

<table>
<thead>
<tr>
<th>Setting</th>
<th>Short description</th>
<th>Selected value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td>Operation Off/On</td>
<td>On</td>
<td>Function must be On</td>
</tr>
<tr>
<td>PowAmpFact</td>
<td>Amplitude factor to scale power calculations</td>
<td>1.000</td>
<td>Typically no scaling is required</td>
</tr>
<tr>
<td>PowAngComp</td>
<td>Angle compensation for phase shift between measured I &amp; U</td>
<td>180.0</td>
<td>Typically no angle compensation is required. However here the required direction of P &amp; Q measurement is towards busbar (Not per IED internal default direction). Therefore angle compensation have to be used in order to get measurements in aligment with the required direction.</td>
</tr>
<tr>
<td>Mode</td>
<td>Selection of measured current and voltage</td>
<td>L1L2</td>
<td>Only UL1L2 phase-to-phase voltage is available</td>
</tr>
<tr>
<td>k</td>
<td>Low pass filter coefficient for power measurement, U and I</td>
<td>0.00</td>
<td>Typically no additional filtering is required</td>
</tr>
<tr>
<td>UGenZeroDb</td>
<td>Zero point clamping in % of Ubase</td>
<td>25</td>
<td>Set minimum voltage level to 25%</td>
</tr>
<tr>
<td>IGenZeroDb</td>
<td>Zero point clamping in % of Ibase</td>
<td>3</td>
<td>Set minimum current level to 3%</td>
</tr>
<tr>
<td>UBase (set in Global base)</td>
<td>Base setting for voltage level in kV</td>
<td>35.00</td>
<td>Set LV side rated phase-to-phase voltage</td>
</tr>
<tr>
<td>IBase (set in Global base)</td>
<td>Base setting for current level in A</td>
<td>495</td>
<td>Set transformer LV winding rated current</td>
</tr>
<tr>
<td>SBase (set in Global base)</td>
<td>Base setting for power in MVA</td>
<td>31.5</td>
<td>Set based on rated power</td>
</tr>
</tbody>
</table>

### 12.2 Gas medium supervision SSIMG
#### 12.2.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation gas monitoring function</td>
<td>SSIMG</td>
<td>-</td>
<td>63</td>
</tr>
</tbody>
</table>

#### 12.2.2 Application

Gas medium supervision (SSIMG) is used for monitoring the circuit breaker condition. Proper arc extinction by the compressed gas in the circuit breaker is very important. When the pressure becomes too low compared to the required value, the circuit breaker operation shall be blocked to minimize the risk of internal failure. Binary information based on the gas pressure in the circuit breaker is used as an input signal to the function. The function generates alarms based on the received information.
12.2.3 Setting guidelines

The parameters for Gas medium supervision SSIMG can be set via local HMI or Protection and Control Manager PCM600.

**Operation**: This is used to disable/enable the operation of gas medium supervision i.e. Off/On.

**PresAlmLimit**: This is used to set the limit for a pressure alarm condition in the circuit breaker.

**PresLOLimit**: This is used to set the limit for a pressure lockout condition in the circuit breaker.

**TempAlarmLimit**: This is used to set the limit for a temperature alarm condition in the circuit breaker.

**TempLOLimit**: This is used to set the limit for a temperature lockout condition in the circuit breaker.

**tPressureAlarm**: This is used to set the time delay for a pressure alarm indication, given in s.

**tPressureLO**: This is used to set the time delay for a pressure lockout indication, given in s.

**tTempAlarm**: This is used to set the time delay for a temperature alarm indication, given in s.

**tTempLockOut**: This is used to set the time delay for a temperature lockout indication, given in s.

**tResetPressAlm**: This is used for the pressure alarm indication to reset after a set time delay in s.

**tResetPressLO**: This is used for the pressure lockout indication to reset after a set time delay in s.

**tResetTempLO**: This is used for the temperature lockout indication to reset after a set time delay in s.

**tResetTempAlm**: This is used for the temperature alarm indication to reset after a set time delay in s.

12.3 Liquid medium supervision SSIML

12.3.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation liquid monitoring function</td>
<td>SSIML</td>
<td>-</td>
<td>71</td>
</tr>
</tbody>
</table>

12.3.2 Application

Liquid medium supervision (SSIML) is used for monitoring the oil insulated device condition. For example, transformers, shunt reactors, and so on. When the level becomes too low compared to the required value, the operation is blocked to minimize the risk of internal failures. Binary information based on the oil level in the oil insulated devices are used as input signals to the function. In addition, the function generates alarms based on the received information.
12.3.3 Setting guidelines

The parameters for Liquid medium supervision SSIML can be set via local HMI or Protection and Control Manager PCM600.

Operation: This is used to disable/enable the operation of liquid medium supervision i.e. Off/On.

LevelAlmLimit: This is used to set the limit for a level alarm condition in the oil insulated device.

LevelLOLimit: This is used to set the limit for a level lockout condition in the oil insulated device.

TempAlarmLimit: This is used to set the limit for a temperature alarm condition in the oil insulated device.

TempLOLimit: This is used to set the limit for a temperature lockout condition in the oil insulated device.

tLevelAlarm: This is used to set the time delay for a level alarm indication, given in s.

tLevelLockOut: This is used to set the time delay for a level lockout indication, given in s.

tTempAlarm: This is used to set the time delay for a temperature alarm indication, given in s.

tTempLockOut: This is used to set the time delay for a temperature lockout indication, given in s.

tResetLevelAlm: This is used for the level alarm indication to reset after a set time delay in s.

tResetLevelLO: This is used for the level lockout indication to reset after a set time delay in s.

tResetTempLO: This is used for the temperature lockout indication to reset after a set time delay in s.

tResetTempAlm: This is used for the temperature alarm indication to reset after a set time delay in s.

12.4 Breaker monitoring SSCBR

12.4.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breaker monitoring</td>
<td>SSCBR</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

12.4.2 Application

The circuit breaker maintenance is usually based on regular time intervals or the number of operations performed. This has some disadvantages because there could be a number of abnormal operations or few operations with high-level currents within the predetermined maintenance interval. Hence, condition-based maintenance scheduling is an optimum solution in assessing the condition of circuit breakers.
Circuit breaker contact travel time

Auxiliary contacts provide information about the mechanical operation, opening time and closing time of a breaker. Detecting an excessive traveling time is essential to indicate the need for maintenance of the circuit breaker mechanism. The excessive travel time can be due to problems in the driving mechanism or failures of the contacts.

Circuit breaker status

Monitoring the breaker status ensures proper functioning of the features within the protection relay such as breaker control, breaker failure and autoreclosing. The breaker status is monitored using breaker auxiliary contacts. The breaker status is indicated by the binary outputs. These signals indicate whether the circuit breaker is in an open, closed or error state.

Remaining life of circuit breaker

Every time the breaker operates, the circuit breaker life reduces due to wear. The wear in a breaker depends on the interrupted current. For breaker maintenance or replacement at the right time, the remaining life of the breaker must be estimated. The remaining life of a breaker can be estimated using the maintenance curve provided by the circuit breaker manufacturer.

Circuit breaker manufacturers provide the number of make-break operations possible at various interrupted currents. An example is shown in figure 72.

![Figure 72: An example for estimating the remaining life of a circuit breaker](IEC12000623_1_en.vsd)

**Calculation for estimating the remaining life**
The graph shows that there are 10000 possible operations at the rated operating current and 900 operations at 10 kA and 50 operations at rated fault current. Therefore, if the interrupted current is 10 kA, one operation is equivalent to 10000/900 = 11 operations at the rated current. It is assumed that prior to tripping, the remaining life of a breaker is 10000 operations. Remaining life calculation for three different interrupted current conditions is explained below.

- Breaker interrupts at and below the rated operating current, that is, 2 kA, the remaining life of the CB is decreased by 1 operation and therefore, 9999 operations remaining at the rated operating current.
- Breaker interrupts between rated operating current and rated fault current, that is, 10 kA, one operation at 10 kA is equivalent to 10000/900 = 11 operations at the rated current. The remaining life of the CB would be (10000 – 10) = 9989 at the rated operating current after one operation at 10 kA.
- Breaker interrupts at and above rated fault current, that is, 50 kA, one operation at 50 kA is equivalent to 10000/50 = 200 operations at the rated operating current. The remaining life of the CB would become (10000 – 200) = 9800 operations at the rated operating current after one operation at 50 kA.

Accumulated energy

Monitoring the contact erosion and interrupter wear has a direct influence on the required maintenance frequency. Therefore, it is necessary to accurately estimate the erosion of the contacts and condition of interrupters using cumulative summation of $I^y$. The factor “$y$” depends on the type of circuit breaker. The energy values were accumulated using the current value and exponent factor for CB contact opening duration. When the next CB opening operation is started, the energy is accumulated from the previous value. The accumulated energy value can be reset to initial accumulation energy value by using the Reset accumulating energy input, $RSTIPOW$.

Circuit breaker operation cycles

Routine breaker maintenance like lubricating breaker mechanism is based on the number of operations. A suitable threshold setting helps in preventive maintenance. This can also be used to indicate the requirement for oil sampling for dielectric testing in case of an oil circuit breaker.

Circuit breaker operation monitoring

By monitoring the activity of the number of operations, it is possible to calculate the number of days the breaker has been inactive. Long periods of inactivity degrade the reliability for the protection system.

Circuit breaker spring charge monitoring

For normal circuit breaker operation, the circuit breaker spring should be charged within a specified time. Detecting a long spring charging time indicates the time for circuit breaker maintenance. The last value of the spring charging time can be given as a service value.

Circuit breaker gas pressure indication

For proper arc extinction by the compressed gas in the circuit breaker, the pressure of the gas must be adequate. Binary input available from the pressure sensor is based on the pressure levels inside the arc chamber. When the pressure becomes too low compared to the required value, the circuit breaker operation is blocked.

12.4.3 Setting guidelines

The breaker monitoring function is used to monitor different parameters of the circuit breaker. The breaker requires maintenance when the number of operations has reached a predefined value. For proper functioning of the circuit breaker, it is also essential to monitor...
the circuit breaker operation, spring charge indication or breaker wear, travel time, number of operation cycles and accumulated energy during arc extinction.

Since there is no current measurement in SAM600-IO, evaluation of the following parameters are not possible in the circuit breaker condition monitoring function (SSCBR):

- Circuit breaker status
- Remaining life of the circuit breaker
- Contact erosion estimation
- Circuit breaker contact travel time

Ensure that OPENPOS, CLOSEPOS, INVDPOS, CBLIFEAL, IPOWALPH, IPOWLOPH, TRVTOPAL and TRVTCLAL signals are not used in SAM600–IO.

12.4.3.1 Setting procedure on the IED

The parameters for breaker monitoring (SSCBR) can be set via the local HMI or Protection and Control Manager (PCM600).

Common base IED values for primary current (IBase), primary voltage (UBase) and primary power (SBase) are set in Global base values for settings function GBASVAL.

GlobalBaseSel: It is used to select a GBASVAL function for reference of base values.

Operation: On or Off.

IBase: Base phase current in primary A. This current is used as reference for current settings.

OpenTimeCorr: Correction factor for circuit breaker opening travel time.

CloseTimeCorr: Correction factor for circuit breaker closing travel time.

tTrOpenAlm: Setting of alarm level for opening travel time.

tTrCloseAlm: Setting of alarm level for closing travel time.

OperAlmLevel: Alarm limit for number of mechanical operations.

OperLOLevel: Lockout limit for number of mechanical operations.

CurrExponent: Current exponent setting for energy calculation. It varies for different types of circuit breakers. This factor ranges from 0.5 to 3.0.

AccStopCurr: RMS current setting below which calculation of energy accumulation stops. It is given as a percentage of IBase.

ContTrCorr: Correction factor for time difference in auxiliary and main contacts' opening time.

AlmAccCurrPwr: Setting of alarm level for accumulated energy.

LOAccCurrPwr: Lockout limit setting for accumulated energy.

SpChAlmTime: Time delay for spring charging time alarm.

tDGasPresAlm: Time delay for gas pressure alarm.

tDGasPresLO: Time delay for gas pressure lockout.
**DirCoef**: Directional coefficient for circuit breaker life calculation.

**RatedOperCurr**: Rated operating current of the circuit breaker.

**RatedFltCurr**: Rated fault current of the circuit breaker.

**OperNoRated**: Number of operations possible at rated current.

**OperNoFault**: Number of operations possible at rated fault current.

**CBLifeAlmLevel**: Alarm level for circuit breaker remaining life.

**AccSelCal**: Selection between the method of calculation of accumulated energy.

**OperTimeDelay**: Time delay between change of status of trip output and start of main contact separation.

### 12.5 Event function EVENT

#### 12.5.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event function</td>
<td>EVENT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 12.5.2 Application

When using a Substation Automation system with LON or SPA communication, time-tagged events can be sent at change or cyclically from the IED to the station level. These events are created from any available signal in the IED that is connected to the Event function (EVENT). The EVENT function block is used for LON and SPA communication.

Analog, integer and double indication values are also transferred through the EVENT function.

#### 12.5.3 Setting guidelines

The input parameters for the Event function (EVENT) can be set individually via the local HMI (Main Menu/Settings / IED Settings / Monitoring / Event Function) or via the Parameter Setting Tool (PST).

**EventMask (Ch_1 - 16)**

The inputs can be set individually as:

- **NoEvents**
- **OnSet**, at pick-up of the signal
- **OnReset**, at drop-out of the signal
- **OnChange**, at both pick-up and drop-out of the signal
- **AutoDetect**, the EVENT function makes the reporting decision (reporting criteria for integers have no semantic, prefer to be set by the user)
**LONChannelMask or SPAChannelMask**
Definition of which part of the event function block that shall generate events:

- Off
- Channel 1-8
- Channel 9-16
- Channel 1-16

**MinRepIntVal (1 - 16)**
A time interval between cyclic events can be set individually for each input channel. This can be set between 0 s to 3600 s in steps of 1 s. It should normally be set to 0, that is, no cyclic communication.

It is important to set the time interval for cyclic events in an optimized way to minimize the load on the station bus.

### 12.6 Disturbance report DRPRDRE

#### 12.6.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disturbance report</td>
<td>DRPRDRE</td>
<td></td>
<td></td>
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<tr>
<td>Disturbance report</td>
<td>A1RADR - A4RADR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disturbance report</td>
<td>B1R8DR - B22R8DR</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 12.6.2 Application

To get fast, complete and reliable information about disturbances in the primary and/or in the secondary system it is very important to gather information on fault currents, voltages and events. It is also important having a continuous event-logging to be able to monitor in an overview perspective. These tasks are accomplished by the disturbance report function DRPRDRE and facilitate a better understanding of the power system behavior and related primary and secondary equipment during and after a disturbance. An analysis of the recorded data provides valuable information that can be used to explain a disturbance, basis for change of IED setting plan, improve existing equipment, and so on. This information can also be used in a longer perspective when planning for and designing new installations, that is, a disturbance recording could be a part of Functional Analysis (FA).

Disturbance report DRPRDRE, always included in the IED, acquires sampled data of all selected analog and binary signals connected to the function blocks that is,

- Maximum 30 external analog signals,
- 10 internal derived analog signals, and
- 352 binary signals

Disturbance report function is a common name for several functions; Indications (IND), Event recorder (ER), Event list (EL), Trip value recorder (TVR), Disturbance recorder (DR).
Disturbance report function is characterized by great flexibility as far as configuration, starting conditions, recording times, and storage capacity are concerned. Thus, disturbance report is not dependent on the operation of protective functions, and it can record disturbances that were not discovered by protective functions for one reason or another. Disturbance report can be used as an advanced stand-alone disturbance recorder.

Every disturbance report recording is saved in the IED. The same applies to all events, which are continuously saved in a ring-buffer. Local HMI can be used to get information about the recordings, and the disturbance report files may be uploaded in the PCM600 using the Disturbance handling tool, for report reading or further analysis (using WaveWin, that can be found on the PCM600 installation CD). The user can also upload disturbance report files using FTP or MMS (over 61850–8–1) clients.

If the IED is connected to a station bus (IEC 61850-8-1), the disturbance recorder (record made and fault number) and the fault locator information are available. The same information is obtainable if IEC 60870-5-103 is used.

12.6.3 Setting guidelines

The setting parameters for the Disturbance report function DRPRDRE are set via the local HMI or PCM600.

It is possible to handle up to 40 analog and 352 binary signals, either internal signals or signals coming from external inputs. The binary signals are identical in all functions that is, Disturbance recorder (DR), Event recorder (ER), Indication (IND), Trip value recorder (TVR) and Event list (EL) function.

User-defined names of binary and analog input signals are set using PCM600. The analog and binary signals appear with their user-defined names. The name is used in all related functions (Disturbance recorder (DR), Event recorder (ER), Indication (IND), Trip value recorder (TVR) and Event list (EL)).

Figure 73 shows the relations between Disturbance report, included functions and function blocks. Event list (EL), Event recorder (ER) and Indication (IND) uses information from the binary input function blocks (BxRBDR). Trip value recorder (TVR) uses analog information from the analog input function blocks (AxRADR). Disturbance report function acquires information from both AxRADR and BxRBDR.
Figure 73: Disturbance report functions and related function blocks

For Disturbance report function there are a number of settings which also influences the sub-functions.

Three LED indications placed above the LCD screen makes it possible to get quick status information about the IED.

- **Green LED:**
  - Steady light: **In Service**
  - Flashing light: **Internal failure**
  - Dark: **No power supply**

- **Yellow LED:**
  - Steady light: Triggered on binary signal N with SetLEDx = Start (or Start and Trip)
  - Flashing light: The IED is in test mode

- **Red LED:**
  - Steady light: Triggered on binary signal N with SetLEDx = Trip (or Start and Trip)
  - Flashing: The IED is in configuration mode

**Operation**

The operation of Disturbance report function DRPRDRE has to be set On or Off. If Off is selected, note that no disturbance report is registered, and none sub-function will operate (the only general parameter that influences Event list (EL)).
Operation = Off:

- Disturbance reports are not stored.
- LED information (yellow - start, red - trip) is not stored or changed.

Operation = On:

- Disturbance reports are stored, disturbance data can be read from the local HMI and from a PC for example using PCM600.
- LED information (yellow - start, red - trip) is stored.

Every recording will get a number (0 to 999) which is used as identifier (local HMI, disturbance handling tool and IEC 61850). An alternative recording identification is date, time and sequence number. The sequence number is automatically increased by one for each new recording and is reset to zero at midnight. The maximum number of recordings stored in the IED is 100. The oldest recording will be overwritten when a new recording arrives (FIFO).

To be able to delete disturbance records, Operation parameter has to be On.

The maximum number of recordings depend on each recordings total recording time. Long recording time will reduce the number of recordings to less than 100.

The IED flash disk should NOT be used to store any user files. This might cause disturbance recordings to be deleted due to lack of disk space.

12.6.3.1 Recording times

The different recording times for Disturbance report are set (the pre-fault time, post-fault time, and limit time). These recording times affect all sub-functions more or less but not the Event list (EL) function.

Prefault recording time \((\text{PreFaultRecT})\) is the recording time before the starting point of the disturbance. The setting should be at least \(0.1\) s to ensure enough samples for the estimation of pre-fault values in the Trip value recorder (TVR) function.

Postfault recording time \((\text{PostFaultRecT})\) is the maximum recording time after the disappearance of the trig-signal (does not influence the Trip value recorder (TVR) function).

Recording time limit \((\text{TimeLimit})\) is the maximum recording time after trig. The parameter limits the recording time if some trigging condition (fault-time) is very long or permanently set (does not influence the Trip value recorder (TVR) function).

Operation in test mode

If the IED is in test mode and \(\text{OpModeTest} = \text{Off}\). Disturbance report function does not save any recordings and no LED information is displayed.

If the IED is in test mode and \(\text{OpModeTest} = \text{On}\). Disturbance report function works in normal mode and the status is indicated in the saved recording.
**Post Retrigger**

Disturbance report function does not automatically respond to any new trig condition during a recording, after all signals set as trigger signals have been reset. However, under certain circumstances the fault condition may reoccur during the post-fault recording, for instance by automatic reclosing to a still faulty power line.

In order to capture the new disturbance it is possible to allow retriggering \((PostRetrig = On)\) during the post-fault time. In this case a new, complete recording will start and, during a period, run in parallel with the initial recording.

When the retrig parameter is disabled \((PostRetrig = Off)\), a new recording will not start until the post-fault \((PostFaultRecT or TimeLimit)\) period is terminated. If a new trig occurs during the post-fault period and lasts longer than the proceeding recording a new complete recording will be started.

Disturbance report function can handle a maximum of 3 simultaneous disturbance recordings.

### 12.6.3.2 Binary input signals

Up to 352 binary signals can be selected among internal logical and binary input signals. The configuration tool is used to configure the signals.

For each of the 352 signals, it is also possible to select if the signal is to be used as a trigger for the start of the Disturbance report and if the trigger should be activated on positive (1) or negative (0) slope.

- **OperationN**: Disturbance report may trig for binary input N \((On)\) or not \((Off)\).
- **TrigLevelN**: Trig on positive \((Trig on 1)\) or negative \((Trig on 0)\) slope for binary input N.
- **Func103N**: Function type number \((0-255)\) for binary input N according to IEC-60870-5-103, that is, 128: Distance protection, 160: overcurrent protection, 176: transformer differential protection and 192: line differential protection.
- **Info103N**: Information number \((0-255)\) for binary input N according to IEC-60870-5-103, that is, 69-71: Trip L1-L3, 78-83: Zone 1-6.

See also description in the chapter IEC 60870-5-103.

### 12.6.3.3 Analog input signals

Up to 40 analog signals can be selected among internal analog and analog input signals. PCM600 is used to configure the signals.

The analog trigger of Disturbance report is not affected if analog input M is to be included in the disturbance recording or not \((OperationM = On/Off)\).

If \(OperationM = Off\), no waveform (samples) will be recorded and reported in graph. However, Trip value, pre-fault and fault value will be recorded and reported. The input channel can still be used to trig the disturbance recorder.

If \(OperationM = On\), waveform (samples) will also be recorded and reported in graph.

- **NomValueM**: Nominal value for input M.
- **OverTrigOpM, UnderTrigOpM**: Over or Under trig operation, Disturbance report may trig for high/low level of analog input M \((On)\) or not \((Off)\).
- **OverTrigLeM, UnderTrigLeM**: Over or under trig level, Trig high/low level relative nominal value for analog input M in percent of nominal value.
12.6.3.4 Sub-function parameters

All functions are in operation as long as Disturbance report is in operation.

Indications

*IndicationMaN*: Indication mask for binary input N. If set *(Show)*, a status change of that particular input will be fetched and shown in the disturbance summary on local HMI. If not set *(Hide)*, status change will not be indicated.

*SetLEDN*: Set red LED on local HMI in front of the IED if binary input N changes status.

Disturbance recorder

*OperationM*: Analog channel M is to be recorded by the disturbance recorder *(On)* or not *(Off)*.

If *OperationM* = *Off*, no waveform (samples) will be recorded and reported in graph. However, Trip value, pre-fault and fault value will be recorded and reported. The input channel can still be used to trig the disturbance recorder.

If *OperationM* = *On*, waveform (samples) will also be recorded and reported in graph.

Setting information

*SetInfoInDrep*: Parameter used to enable or disable the settings information in disturbance header.

Event recorder

Event recorder (ER) function has no dedicated parameters.

Trip value recorder

*ZeroAngleRef*: The parameter defines which analog signal that will be used as phase angle reference for all other analog input signals. This signal will also be used for frequency measurement and the measured frequency is used when calculating trip values. It is suggested to point out a sampled voltage input signal, for example, a line or busbar phase voltage (channel 1-30).

Event list

Event list (EL) (SOE) function has no dedicated parameters.

12.6.3.5 Consideration

The density of recording equipment in power systems is increasing, since the number of modern IEDs, where recorders are included, is increasing. This leads to a vast number of recordings at every single disturbance and a lot of information has to be handled if the recording functions do not have proper settings. The goal is to optimize the settings in each IED to be able to capture just valuable disturbances and to maximize the number that is possible to save in the IED.

The recording time should not be longer than necessary *(PostFaultrecT and TimeLimit)*.

- Should the function record faults only for the protected object or cover more?
- How long is the longest expected fault clearing time?
- Is it necessary to include reclosure in the recording or should a persistent fault generate a second recording *(PostRetrig)*?

Minimize the number of recordings:

- Binary signals: Use only relevant signals to start the recording that is, protection trip, carrier receive and/or start signals.
- Analog signals: The level triggering should be used with great care, since unfortunate settings will cause enormously number of recordings. If nevertheless analog input
triggering is used, chose settings by a sufficient margin from normal operation values. Phase voltages are not recommended for trigging.

There is a risk of flash wear out if the disturbance report triggers too often.

Remember that values of parameters set elsewhere are linked to the information on a report. Such parameters are, for example, station and object identifiers, CT and VT ratios.

12.7 Logical signal status report BINSTATREP

12.7.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logical signal status report</td>
<td>BINSTATREP</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

12.7.2 Application

The Logical signal status report (BINSTATREP) function makes it possible to poll signals from various other function blocks.

BINSTATREP has 16 inputs and 16 outputs. The output status follows the inputs and can be read from the local HMI or via SPA communication.

When an input is set, the respective output is set for a user defined time. If the input signal remains set for a longer period, the output will remain set until the input signal resets.

INPUTn

OUTPUTn

\[ t \quad t \]

*Figure 74: BINSTATREP logical diagram*

12.7.3 Setting guidelines

The pulse time \( t \) is the only setting for the Logical signal status report (BINSTATREP). Each output can be set or reset individually, but the pulse time will be the same for all outputs in the entire BINSTATREP function.

12.8 Limit counter L4UFCNT
12.8.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit counter</td>
<td>L4UFCNT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

12.8.2 Application

Limit counter (L4UFCNT) is intended for applications where positive and/or negative flanks on a binary signal need to be counted.

The limit counter provides four independent limits to be checked against the accumulated counted value. The four limit reach indication outputs can be utilized to initiate proceeding actions. The output indicators remain high until the reset of the function.

It is also possible to initiate the counter from a non-zero value by resetting the function to the wanted initial value provided as a setting.

If applicable, the counter can be set to stop or rollover to zero and continue counting after reaching the maximum count value. The steady overflow output flag indicates the next count after reaching the maximum count value. It is also possible to set the counter to rollover and indicate the overflow as a pulse, which lasts up to the first count after rolling over to zero. In this case, periodic pulses will be generated at multiple overflow of the function.

12.8.3 Setting guidelines

The parameters for Limit counter L4UFCNT are set via the local HMI or PCM600.

12.9 Running hour-meter TEILGAPC

12.9.1 Identification

<table>
<thead>
<tr>
<th>Function Description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Running hour-meter</td>
<td>TEILGAPC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

12.9.2 Application

The function is used for user-defined logics and it can also be used for different purposes internally in the IED. An application example is to accumulate the total running/energized time of the generator, transformer, reactor, capacitor bank or even line.

Settable time limits for warning and alarm are provided. The time limit for overflow indication is fixed to 99999.9 hours. At overflow the accumulated time resets and the accumulation starts from zero again.

12.9.3 Setting guidelines

The settings $t_{\text{Alarm}}$ and $t_{\text{Warning}}$ are user settable limits defined in hours. The achievable resolution of the settings is 0.1 hours (6 minutes).
\( t_{\text{Alarm}} \) and \( t_{\text{Warning}} \) are independent settings, that is, there is no check if \( t_{\text{Alarm}} > t_{\text{Warning}} \).

The limit for the overflow supervision is fixed at 99999.9 hours.

The setting \( t_{\text{AddToTime}} \) is a user settable time parameter in hours.
Section 13  

Metering

13.1  
Pulse-counter logic PCFCNT

13.1.1  
Identification

<table>
<thead>
<tr>
<th>Function description</th>
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<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse-counter logic</td>
<td>PCFCNT</td>
<td></td>
<td>-</td>
</tr>
</tbody>
</table>

13.1.2  
Application

Pulse-counter logic (PCFCNT) function counts externally generated binary pulses, for instance pulses coming from an external energy meter, for calculation of energy consumption values. The pulses are captured by the binary input module (BIM), and read by the PCFCNT function. The number of pulses in the counter is then reported via the station bus to the substation automation system or read via the station monitoring system as a service value. When using IEC 61850–8–1, a scaled service value is available over the station bus.

The normal use for this function is the counting of energy pulses from external energy meters. An optional number of inputs from an arbitrary input module in IED can be used for this purpose with a frequency of up to 40 Hz. The pulse-counter logic PCFCNT can also be used as a general purpose counter.

13.1.3  
Setting guidelines

Parameters that can be set individually for each pulse counter from PCM600:

- **Operation**: Off/On
- **tReporting**: 0-3600s
- **EventMask**: NoEvents/ReportEvents

Configuration of inputs and outputs of PCFCNT is made via PCM600.

On the Binary input module (BIM), the debounce filter default time is set to 5ms, that is, the counter suppresses pulses with a pulse length less than 5 ms. The input oscillation blocking frequency is preset to 40 Hz meaning that the counter detects the input to oscillate if the input frequency is greater than 40 Hz. Oscillation suppression is released at 30 Hz. Block/release values for oscillation can be changed on the local HMI and PCM600 under **Main menu/Configuration/I/O modules**.

The setting is common for all input channels on BIM, that is, if limit changes are made for inputs not connected to the pulse counter, the setting also influences the inputs on the same board used for pulse counting.
13.2 Function for energy calculation and demand handling ETPMMTR

13.2.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
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<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function for energy calculation and demand handling</td>
<td>ETPMMTR</td>
<td>W_Varh</td>
<td>-</td>
</tr>
</tbody>
</table>

13.2.2 Application

Energy calculation and demand handling function (ETPMMTR) is intended for statistics of the forward and reverse active and reactive energy. It has a high accuracy basically given by the measurements function (CVMMXN). This function has a site calibration possibility to further increase the total accuracy.

The function is connected to the instantaneous outputs of (CVMMXN) as shown in figure 75.

![Figure 75: Connection of energy calculation and demand handling function ETPMMTR to the measurements function (CVMMXN)](IEC13000190-2-en.vsdx)

The energy values can be read through communication in MWh and MVArh in monitoring tool of PCM600 and/or alternatively the values can be presented on the local HMI. The local HMI graphical display is configured with PCM600 Graphical Display Editor tool (GDE) with a measuring value which is selected to the active and reactive component as preferred. Also all Accumulated Active Forward, Active Reverse, Reactive Forward and Reactive Reverse energy values can be presented.

Maximum demand values are presented in MWh or MVArh in the same way.

Alternatively, the energy values can be presented with use of the pulse counters function (PCGGIO). The output energy values are scaled with the pulse output setting values $EAFAccPlsQty$, $EARAccPlsQty$, $ERFAccPlsQty$ and $ERVAccPlsQty$ of the energy metering function and then the pulse counter can be set-up to present the correct values by scaling in this function. Pulse counter values can then be presented on the local HMI in the same way and/or sent to the SA (Substation Automation) system through communication where the total energy then is calculated by summation of the energy pulses. This principle is good for
very high values of energy as the saturation of numbers else will limit energy integration to about one year with 50 kV and 3000 A. After that the accumulation will start on zero again.

### 13.2.3 Setting guidelines

The parameters are set via the local HMI or PCM600.

The following settings can be done for the energy calculation and demand handling function ETPMMTR:

- **GlobalBaseSel**: Selects the global base value group used by the function to define $I_{\text{Base}}$, $U_{\text{Base}}$ and $S_{\text{Base}}$.

  - **Operation**: Off/On
  - **EnaAcc**: Off/On is used to switch the accumulation of energy on and off.
  - **$t_{\text{Energy}}$**: Time interval when energy is measured.
  - **$t_{\text{EnergyOnPls}}$**: gives the pulse length ON time of the pulse. It should be at least 100 ms when connected to the Pulse counter function block. Typical value can be 100 ms.
  - **$t_{\text{EnergyOffPls}}$**: gives the OFF time between pulses. Typical value can be 100 ms.
  - **$E_{\text{DeltaAccPlsQty}}$ and $E_{\text{AccPlsQty}}$**: gives the MWh value in each pulse. It should be selected together with the setting of the Pulse counter (PCGGIO) settings to give the correct total pulse value.
  - **$E_{\text{RealAccPlsQty}}$ and $E_{\text{VarAccPlsQty}}$**: gives the MVArh value in each pulse. It should be selected together with the setting of the Pulse counter (PCGGIO) settings to give the correct total pulse value.

For the advanced user there are a number of settings for direction, zero clamping, max limit, and so on. Normally, the default values are suitable for these parameters.
## Section 14  Ethernet-based communication

### 14.1 Access point

#### 14.1.1 Application

The access points are used to connect the IED to the communication buses (like the station bus) that use communication protocols. The access point can be used for single and redundant data communication. The access points are also used for communication with the merging units and for time synchronization using Precision Time Protocol (PTP).

#### 14.1.2 Setting guidelines

The physical ports allocated to access points 2–4 have to be added in the hardware tool in PCM600 before the access points can be configured. The factory setting only includes the physical ports allocated to the front port and access point 1.

The settings for the access points are configured using the Ethernet configuration tool (ECT) in PCM600.

The access point is activated if the Operation checkbox is checked for the respective access point and a partial or common write to IED is performed.

To increase security, it is recommended to deactivate the access point when it is not in use.

**Redundancy** and **PTP** cannot be set for the front port (Access point 0) as redundant communication and PTP are only available for the rear optical Ethernet ports.

**Subnetwork** shows the SCL subnetwork to which the access point is connected. This column shows the SCL subnetworks available in the PCM600 project. SCL subnetworks can be created/deleted in the Subnetworks tab of IEC 61850 Configuration tool in PCM600.

When saving the ECT configuration after selecting a subnetwork, ECT creates the access point in the SCL model. Unselecting the subnetwork removes the access point from the SCL model. This column is editable for IEC61850 Ed2 IEDs and not editable for IEC61850 Ed1 IEDs because in IEC61850 Ed1 only one access point can be modelled in SCL.

The IP address can be set in **IP address**. ECT validates the value, the access points have to be on separate subnetworks.

The subnetwork mask can be set in **Subnet mask**. This field will be updated to the SCL model based on the **Subnetwork** selection.

To select which communication protocols can be run on the respective access points, check or uncheck the check box for the relevant protocol. The protocols are not activated/deactivated in ECT, only filtered for the specific access point. For information on how to activate the individual communication protocols, see the communication protocol chapters.
To increase security it is recommended to uncheck protocols that are not used on the access point.

The default gateway can be selected by entering the IP address in Default gateway. The default gateway is the router that is used to communicate with the devices in the other subnetwork. By default this is set to 0.0.0.0 which means that no default gateway is selected. ECT validates the entered value, but the default gateway has to be in the same subnetwork as the access point. The default gateway is the router that is being used as default, that is when no route has been set up for the destination. If communication with a device in another subnetwork is needed, a route has to be set up. For more information on routes, see the Routes chapter in the Technical manual and the Application manual.

DHCP can be activated for the front port from the LHMI in Main menu/Configuration/Communication/Ethernet configuration/Front port/DHCP:1

### 14.2 Redundant communication

#### 14.2.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 62439-3 Parallel redundancy protocol</td>
<td>PRP</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>IEC 62439-3 High-availability seamless redundancy</td>
<td>HSR</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Access point diagnostic for redundant Ethernet ports</td>
<td>RCHLCCH</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 14.2.2 Application

Dynamic access point diagnostic (RCHLCCH) is used to supervise and assure redundant Ethernet communication over two channels. This will secure data transfer even though one communication channel might not be available for some reason.

Parallel Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR) provides redundant communication over station bus running the available communication protocols. The redundant communication uses two Ethernet ports.
14.2.3 Setting guidelines

Redundant communication is configured with the Ethernet configuration tool in PCM600.
Redundancy: redundant communication is activated when the parameter is set to PRP-0, PRP-1 or HSR. The settings for the next access point will be hidden and PhyPortB will show the second port information. Redundant communication is activated after a common write to IED is done.

PRP-1 should be used primarily, PRP-0 is intended only for use in existing PRP-networks. PRP-1 and HSR can be combined in a mixed network.

If the access point is not taken into operation, the write option in Ethernet Configuration Tool can be used to activate the access point.

### Figure 78: ECT screen with Redundancy set to PRP-1 on Access point 1 and HSR Access point 3

#### 14.3 Merging unit

#### 14.3.1 Application

The IEC/UCA 61850-9-2LE process bus communication protocol enables an IED to communicate with devices providing measured values in digital format, commonly known as Merging Units (MU). The rear access points are used for the communication.

The merging units (MU) are called so because they can gather analog values from one or more measuring transformers, sample the data and send the data over process bus to other clients (or subscribers) in the system. Some merging units are able to get data from classical measuring transformers, others from non-conventional measuring transducers and yet others can pick up data from both types.
14.3.2 Setting guidelines

For information on the merging unit setting guidelines, see section IEC/UCA 61850-9-2LE communication protocol.

14.4 Routes

14.4.1 Application

Setting up a route enables communication to a device that is located in another subnetwork. Routing is used when the destination device is not in the same subnetwork as the default gateway.

The route specifies that when a package is sent to the destination device it should be sent through the selected router. If no route is specified the source device will not find the destination device.

14.4.2 Setting guidelines

Routes are configured using the Ethernet configuration tool in PCM600.

Operation for the route can be set to On/Off by checking and unchecking the check-box in the operation column.

Gateway specifies the address of the gateway.

Destination specifies the destination.

Destination subnet mask specifies the subnetwork mask of the destination.
Section 15  Station communication

15.1  Communication protocols

Each IED is provided with several communication interfaces enabling it to connect to one or many substation level systems or equipment, either on the Substation Automation (SA) bus or Substation Monitoring (SM) bus.

Available communication protocols are:

- IEC 61850-8-1 communication protocol
- IEC/UCA 61850-9-2LE communication protocol
- LON communication protocol
- SPA communication protocol
- IEC 60870-5-103 communication protocol

Several protocols can be combined in the same IED.

15.2  IEC 61850-8-1 communication protocol

15.2.1  Application IEC 61850-8-1

IEC 61850-8-1 communication protocol allows vertical communication to HSI clients and allows horizontal communication between two or more intelligent electronic devices (IEDs) from one or several vendors to exchange information and to use it in the performance of their functions and for correct co-operation.

GOOSE (Generic Object Oriented Substation Event), which is a part of IEC 61850–8–1 standard, allows the IEDs to communicate state and control information amongst themselves, using a publish-subscribe mechanism. That is, upon detecting an event, the IED(s) use a multi-cast transmission to notify those devices that have registered to receive the data. An IED can, by publishing a GOOSE message, report its status. It can also request a control action to be directed at any device in the network.

Figure 80 shows the topology of an IEC 61850–8–1 configuration. IEC 61850–8–1 specifies only the interface to the substation LAN. The LAN itself is left to the system integrator.
### Figure 80: SA system with IEC 61850–8–1

Figure 80 shows the GOOSE peer-to-peer communication.

### Figure 81: Example of a broadcasted GOOSE message

15.2.2 Setting guidelines

There are two settings related to the IEC 61850–8–1 protocol:

*Operation:* User can set IEC 61850 communication to *On* or *Off.*
**GOOSEPortEd1**: Selection of the Ethernet link where GOOSE traffic shall be sent and received. This is only valid for Edition 1 and can be ignored if Edition 2 is used. For Edition 2, the Ethernet link selection is done with the Ethernet Configuration Tool (ECT) in PCM600.

### 15.2.3 Horizontal communication via GOOSE

#### 15.2.3.1 Sending data

In addition to the data object and data attributes of the logical nodes, it is possible to send the outputs of the function blocks using the generic communication blocks. The outputs of this function can be set in a dataset and be sent in a GOOSE Control Block to other subscriber IEDs. There are different function blocks for different type of sending data.

**Generic communication function for Single Point indication SPGAPC, SP16GAPC**

**Application**

Generic communication function for Single Point Value (SPGAPC) function is used to send one single logical output to other systems or equipment in the substation. SP16GAPC can be used to send up to 16 single point values from the application functions running in the same cycle time. SPGAPC has one visible input and SPGAPC16 has 16 visible inputs that should be connected in the ACT tool.

**Setting guidelines**

There are no settings available for the user for SPGAPC.

**Generic communication function for Measured Value MVGAPC**

**Application**

Generic communication function for measured values (MVGAPC) function is used to send the instantaneous value of an analog signal to other systems or equipment in the substation. It can also be used inside the same IED, to attach a RANGE aspect to an analog value and to permit measurement supervision on that value.

**Setting guidelines**

The settings available for Generic communication function for Measured Value (MVGAPC) function allows the user to choose a deadband and a zero deadband for the monitored signal. Values within the zero deadband are considered as zero.

The high and low limit settings provides limits for the high-high-, high, normal, low and low-low ranges of the measured value. The actual range of the measured value is shown on the range output of MVGAPC function block. When a Measured value expander block (RANGE_XP) is connected to the range output, the logical outputs of the RANGE_XP are changed accordingly.

#### 15.2.3.2 Receiving data

The GOOSE data must be received at function blocks. There are different GOOSE receiving function blocks depending on the type of the received data. Refer to the Engineering manual for more information about how to configure GOOSE.

<table>
<thead>
<tr>
<th>Function block type</th>
<th>Data Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOOSEBINRCV</td>
<td>16 single point</td>
</tr>
<tr>
<td>GOOSEINTLKRCV</td>
<td>2 single points</td>
</tr>
<tr>
<td></td>
<td>16 double points</td>
</tr>
<tr>
<td>GOOSEDPRCV</td>
<td>Double point</td>
</tr>
</tbody>
</table>

Table continues on next page
<table>
<thead>
<tr>
<th>Function block type</th>
<th>Data Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOOSE_INTRCV</td>
<td>Integer</td>
</tr>
<tr>
<td>GOOSE_MVRCV</td>
<td>Analog value</td>
</tr>
<tr>
<td>GOOSE_SPRCV</td>
<td>Single point</td>
</tr>
<tr>
<td>GOOSE_XLNRCV</td>
<td>Switch status</td>
</tr>
</tbody>
</table>

**Application**

The GOOSE receive function blocks are used to receive subscribed data from the GOOSE protocol. The validity of the data value is exposed as outputs of the function block as well as the validity of the communication. It is recommended to use these outputs to ensure that only valid data is handled on the subscriber IED. An example could be to control the external reservation before operating on a bay. In the figure below, the GOOSE_SPRCV is used to receive the status of the bay reservation. The validity of the received data is used in additional logic to guarantee that the value has good quality before operation on that bay.

**Figure 82: GOOSE_SPRCV and AND function blocks - checking the validity of the received data**

## 15.3 IEC/UCA 61850-9-2LE communication protocol

### 15.3.1 Introduction

Every IED can be provided with communication interfaces enabling it to connect to the process buses in order to get data from analog data acquisition units close to the process (primary apparatus), commonly known as Merging Units (MU). The protocol used in this case is the IEC/UCA 61850-9-2LE communication protocol.

The IEC/UCA 61850-9-2LE standard does not specify the quality of the sampled values. Thus, the accuracy of the current and voltage inputs to the merging unit and the inaccuracy added by the merging unit must be coordinated with the requirement for the actual type of protection function.

Factors influencing the accuracy of the sampled values from the merging unit are, for example, anti aliasing filters, frequency range, step response, truncating, A/D conversion inaccuracy, time tagging accuracy etc.

In principle, the accuracy of the current and voltage transformers, together with the merging unit, will have the same quality as the direct input of currents and voltages.

The process bus physical layout can be arranged in several ways, described in Annex B of the standard, depending on what are the needs for sampled data in a substation.
Figure 83: Example of a station configuration with separated process bus and station bus.

The IED can get analog values simultaneously from a classical CT or VT and from a Merging Unit, like in this example:

The merging units (MU) are called so because they can gather analog values from one or more measuring transformers, sample the data and send the data over process bus to other clients (or subscribers) in the system. Some merging units are able to get data from classical measuring transformers, others from non-conventional measuring transducers and yet others can pick up data from both types. The electronic part of a non-conventional measuring transducer (like a Rogowski coil or a capacitive divider) can represent a MU by itself as long as it can send sampled data over process bus.
15.3.2 Faulty merging unit for bay in service

When a merging unit goes faulty while the bay is in service, the protection functions connected to that merging unit get blocked. Also, protection functions configured in a 1 1/2 circuit breaker applications, where two SV streams from different merging units are combined get blocked. Thus, this has no effect on protection functions in a 1 1/2 circuit breaker configuration.

This can be resolved by connecting external binary input signals to the BLOCK input on the respective SMAI function blocks with the use of ACT. When the BLOCK input on a SMAI function is energized, the SMAI function delivers a magnitude of zero with good quality for all the channels. Thus, this has no effect on a busbar protection, nor protections in an 1 1/2 circuit breaker configuration.
SMAI function blocks exist in different cycle times, and all the SMAI blocks that receive SV streams from the merging units must have the block input signal configured in the same way to get the correct behavior.

![Configuration of current inputs using SMAIs in a 1 1/2 circuit breaker application.](image)

**Figure 85:** Configuration of current inputs using SMAIs in a 1 1/2 circuit breaker application.

**Procedure to bring protections back into service and enable maintenance of a faulty merging unit**

1. Disconnect bay.
2. Energize binary input, block of bay. Protections are now back in service.
3. Maintenance of the merging unit can start.

**Procedure to bring bay back into service after maintenance of a merging unit**

1. Energize merging unit.
2. De-energize binary input block of bay. Protections are now back in service.
3. Reconnect bay.

### 15.3.3 Bay out of service for maintenance

When a bay need maintenance and has energized merging unit connected, it is always a risk to get unplanned interruptions in the auxiliary power supply which may lead to unwanted blocking of protections.

This can be resolved by using the same ACT configuration recommendations and procedures as described in section [Faulty merging unit for bay in service](#).

### 15.3.4 Setting guidelines

Merging Units (MUs) have several settings on local HMI under:
• **Main menu/Configuration/Analog modules/MUx:92xx.** The corresponding settings are also available in PST (PCM600).
• **Main menu/Configuration/Communication/Merging units configuration/MUx:92xx.** The corresponding settings are also available in ECT (PCM600).

Xx can take value 1–4.

### 15.3.4.1 Specific settings related to the IEC/UCA 61850-9-2LE communication

The process bus communication IEC/UCA 61850-9-2LE has specific settings, similar to the analog inputs modules.

If there are more than one sample group involved, time synch is mandatory. If there is no time synchronization, the protection functions will be blocked due to condition blocking.

**CTStarPoint**: These parameters specify the direction to or from object. See also section "Setting of current channels".

**SyncLostMode**: If this parameter is set to *Block* and the IED hardware time synchronization is lost or the synchronization to the MU time is lost, the protection functions in the list "" will be blocked due to conditional blocking. If this parameter is set to *BlockOnLostUTC*, the protection functions in list "" are blocked if the IED hardware time synchronization is lost or the synchronization of the MU time is lost or the IED has lost global common synchronization (i.e. GPS, IRIG-B or PTP). *SYNCH* output will be set if IED hardware time synchronization is lost. *MUSYNCH* output will be set if either of MU or IED hardware time synchronization is lost.

Binary signals over LDCM are transmitted as valid and processed normally even when analog signals are transmitted as invalid due to loss of communication or loss of time synchronization.

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 Identification</th>
<th>Function description</th>
<th>IEC 61850 Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accidental energizing protection for synchronous generator</td>
<td>AEGPVOC</td>
<td>Two step overvoltage protection</td>
<td>OV2PTOV</td>
</tr>
<tr>
<td>Broken conductor check</td>
<td>BRCPTOC</td>
<td>Four step single phase overcurrent protection</td>
<td>PH4SPTOC</td>
</tr>
<tr>
<td>Capacitor bank protection</td>
<td>CBPGAPC</td>
<td>Radial feeder protection</td>
<td>PAPGAPC</td>
</tr>
<tr>
<td>Pole discordance protection</td>
<td>CCPDSC</td>
<td>Instantaneous phase overcurrent protection</td>
<td>PHPIOC</td>
</tr>
<tr>
<td>Breaker failure protection</td>
<td>CCRBRF</td>
<td>PoleSlip/Out-of-step protection</td>
<td>PSPPPAM</td>
</tr>
<tr>
<td>Breaker failure protection, single phase version</td>
<td>CCSRBF</td>
<td>Restricted earth fault protection, low impedance</td>
<td>REFPDIF</td>
</tr>
<tr>
<td>Current circuit supervision</td>
<td>CCSSPVC</td>
<td>Two step residual overvoltage protection</td>
<td>ROV2PTOV</td>
</tr>
<tr>
<td>Compensated over- and undervoltage protection</td>
<td>COUVGAPC</td>
<td>Rate-of-change frequency protection</td>
<td>SAPFRC</td>
</tr>
<tr>
<td>General current and voltage protection</td>
<td>CVGAPC</td>
<td>Overfrequency protection</td>
<td>SAPTOF</td>
</tr>
</tbody>
</table>

Table 29: Blocked protection functions if IEC/UCA 61850-9-2LE communication is interrupted and functions are connected to specific MUs

Table continues on next page.
<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 Identification</th>
<th>Function description</th>
<th>IEC 61850 Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current reversal and weak-end infeed logic for residual overcurrent protection</td>
<td>ECRWPSCH</td>
<td>Underfrequency protection</td>
<td>SAPTUF</td>
</tr>
<tr>
<td>Four step residual overcurrent protection</td>
<td>EF4PTOC</td>
<td>Sudden change in current variation</td>
<td>SCCVPTOC</td>
</tr>
<tr>
<td>Instantaneous residual overcurrent protection</td>
<td>EFPIOC</td>
<td>Sensitive Directional residual over current and power protection</td>
<td>SDEPSDE</td>
</tr>
<tr>
<td>Phase selection, quadrilateral characteristic with fixed angle</td>
<td>FDPSPDIS</td>
<td>Synchrocheck, energizing check, and synchronizing</td>
<td>SESRSYN</td>
</tr>
<tr>
<td>Faulty phase identification with load encroachment</td>
<td>FMPSPPDIS</td>
<td>Circuit breaker condition monitoring</td>
<td>SSCBR</td>
</tr>
<tr>
<td>Phase selection, quadrilateral characteristic with settable angle</td>
<td>FRPSPDIS</td>
<td>Insulation gas monitoring</td>
<td>SSIMG</td>
</tr>
<tr>
<td>Frequency time accumulation protection</td>
<td>FTAQFVR</td>
<td>Insulation liquid monitoring</td>
<td>SSIML</td>
</tr>
<tr>
<td>Fuse failure supervision</td>
<td>FUFSPPVC</td>
<td>Stub protection</td>
<td>STBPHTOC</td>
</tr>
<tr>
<td>Generator differential protection</td>
<td>GENPDIF</td>
<td>Transformer differential protection, two winding</td>
<td>T2WPDIS</td>
</tr>
<tr>
<td>Directional Overpower protection</td>
<td>GOPPDOP</td>
<td>Transformer differential protection, three winding</td>
<td>T3WPDIS</td>
</tr>
<tr>
<td>Generator rotor overload protection</td>
<td>GRPTTR</td>
<td>Automatic voltage control for tapchanger, single control</td>
<td>TRIATCC</td>
</tr>
<tr>
<td>Generator stator overload protection</td>
<td>GSPTTR</td>
<td>Automatic voltage control for tapchanger, parallel control</td>
<td>TR8ATCC</td>
</tr>
<tr>
<td>Directional Underpower protection</td>
<td>GUDDPDUP</td>
<td>Thermal overload protection, two time constants</td>
<td>TRPTTR</td>
</tr>
<tr>
<td>3Ph High impedance differential protection</td>
<td>HZPDIF</td>
<td>Two step undervoltage protection</td>
<td>UV2PTUV</td>
</tr>
<tr>
<td>Line differential protection, 3 CT sets, 2-3 line ends</td>
<td>L3CPDIF</td>
<td>Voltage differential protection</td>
<td>VDCPTOV</td>
</tr>
<tr>
<td>Line differential protection, 6 CT sets, 3-5 line ends</td>
<td>L6CPDIF</td>
<td>Fuse failure supervision</td>
<td>VDRFUF</td>
</tr>
<tr>
<td>Low active power and power factor protection</td>
<td>LAPPAGPC</td>
<td>Voltage-restrained time overcurrent protection</td>
<td>VRPVOC</td>
</tr>
<tr>
<td>Negative sequence overcurrent protection</td>
<td>LCNSPTOC</td>
<td>Local acceleration logic</td>
<td>ZCLCPSC</td>
</tr>
<tr>
<td>Negative sequence overvoltage protection</td>
<td>LCNSPTOV</td>
<td>Scheme communication logic for distance or overcurrent protection</td>
<td>ZCPSCH</td>
</tr>
<tr>
<td>Three phase overcurrent</td>
<td>LCP3PTOC</td>
<td>Current reversal and weak-end infeed logic for distance protection</td>
<td>ZCRWPSCH</td>
</tr>
</tbody>
</table>

Table continues on next page
<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>Function description</th>
<th>IEC 61850 identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three phase undercurrent</td>
<td>LCP3PTUC</td>
<td>Automatic switch onto fault logic, voltage and current based</td>
<td>ZCVPFSOF</td>
</tr>
<tr>
<td>Thermal overload protection, one time constant</td>
<td>LCPTTR</td>
<td>Under impedance protection for generator</td>
<td>ZGVPDIS</td>
</tr>
<tr>
<td>Zero sequence overcurrent protection</td>
<td>LCZSPTOC</td>
<td>Fast distance protection</td>
<td>ZMFCPDIS</td>
</tr>
<tr>
<td>Zero sequence overvoltage protection</td>
<td>LCZSPTOV</td>
<td>High speed distance protection</td>
<td>ZMFPDIS</td>
</tr>
<tr>
<td>Line differential coordination</td>
<td>LDLPSC</td>
<td>Distance measuring zone, quadrilateral characteristic for series compensated lines</td>
<td>ZMCAPIDIS</td>
</tr>
<tr>
<td>Additional security logic for differential protection</td>
<td>LDRGFC</td>
<td>Distance measuring zone, quadrilateral characteristic for series compensated lines</td>
<td>ZMCPDIS</td>
</tr>
<tr>
<td>Loss of excitation</td>
<td>LEXPDIS</td>
<td>Fullscheme distance protection, mho characteristic</td>
<td>ZMHPDIS</td>
</tr>
<tr>
<td>Thermal overload protection, one time constant</td>
<td>LFPTTR</td>
<td>Fullscheme distance protection, quadrilateral for earth faults</td>
<td>ZMMAPDIS</td>
</tr>
<tr>
<td>Loss of voltage check</td>
<td>LOVPTUV</td>
<td>Fullscheme distance protection, quadrilateral for earth faults</td>
<td>ZMMPDIS</td>
</tr>
<tr>
<td>Line differential protection 3 CT sets, with in zone transformers, 2-3 line ends</td>
<td>LT3CPDIF</td>
<td>Distance protection zone, quadrilateral characteristic</td>
<td>ZMQAPDIS</td>
</tr>
<tr>
<td>Line differential protection 6 CT sets, with in zone transformers, 3-5 line ends</td>
<td>LT6CPDIF</td>
<td>Distance protection zone, quadrilateral characteristic</td>
<td>ZMQPDIS</td>
</tr>
<tr>
<td>Negativ sequence time overcurrent protection for machines</td>
<td>NS2PTOC</td>
<td>Distance protection zone, quadrilateral characteristic, separate settings</td>
<td>ZMRAPDIS</td>
</tr>
<tr>
<td>Four step directional negative phase sequence overcurrent protection</td>
<td>NS4PTOC</td>
<td>Distance protection zone, quadrilateral characteristic, separate settings</td>
<td>ZMRPDIS</td>
</tr>
<tr>
<td>Four step phase overcurrent protection</td>
<td>OC4PTOC</td>
<td>Power swing detection</td>
<td>ZMRPSB</td>
</tr>
<tr>
<td>Overexcitation protection</td>
<td>OEXPVPH</td>
<td>Mho Impedance supervision logic</td>
<td>ZSMGAPC</td>
</tr>
<tr>
<td>Out-of-step protection</td>
<td>OOSPPAM</td>
<td>Transformer tank overcurrent protection</td>
<td>TPIIOC</td>
</tr>
<tr>
<td>Busbar differential protection, check zone</td>
<td>BCZPDIF</td>
<td>Busbar differential protection, bus interconnection xx</td>
<td>BICPTRC_x, (1≤x≤5)</td>
</tr>
<tr>
<td>Busbar differential protection, dynamic zone selection</td>
<td>BDZSGAPC</td>
<td>Busbar differential protection, zone 1</td>
<td>BZNPDIS_x, (1≤x≤6)</td>
</tr>
</tbody>
</table>

Table continues on next page
### Function description

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 Identification</th>
<th>Function description</th>
<th>IEC 61850 Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Busbar differential protection, single phase feeder xx</td>
<td>BFPTRC_Fx, (1≤x≤24)</td>
<td>Voltage delta supervision, 2 phase</td>
<td>DELVSPVC</td>
</tr>
<tr>
<td>Voltage delta supervision, 2 phase</td>
<td>DELVSPVC</td>
<td>Current delta supervision, 2 phase</td>
<td>DELISPVC</td>
</tr>
<tr>
<td>DELVSPVC</td>
<td></td>
<td>Current harmonic monitoring, 2 phase</td>
<td>CHMMHAN</td>
</tr>
</tbody>
</table>

#### 15.3.4.2 Setting examples for IEC/UCA 61850-9-2LE and time synchronization

The IED and the Merging Units (MU) should use the same time reference especially if analog data is used from several sources, for example from an internal TRM and an MU, or if several physical MUs are used. Having the same time reference is important to correlate data so that channels from different sources refer to the correct phase angle.

When only one MU is used as an analog source, it is theoretically possible to do without time synchronization. However, this would mean that timestamps for analog and binary data/events become uncorrelated. If the IED has no time synchronization source configured, then the binary data/events will be synchronized with the merging unit. However, the global/complete time might not be correct. Disturbance recordings then appear incorrect since analog data is timestamped by MU, and binary events use the internal IED time. It is thus recommended to use time synchronization also when analog data emanate from only one MU.

An external time source can be used to synchronize both the IED and the MU. It is also possible to use the MU as a clock master to synchronize the IED from the MU. When using an external clock, it is possible to set the IED to be synchronized via PPS, IRIG-B or PTP. It is also possible to use an internal GPS receiver in the IED (if the external clock is using GPS).
Using PTP for synchronizing the MU

![Diagram showing the synchronization process]

**Figure 86:** Setting example with PTP synchronization

Settings on the local HMI under **Main menu/Configuration/Time/Synchronization/TIMESYNCHGEN:1/IEC61850-9-2:**

- **HwSyncSrc:** is not used as the SW-time and HW-time are connected with each other due to PTP
- **SyncLostMode:** set to **Block** to block protection functions if time synchronization is lost or set to **BlockOnLostUTC** if the protection functions are to be blocked when global common synchronization is lost
- **SyncAccLevel:** can be set to 1μs since this corresponds to a maximum phase angle error of 0.018 degrees at 50Hz

Settings on the local HMI under **Main menu/Configuration/Communication/Ethernet configuration/Access point/AP_X:**

- **Operation:** On
- **PTP:** On

Two status monitoring signals can be:

- **SYNCH** signal on the MUx function block indicates that protection functions are blocked due to loss of internal time synchronization to the IED
- **MUSYNCH** signal on the MUx function block monitors the synchronization flag *smpSynch* in the datastream and IED hardware time synchronization.
Using MU for time synchronization via PPS

This example is not valid when GPS time is used for differential protection or when PTP is enabled.

![Diagram of IED, MU, and PPS synchronization]

**Figure 87: Setting example when MU is the synchronizing source**

Settings on the local HMI under **Main menu/Configuration/Time/Synchronization/TIMESYNCHGEN:1/IEC61850-9-2**:

- *HwSyncSrc* set to *PPS* as generated by the MU (ABB MU)
- *SyncLostMode* : set to *Block* to block protection functions if time synchronization is lost
- *SyncAccLevel* can be set to 4μs since this corresponds to a maximum phase angle error of 0.072 degrees at 50Hz

Settings on the local HMI under **Main menu/Configuration/Time/Synchronization/TIMESYNCHGEN:1/General**:

- *fineSyncSource* can be set to something different to correlate events and data to other IEDs in the station.

Two status monitoring signals can be:

- *SYNCH* signal on the MUx function block indicates that protection functions are blocked due to loss of internal time synchronization to the IED.
- *MUSYNCH* signal on the MUx function block monitors the synchronization flag *smpSynch* in the datastream and IED hardware time synchronization.

*SMPLLOST* indicates that merging unit data are generated by internal substitution or one/more channel's Quality is not good or merging unit is in Testmode/detailed quality=Test, IED is not in test mode.

**Using external clock for time synchronization**

This example is not valid when GPS time is used for differential protection or when PTP is enabled.
Figure 88: Setting example with external synchronization

Settings on the local HMI under **Main menu/Configuration/Time/Synchronization/TIMESYNCHGEN:1/IEC61850-9-2:**

- **HwSyncSrc:** set to **PPS/IRIG-B** depending on available outputs on the clock.
- **SyncLostMode:** set to **Block** to block protection functions if time synchronization is lost.
- **SyncAccLevel:** can be set to **4μs** since this corresponds to a maximum phase angle error of 0.072 degrees at 50Hz.
- **fineSyncSource:** should be set to **IRIG-B** if available from the clock. If **PPS** is used for **HWSyncSrc,** "full-time" has to be acquired from another source. If station clock is on the local area network (LAN) and has an sntp-server, this is one option.

Two status monitoring signals can be:

- **SYNCH** signal on the MUx function block indicates that protection functions are blocked due to loss of internal time synchronization to the IED (that is loss of the hardware **synchSrc**).
- **MUSYNCH** signal on the MUx function block monitors the synchronization flag **smpSynch** in the datastream and IED hardware time synchronization.

**No time synchronization**

This example is not valid when GPS time is used for differential protection or when PTP is enabled.
Figure 89: Setting example without time synchronization

It is also possible to use IEC/UCA 61850-9-2LE communication without time synchronization.

Settings on the local HMI under Main menu/Configuration/Time/Synchronization/TIMESYNCHGEN:1/IEC61850-9-2:

- $HwSyncSrc$: set to Off
- $SyncLostMode$: set to No block to indicate that protection functions are not blocked
- $SyncAccLevel$: set to unspecified

Two status monitoring signals with no time synchronization:

- $SYNCH$ signal on the MUx function block indicates that protection functions are blocked due to loss of internal time synchronization to the IED. Since $SyncLostMode$ is set to No block, this signal is not set.
- $MUSYNCH$ signal on the MUx function block is set if the datastream indicates time synchronization loss. However, protection functions are not blocked.

To get higher availability in protection functions, it is possible to avoid blocking during time synchronization loss if there is a single source of analog data. This means that if there is only one physical MU and no TRM, parameter $SyncLostMode$ is set to No block but parameter $HwSyncSrc$ is still set to PPS. This maintains analog and binary data correlation in disturbance recordings without blocking protection functions if PPS is lost.

**15.3.5 IEC 61850 quality expander QUALEXP**

The quality expander component is used to display the detailed quality of an IEC/UCA 61850-9-2LE analog channel. The component expands the channel quality output of a Merging Unit analog channel received in the IED as per the IEC 61850-7-3 standard. This component can be used during the ACT monitoring to get the particular channel quality of the Merging Unit.

Figure 90 depicts the usage of the quality expander block in ACT.
Figure 90: Quality expander block in ACT

The expanded quality bits are visible on the outputs as per IEC 61850-7-3 standard. When written to IED, the configuration will show the expanded form of the respective MU channel quality information during the online monitoring in the ACT.

The quality expander function is intended for monitoring purposes, not for being used in a logic controlling the behaviour of the protection or control functions in the IED. The function outputs are updated once every second and, therefore, do not reflect the quality bits in real time.

15.4 LON communication protocol

15.4.1 Application

Figure 91: Example of LON communication structure for a station automation system

An optical network can be used within the station automation system. This enables communication with the IEDs through the LON bus from the operator’s workplace, from the control center and also from other IEDs via bay-to-bay horizontal communication. For LON communication an SLM card should be ordered for the IEDs.
The fiber optic LON bus is implemented using either glass core or plastic core fiber optic cables.

**Table 30: Specification of the fiber optic connectors**

<table>
<thead>
<tr>
<th></th>
<th>Glass fiber</th>
<th>Plastic fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable connector</td>
<td>ST-connector</td>
<td>snap-in connector</td>
</tr>
<tr>
<td>Cable diameter</td>
<td>62.5/125 m</td>
<td>1 mm</td>
</tr>
<tr>
<td>Max. cable length</td>
<td>1000 m</td>
<td>10 m</td>
</tr>
<tr>
<td>Wavelength</td>
<td>820-900 nm</td>
<td>660 nm</td>
</tr>
<tr>
<td>Transmitted power</td>
<td>-13 dBm (HFBR-1414)</td>
<td>-13 dBm (HFBR-1521)</td>
</tr>
<tr>
<td>Receiver sensitivity</td>
<td>-24 dBm (HFBR-2412)</td>
<td>-20 dBm (HFBR-2521)</td>
</tr>
</tbody>
</table>

**The LON Protocol**

The LON protocol is specified in the LonTalkProtocol Specification Version 3 from Echelon Corporation. This protocol is designed for communication in control networks and is a peer-to-peer protocol where all the devices connected to the network can communicate with each other directly. For more information of the bay-to-bay communication, refer to the section Multiple command function.

**Hardware and software modules**

The hardware needed for applying LON communication depends on the application, but one very central unit needed is the LON Star Coupler and optical fibers connecting the star coupler to the IEDs. To interface the IEDs from the MicroSCADA with Classic Monitor, application library LIB520 is required.

The HV Control 670 software module is included in the LIB520 high-voltage process package, which is a part of the Application Software Library in MicroSCADA applications.

The HV Control 670 software module is used for control functions in the IEDs. The module contains a process picture, dialogues and a tool to generate a process database for the control application in MicroSCADA.

When using MicroSCADA Monitor Pro instead of the Classic Monitor, SA LIB is used together with 670 series Object Type files.

Use the LON Network Tool (LNT) to set the LON communication. This is a software tool applied as one node on the LON bus. To communicate via LON, the IEDs need to know

- The node addresses of the other connected IEDs.
- The network variable selectors to be used.

This is organized by LNT.

The node address is transferred to LNT via the local HMI by setting the parameter `ServicePinMsg = Yes`. The node address is sent to LNT via the LON bus, or LNT can scan the network for new nodes.

The communication speed of the LON bus is set to the default of 1.25 Mbit/s. This can be changed by LNT.
15.4.2 MULTICMDRCV and MULTICMDSND

15.4.2.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple command and receive</td>
<td>MULTICMDRCV</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Multiple command and send</td>
<td>MULTICMDSND</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

15.4.2.2 Application

The IED provides two function blocks enabling several IEDs to send and receive signals via the interbay bus. The sending function block, MULTICMDSND, takes 16 binary inputs. LON enables these to be transmitted to the equivalent receiving function block, MULTICMDRCV, which has 16 binary outputs.

15.4.2.3 Setting guidelines

**Settings**

The parameters for the multiple command function are set via PCM600.

The *Mode* setting sets the outputs to either a *Steady* or *Pulsed* mode.

15.5 SPA communication protocol

15.5.1 Application

SPA communication protocol is an alternative to IEC 60870-5-103, and they use the same rear communication port.

When communicating with a PC connected to the utility substation LAN via WAN and the utility office LAN (see Figure *92*), and when using the rear optical Ethernet port, the only hardware required for a station monitoring system is:

- Optical fibers from the IED to the utility substation LAN
- PC connected to the utility office LAN
SPA communication is mainly used for the Station Monitoring System. It can include different IEDs with remote communication possibilities. Connection to a PC can be made directly (if the PC is located in the substation), via a telephone modem through a telephone network with ITU (former CCITT) characteristics or via a LAN/WAN connection.

<table>
<thead>
<tr>
<th>Material</th>
<th>Distance Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>glass</td>
<td>&lt;1000 m according to optical budget</td>
</tr>
<tr>
<td>plastic</td>
<td>&lt;25 m (inside cubicle) according to optical budget</td>
</tr>
</tbody>
</table>

**Functionality**

The SPA protocol V2.5 is an ASCII-based protocol for serial communication. The communication is based on a master-slave principle, where the IED is a slave and the PC is the master. Only one master can be applied on each fiber optic loop. A program is required in the master computer for interpretation of the SPA-bus codes and for translation of the data that should be sent to the IED.

For the specification of the SPA protocol V2.5, refer to SPA-bus Communication Protocol V2.5.

**15.5.2 Setting guidelines**

SPA, IEC 60870-5-103 and DNP3 use the same rear communication port. This port can be set for SPA use on the local HMI under **Main menu /Configuration /Communication /Station communication/Port configuration/SLM optical serial port/PROTOCOL:1**. When the communication protocol is selected, the IED is automatically restarted, and the port then operates as a SPA port.

The SPA communication setting parameters are set on the local HMI under **Main menu/Configuration/Communication/Station communication/SPA/SPA:1**.

The most important SPA communication setting parameters are **SlaveAddress** and **BaudRate**. They are essential for all communication contact to the IED. **SlaveAddress** and **BaudRate** can be set only on the local HMI for rear and front channel communication.

**SlaveAddress** can be set to any value between 1–899 as long as the slave number is unique within the used SPA loop. **BaudRate** (communication speed) can be set between 300–38400 baud. **BaudRate** should be the same for the whole station although different communication speeds in a loop are possible. If different communication speeds are used in the same fiber...
optical loop or RS485 network, take this into account when making the communication setup in the communication master (the PC).

With local fiber optic communication, communication speed is usually set to 19200 or 38400 baud. With telephone communication, the speed setting depends on the quality of the connection and the type of modem used. Refer to technical data to determine the rated communication speed for the selected communication interfaces.

The IED does not adapt its speed to the actual communication conditions because the communication speed is set on the local HMI.

### 15.6 IEC 60870-5-103 communication protocol

#### 15.6.1 Application

![Diagram of IEC 60870-5-103 communication structure for a substation automation system](IEC05000680-4-en.vsd)

**Figure 93**: Example of IEC 60870-5-103 communication structure for a substation automation system

IEC 60870-5-103 communication protocol is mainly used when a protection IED communicates with a third party control or monitoring system. This system must have software that can interpret the IEC 60870-5-103 communication messages.

When communicating locally in the station using a Personal Computer (PC) or a Remote Terminal Unit (RTU) connected to the Communication and processing module, the only hardware needed is optical fibers and an opto/electrical converter for the PC/RTU, or a RS-485 connection depending on the used IED communication interface.
15.6.1.1 Functionality

IEC 60870-5-103 is an unbalanced (master-slave) protocol for coded-bit serial communication exchanging information with a control system. In IEC terminology a primary station is a master and a secondary station is a slave. The communication is based on a point-to-point principle. The master must have software that can interpret the IEC 60870-5-103 communication messages. For detailed information about IEC 60870-5-103, refer to IEC 60870 standard part 5: Transmission protocols, and to the section 103, Companion standard for the informative interface of protection equipment.

15.6.1.2 Design

General

The protocol implementation consists of the following functions:

- Event handling
- Report of analog service values (measurands)
- Fault location
- Command handling
  - Autorecloser ON/OFF
  - Teleprotection ON/OFF
  - Protection ON/OFF
  - LED reset
  - Characteristics 1 - 4 (Setting groups)
- File transfer (disturbance files)
- Time synchronization

Hardware

When communicating locally with a Personal Computer (PC) or a Remote Terminal Unit (RTU) in the station, using the SPA/IEC port, the only hardware needed is:
- Optical fibers, glass/plastic
- Opto/electrical converter for the PC/RTU
- PC/RTU

Commands

The commands defined in the IEC 60870-5-103 protocol are represented in dedicated function blocks. These blocks have output signals for all available commands according to the protocol. For more information, refer to the Communication protocol manual, IEC 60870-5-103.

- IED commands in control direction

  Function block with defined IED functions in control direction, I103IEDCMD. This block use PARAMETR as FUNCTION TYPE, and INFORMATION NUMBER parameter is defined for each output signal.

- Function commands in control direction

  Function block with pre-defined functions in control direction, I103CMD. This block includes the FUNCTION TYPE parameter, and the INFORMATION NUMBER parameter is defined for each output signal.

- Function commands in control direction

  Function block with user defined functions in control direction, I103UserCMD. These function blocks include the FUNCTION TYPE parameter for each block in the private range, and the INFORMATION NUMBER parameter for each output signal.
Status

For more information on the function blocks below, refer to the *Communication protocol manual, IEC 60870-5-103.*

The events created in the IED available for the IEC 60870-5-103 protocol are based on the:

- **IED status indication in monitor direction**

  Function block with defined IED functions in monitor direction, I103IED. This block use PARAMETER as FUNCTION TYPE, and INFORMATION NUMBER parameter is defined for each input signal.

- **Function status indication in monitor direction, user-defined**

  Function blocks with user defined input signals in monitor direction, I103UserDef. These function blocks include the FUNCTION TYPE parameter for each block in the private range, and the INFORMATION NUMBER parameter for each input signal.

- **Supervision indications in monitor direction**

  Function block with defined functions for supervision indications in monitor direction, I103Superv. This block includes the FUNCTION TYPE parameter, and the INFORMATION NUMBER parameter is defined for each output signal.

- **Earth fault indications in monitor direction**

  Function block with defined functions for earth fault indications in monitor direction, I103EF. This block includes the FUNCTION TYPE parameter, and the INFORMATION NUMBER parameter is defined for each output signal.

- **Fault indications in monitor direction**

  Function block with defined functions for fault indications in monitor direction, I103FLTPROT. This block includes the FUNCTION TYPE parameter, and the INFORMATION NUMBER parameter is defined for each input signal.

  This block is suitable for distance protection, line differential, transformer differential, overcurrent and earth-fault protection functions.

- **Autorecloser indications in monitor direction**

  Function block with defined functions for autorecloser indications in monitor direction, I103AR. This block includes the FUNCTION TYPE parameter, and the INFORMATION NUMBER parameter is defined for each output signal.

Measurands

The measurands can be included as type 3.1, 3.2, 3.3, 3.4 and type 9 according to the standard.

- **Measurands in public range**

  Function block that reports all valid measuring types depending on connected signals, I103Meas.

- **Measurands in private range**
Function blocks with user defined input measurands in monitor direction, I103MeasUsr. These function blocks include the FUNCTION TYPE parameter for each block in the private range, and the INFORMATION NUMBER parameter for each block.

Fault location
The fault location is expressed in reactive ohms. In relation to the line length in reactive ohms, it gives the distance to the fault in percent. The data is available and reported when the fault locator function is included in the IED.

Disturbance recordings
- The transfer functionality is based on the Disturbance recorder function. The analog and binary signals recorded will be reported to the master by polling. The eight last disturbances that are recorded are available for transfer to the master. A file that has been transferred and acknowledged by the master cannot be transferred again.
- The binary signals that are included in the disturbance recorder are those that are connected to the disturbance function blocks B1RBDR to B22RBDR. These function blocks include the function type and the information number for each signal. For more information on the description of the Disturbance report in the Technical reference manual. The analog channels, that are reported, are those connected to the disturbance function blocks A1RADR to A4RADR. The eight first ones belong to the public range and the remaining ones to the private range.

15.6.2 Settings

15.6.2.1 Settings for RS485 and optical serial communication

General settings
SPA, DNP and IEC 60870-5-103 can be configured to operate on the SLM optical serial port while DNP and IEC 60870-5-103 additionally can utilize the RS485 port. A single protocol can be active on a given physical port at any time.

Two different areas in the HMI are used to configure the IEC 60870-5-103 protocol.

1. The port specific IEC 60870-5-103 protocol parameters are configured under:
   Main menu/Configuration/Communication/Station Communication/IEC60870-5-103/
   - <config-selector>
   - SlaveAddress
   - BaudRate
   - RevPolarity (optical channel only)
   - CycMeasRepTime
   - MasterTimeDomain
   - TimeSyncMode
   - EvalTimeAccuracy
   - EventRepMode
   - CmdMode
   - RepIntermediatePos

   <config-selector> is:
   - “OPTICAL103:1” for the optical serial channel on the SLM
   - “RS485103:1” for the RS485 port

2. The protocol to activate on a physical port is selected under:
   Main menu/Configuration/Communication/Station Communication/Port configuration/
   - RS485 port
The general settings for IEC 60870-5-103 communication are the following:

- **SlaveAddress and BaudRate**: Settings for slave number and communication speed (baud rate). The slave number can be set to any value between 1 and 254. The communication speed can be set either to 9600 bits/s or 19200 bits/s.
- **RevPolarity**: Setting for inverting the light (or not). Standard IEC 60870-5-103 setting is On.
- **CycMeasRepTime**: See I103MEAS function block for more information.
- **EventRepMode**: Defines the mode for how events are reported. The event buffer size is 1000 events.

### Event reporting mode

If **EventRepMode = SeqOfEvent**, all GI and spontaneous events will be delivered in the order they were generated by BSW. The most recent value is the latest value delivered. All GI data from a single block will come from the same cycle.

If **EventRepMode = HiPriSpont**, spontaneous events will be delivered prior to GI event. To prevent old GI data from being delivered after a new spontaneous event, the pending GI event is modified to contain the same value as the spontaneous event. As a result, the GI dataset is not time-correlated.

### 15.6.2.2 Settings from PCM600

**I103USEDEF**

For each input of the I103USEDEF function there is a setting for the information number of the connected signal. The information number can be set to any value between 0 and 255. To get proper operation of the sequence of events the event masks in the event function is to be set to ON_CHANGE. For single-command signals, the event mask is to be set to ON_SET.

In addition there is a setting on each event block for function type. Refer to description of the Main Function type set on the local HMI.

**Commands**

As for the commands defined in the protocol there is a dedicated function block with eight output signals. Use PCM600 to configure these signals. To realize the BlockOfInformation command, which is operated from the local HMI, the output BLKINFO on the IEC command function block ICOM has to be connected to an input on an event function block. This input must have the information number 20 (monitor direction blocked) according to the standard.
Disturbance Recordings
For each input of the Disturbance recorder function there is a setting for the information number of the connected signal. The function type and the information number can be set to any value between 0 and 255. To get INF and FUN for the recorded binary signals, there are parameters on the disturbance recorder for each input. The user must set these parameters to whatever he connects to the corresponding input.

Refer to description of Main Function type set on the local HMI.

Recorded analog channels are sent with ASDU26 and ASDU31. One information element in these ASDUs is called ACC, and it indicates the actual channel to be processed. The channels on disturbance recorder are sent with an ACC as shown in Table 31.

Table 31: Channels on disturbance recorder sent with a given ACC

<table>
<thead>
<tr>
<th>DRA#-Input</th>
<th>ACC</th>
<th>IEC 60870-5-103 meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>IL1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>IL2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>IL3</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>IN</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>UL1</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>UL2</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>UL3</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>UN</td>
</tr>
<tr>
<td>9</td>
<td>64</td>
<td>Private range</td>
</tr>
<tr>
<td>10</td>
<td>65</td>
<td>Private range</td>
</tr>
<tr>
<td>11</td>
<td>66</td>
<td>Private range</td>
</tr>
<tr>
<td>12</td>
<td>67</td>
<td>Private range</td>
</tr>
<tr>
<td>13</td>
<td>68</td>
<td>Private range</td>
</tr>
<tr>
<td>14</td>
<td>69</td>
<td>Private range</td>
</tr>
<tr>
<td>15</td>
<td>70</td>
<td>Private range</td>
</tr>
<tr>
<td>16</td>
<td>71</td>
<td>Private range</td>
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<td>17</td>
<td>72</td>
<td>Private range</td>
</tr>
<tr>
<td>18</td>
<td>73</td>
<td>Private range</td>
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<tr>
<td>19</td>
<td>74</td>
<td>Private range</td>
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<td>20</td>
<td>75</td>
<td>Private range</td>
</tr>
<tr>
<td>21</td>
<td>76</td>
<td>Private range</td>
</tr>
<tr>
<td>22</td>
<td>77</td>
<td>Private range</td>
</tr>
<tr>
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</tr>
<tr>
<td>24</td>
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<td>25</td>
<td>80</td>
<td>Private range</td>
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<td>26</td>
<td>81</td>
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</tr>
<tr>
<td>27</td>
<td>82</td>
<td>Private range</td>
</tr>
<tr>
<td>28</td>
<td>83</td>
<td>Private range</td>
</tr>
<tr>
<td>29</td>
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<td>Private range</td>
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<td>30</td>
<td>85</td>
<td>Private range</td>
</tr>
<tr>
<td>31</td>
<td>86</td>
<td>Private range</td>
</tr>
<tr>
<td>32</td>
<td>87</td>
<td>Private range</td>
</tr>
</tbody>
</table>

Table continues on next page
### 15.6.3 Function and information types

Product type IEC103mainFunType value Comment:

- **REL 128** Compatible range
- **REC 242** Private range, use default
- **RED 192** Compatible range
- **RET 176** Compatible range
- **REB 207** Private range
- **REQ 245** Private range

Refer to the tables in the Technical reference manual /Station communication, specifying the information types supported by the communication protocol IEC 60870-5-103.

To support the information, corresponding functions must be included in the protection IED.

There is no representation for the following parts:

- Generating events for test mode
- Cause of transmission: Info no 11, Local operation

Glass or plastic fiber should be used. BFOC/2.5 is the recommended interface to use (BFOC/2.5 is the same as ST connectors). ST connectors are used with the optical power as specified in standard.

For more information, refer to IEC standard IEC 60870-5-103.

### 15.7 DNP3 Communication protocol

#### 15.7.1 Application

For more information on the application and setting guidelines for the DNP3 communication protocol refer to the DNP3 Communication protocol manual.
Section 16  Security

16.1  Authority status ATHSTAT

16.1.1  Application

Authority status (ATHSTAT) function is an indication function block, which informs about two events related to the IED and the user authorization:

- the fact that at least one user has tried to log on wrongly into the IED and it was blocked (the output USRBLKED)
- the fact that at least one user is logged on (the output LOGGEDON)

The two outputs of ATHSTAT function can be used in the configuration for different indication and alarming reasons, or can be sent to the station control for the same purpose.

16.2  Self supervision with internal event list INTERRSIG

16.2.1  Application

The protection and control IEDs have many functions included. The included self-supervision with internal event list function block provides good supervision of the IED. The fault signals make it easier to analyze and locate a fault.

Both hardware and software supervision is included and it is also possible to indicate possible faults through a hardware contact on the power supply module and/or through the communication.

Internal events are generated by the built-in supervisory functions. The supervisory functions supervise the status of the various modules in the IED and, in case of failure, a corresponding event is generated. Similarly, when the failure is corrected, a corresponding event is generated.

Apart from the built-in supervision of the various modules, events are also generated when the status changes for the:

- built-in real time clock (in operation/out of order).
- external time synchronization (in operation/out of order).

Events are also generated:

- whenever any setting in the IED is changed.

The internal events are time tagged with a resolution of 1 ms and stored in a list. The list can store up to 40 events. The list is based on the FIFO principle, that is, when it is full, the oldest event is overwritten. The list contents cannot be modified, but the whole list can be cleared using the Reset menu in the LHMI.

The list of internal events provides valuable information, which can be used during commissioning and fault tracing.
The information can, in addition to be viewed on the built in HMI, also be retrieved with the aid of a PC with PCM600 installed and by using the Event Monitoring Tool. The PC can either be connected to the front port, or to the port at the back of the IED.

16.3 Change lock CHNGLCK

16.3.1 Application

Change lock function CHNGLCK is used to block further changes to the IED configuration once the commissioning is complete. The purpose is to make it impossible to perform inadvertent IED configuration and setting changes.

However, when activated, CHNGLCK will still allow the following actions that does not involve reconfiguring of the IED:

- Monitoring
- Reading events
- Resetting events
- Reading disturbance data
- Clear disturbances
- Reset LEDs
- Reset counters and other runtime component states
- Control operations
- Set system time
- Enter and exit from test mode
- Change of active setting group

The binary input controlling the function is defined in ACT or SMT. The CHNGLCK function is configured using ACT.

LOCK Binary input signal that will activate/deactivate the function, defined in ACT or SMT.

When CHNGLCK has a logical one on its input, then all attempts to modify the IED configuration and setting will be denied and the message "Error: Changes blocked" will be displayed on the local HMI; in PCM600 the message will be "Operation denied by active ChangeLock". The CHNGLCK function should be configured so that it is controlled by a signal from a binary input card. This guarantees that by setting that signal to a logical zero, CHNGLCK is deactivated. If any logic is included in the signal path to the CHNGLCK input, that logic must be designed so that it cannot permanently issue a logical one to the CHNGLCK input. If such a situation would occur in spite of these precautions, then please contact the local ABB representative for remedial action.
16.4 Denial of service SCHLCCH/RCHLCCH

16.4.1 Application

The denial of service functionality is designed to limit the CPU load that can be produced by Ethernet network traffic on the IED. The communication facilities must not be allowed to compromise the primary functionality of the device. All inbound network traffic will be quota controlled so that too heavy network loads can be controlled. Heavy network load might for instance be the result of malfunctioning equipment connected to the network.

The functions Access point diagnostics function block measure the IED load from communication and, if necessary, limit it for not jeopardizing the IEDs control and protection functionality due to high CPU load. The function has the following denial of service related outputs:

- LINKSTS indicates the Ethernet link status for the rear ports (single communication)
- CHALISTS and CHBLISTS indicates the Ethernet link status for the rear ports channel A and B (redundant communication)
- LinkStatus indicates the Ethernet link status for the front port

16.4.2 Setting guidelines

The function does not have any parameters available in the local HMI or PCM600.
Section 17  Basic IED functions

17.1  IED identifiers TERMINALID

17.1.1  Application

IED identifiers (TERMINALID) function allows the user to identify the individual IED in the system, not only in the substation, but in a whole region or a country.

Use only characters A-Z, a-z and 0-9 in station, object and unit names.

17.2  Product information PRODINF

17.2.1  Application

Product information contains unchangeable data that uniquely identifies the IED.

Product information data is visible on the local HMI under Main menu/Diagnostics/IED status/Product identifiers and under Main menu/Diagnostics/IED Status/Identifiers:

Product information data is visible on the local HMI under Main menu/Diagnostics/IED status/Product identifiers and under Main menu/Diagnostics/IED Status/Identifiers:

- ProductVer
- ProductDef
- FirmwareVer
- SerialNo
- OrderingNo
- ProductionDate
- IEDProdType

Figure 95: IED summary
This information is very helpful when interacting with ABB product support (for example during repair and maintenance).

17.2.2  Factory defined settings

The factory defined settings are very useful for identifying a specific version and very helpful in the case of maintenance, repair, interchanging IEDs between different Substation Automation Systems and upgrading. The factory made settings can not be changed by the customer. They can only be viewed. The settings are found in the local HMI under Main menu/Diagnostics/IED status/Product identifiers

The following identifiers are available:

- IEDProdType
  - Describes the type of the IED. Example: REL650
- ProductDef
• Describes the release number from the production. Example: 2.1.0

• FirmwareVer
  • Describes the firmware version.
  • The firmware version can be checked from **Main menu/Diagnostics/IED status/ Product identifiers**
  • Firmware version numbers run independently from the release production numbers. For every release number there can be one or more firmware versions depending on the small issues corrected in between releases.

• ProductVer
  • Describes the product version. Example: 2.1.0

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>is the Major version of the manufactured product this means, new platform of the product</td>
</tr>
<tr>
<td>2</td>
<td>is the Minor version of the manufactured product this means, new functions or new hardware added to the product</td>
</tr>
<tr>
<td>3</td>
<td>is the Major revision of the manufactured product this means, functions or hardware is either changed or enhanced in the product</td>
</tr>
</tbody>
</table>

• IEDMainFunType
  • Main function type code according to IEC 60870-5-103. Example: 128 (meaning line protection).

• SerialNo
• OrderingNo
• ProductionDate

### 17.3 Measured value expander block **RANGE_XP**

#### 17.3.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured value expander block</td>
<td>RANGE_XP</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 17.3.2 Application

The current and voltage measurements functions (CVMMXN, CMMXU, VMMXU and VNMMXU), current and voltage sequence measurement functions (CMSQI and VMSQI) and IEC 61850 generic communication I/O functions (MVGAPC) are provided with measurement supervision functionality. All measured values can be supervised with four settable limits, that is low-low limit, low limit, high limit and high-high limit. The measure value expander block (RANGE_XP) has been introduced to be able to translate the integer output signal from the measuring functions to 5 binary signals, that is below low-low limit, below low limit, normal, above high-high limit or above high limit. The output signals can be used as conditions in the configurable logic.

#### 17.3.3 Setting guidelines

There are no settable parameters for the measured value expander block function.
17.4 Parameter setting groups

17.4.1 Application

Six sets of settings are available to optimize IED operation for different power system conditions. By creating and switching between fine tuned setting sets, either from the local HMI or configurable binary inputs, results in a highly adaptable IED that can cope with a variety of power system scenarios.

Different conditions in networks with different voltage levels require highly adaptable protection and control units to best provide for dependability, security and selectivity requirements. Protection units operate with a higher degree of availability, especially, if the setting values of their parameters are continuously optimized according to the conditions in the power system.

Operational departments can plan for different operating conditions in the primary equipment. The protection engineer can prepare the necessary optimized and pre-tested settings in advance for different protection functions. Six different groups of setting parameters are available in the IED. Any of them can be activated through the different programmable binary inputs by means of external or internal control signals.

A function block, SETGRPS, defines how many setting groups are used. Setting is done with parameter MAXSETGR and shall be set to the required value for each IED. Only the number of setting groups set will be available in the Parameter Setting tool for activation with the ActiveGroup function block.

17.4.2 Setting guidelines

The setting ActiveSetGrp, is used to select which parameter group to be active. The active group can also be selected with configured input to the function block SETGRPS.

The length of the pulse, sent out by the output signal SETCHGD when an active group has changed, is set with the parameter t.

The parameter MAXSETGR defines the maximum number of setting groups in use to switch between. Only the selected number of setting groups will be available in the Parameter Setting tool (PST) for activation with the ActiveGroup function block.

17.5 Rated system frequency PRIMVAL

17.5.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary system values</td>
<td>PRIMVAL</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

17.5.2 Application

The rated system frequency and phase rotation direction are set under Main menu/Configuration/Power system/Primary Values in the local HMI and PCM600 parameter setting tree.
17.5.3 Setting guidelines

Set the system rated frequency. Refer to section "Signal matrix for analog inputs SMAI" for description on frequency tracking.

17.6 Summation block 3 phase 3PHSUM

17.6.1 Application

The analog summation block 3PHSUM function block is used in order to get the sum of two sets of 3 phase analog signals (of the same type) for those IED functions that might need it.

17.6.2 Setting guidelines

The summation block receives the three-phase signals from SMAI blocks. The summation block has several settings.

**SummationType**: Summation type (Group 1 + Group 2, Group 1 - Group 2, Group 2 - Group 1 or – (Group 1 + Group 2)).

**DFTReference**: The reference DFT block (InternalDFT Ref, DFTRefGrp1 or External DFT ref).

- **DFTRefGrp1**: This setting means use own internal adaptive DFT reference (this setting makes the SUM3PH self DFT adaptive, that is, it will use the measured frequency for the summation signal to adapt DFT).
- **InternalDFTRef**: Gives fixed window DFT (to nominal system frequency).
- **ExternalDFTRef**: This setting means that the DFT samples-per-cycle (adaptive DFT) will be controlled by SMAI1 SPFCOUT.

**FreqMeasMinVal**: The minimum value of the voltage for which the frequency is calculated, expressed as percent of UBasebase voltage setting (for each instance x).

**GlobalBaseSel**: Selects the global base value group used by the function to define (IBase), (UBase) and (SBase).

17.7 Global base values GBASVAL

17.7.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global base values</td>
<td>GBASVAL</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
### 17.7.2 Application

Global base values function (GBASVAL) is used to provide global values, common for all applicable functions within the IED. One set of global values consists of values for current, voltage and apparent power and it is possible to have twelve different sets.

This is an advantage since all applicable functions in the IED use a single source of base values. This facilitates consistency throughout the IED and also facilitates a single point for updating values when necessary.

Each applicable function in the IED has a parameter, *GlobalBaseSel*, defining one out of the twelve sets of GBASVAL functions.

### 17.7.3 Setting guidelines

- **UBase**: Phase-to-phase voltage value to be used as a base value for applicable functions throughout the IED.
- **IBase**: Phase current value to be used as a base value for applicable functions throughout the IED.
- **SBase**: Standard apparent power value to be used as a base value for applicable functions throughout the IED, typically $S_{Base} = \sqrt{3} \cdot U_{Base} \cdot I_{Base}$.

### 17.8 Signal matrix for binary inputs SMBl

#### 17.8.1 Application

The Signal matrix for binary inputs function SMBl is used within the Application Configuration tool in direct relation with the Signal Matrix tool. SMBl represents the way binary inputs are brought in for one IED configuration.

#### 17.8.2 Setting guidelines

There are no setting parameters for the Signal matrix for binary inputs SMBl available to the user in Parameter Setting tool. However, the user shall give a name to SMBl instance and the SMBl inputs, directly in the Application Configuration tool. These names will define SMBl function in the Signal Matrix tool. The user defined name for the input or output signal will also appear on the respective output or input signal.

### 17.9 Signal matrix for binary outputs SMBO

#### 17.9.1 Application

The Signal matrix for binary outputs function SMBO is used within the Application Configuration tool in direct relation with the Signal Matrix tool. SMBO represents the way binary outputs are sent from one IED configuration.
17.9.2 Setting guidelines

There are no setting parameters for the Signal matrix for binary outputs SMBO available to the user in Parameter Setting tool. However, the user must give a name to SMBO instance and SMBO outputs, directly in the Application Configuration tool. These names will define SMBO function in the Signal Matrix tool.

17.10 Signal matrix for analog inputs SMAI

17.10.1 Application

Signal matrix for analog inputs (SMAI), also known as the preprocessor function block, analyses the connected four analog signals (three phases and neutral) and calculates all relevant information from them like the phasor magnitude, phase angle, frequency, true RMS value, harmonics, sequence components and so on. This information is then used by the respective functions connected to this SMAI block in ACT (for example protection, measurement or monitoring functions).

17.10.2 Frequency values

The SMAI function includes a functionality based on the level of positive sequence voltage, MinValFreqMeas, to validate if the frequency measurement is valid or not. If the positive sequence voltage is lower than MinValFreqMeas, the function freezes the frequency output value for 500 ms and after that the frequency output is set to the nominal value. A signal is available for the SMAI function to prevent operation due to non-valid frequency values. MinValFreqMeas is set as % of UBase/√3

If SMAI setting ConnectionType is Ph-Ph, at least two of the inputs GRPxL1, GRPxL2 and GRPxL3, where 1≤x≤12, must be connected in order to calculate the positive sequence voltage. Note that phase to phase inputs shall always be connected as follows: L1-L2 to GRPxL1, L2-L3 to GRPxL2, L3-L1 to GRPxL3. If SMAI setting ConnectionType is Ph-N, all three inputs GRPxL1, GRPxL2 and GRPxL3 must be connected in order to calculate the positive sequence voltage.

If only one phase-phase voltage is available and SMAI setting ConnectionType is Ph-Ph, the user is advised to connect two (not three) of the inputs GRPxL1, GRPxL2 and GRPxL3 to the same voltage input as shown in figure 96 to make SMAI calculate a positive sequence voltage.

![Diagram of SMAI](image)

*Figure 96: Connection example*
The above described scenario does not work if SMAI setting ConnectionType is Ph-N. If only one phase-earth voltage is available, the same type of connection can be used but the SMAI ConnectionType setting must still be Ph-Ph and this has to be accounted for when setting MinValFreqMeas. If SMAI setting ConnectionType is Ph-N and the same voltage is connected to all three SMAI inputs, the positive sequence voltage will be zero and the frequency functions will not work properly.

The outputs from the above configured SMAI block shall only be used for Overfrequency protection (SAPTOF), Underfrequency protection (SAPTUF) and Rate-of-change frequency protection (SAPFRC) due to that all other information except frequency and positive sequence voltage might be wrongly calculated.

### 17.10.3 Setting guidelines

The parameters for the signal matrix for analog inputs (SMAI) functions are set via the local HMI or PCM600.

Every SMAI function block can receive four analog signals (three phases and one neutral value), either voltage or current. SMAI outputs give information about every aspect of the 3ph analog signals acquired (phase angle, RMS value, frequency and frequency derivates, and so on – 244 values in total). Besides the block “group name”, the analog inputs type (voltage or current) and the analog input names that can be set directly in ACT.

Application functions should be connected to a SMAI block with same task cycle as the application function, except for e.g. measurement functions that run in slow cycle tasks.

\[DFTRefExtOut\]: Parameter valid only for function block SMAI1.

Reference block for external output (SPFCOUT function output).

\[DFTReference\]: Reference DFT for the SMAI block use.

These DFT reference block settings decide DFT reference for DFT calculations. The setting InternalDFTRef will use fixed DFT reference based on set system frequency. DFTRefGrp(n) will use DFT reference from the selected group block, when own group is selected, an adaptive DFT reference will be used based on calculated signal frequency from own group. The setting ExternalDFTRef will use reference based on what is connected to input DFTSPFC.

The setting ConnectionType: Connection type for that specific instance (n) of the SMAI (if it is Ph-N or Ph-Ph). Depending on connection type setting the not connected Ph-N or Ph-Ph outputs will be calculated as long as they are possible to calculate. E.g. at Ph-Ph connection L1, L2 and L3 will be calculated for use in symmetrical situations. If N component should be used respectively the phase component during faults \(I_N/U_N\) must be connected to input 4.

\[Negation\]: If the user wants to negate the 3ph signal, it is possible to choose to negate only the phase signals Negate3Ph, only the neutral signal NegateN or both Negate3Ph+N. negation means rotation with 180° of the vectors.

\[GlobalBaseSel\]: Selects the global base value group used by the function to define \((I_{Base})\), \((U_{Base})\) and \((S_{Base})\).

\[MinValFreqMeas\]: The minimum value of the voltage for which the frequency is calculated, expressed as percent of UBase (for each instance n).
Settings \textit{DFTRefExtOut} and \textit{DFTReference} shall be set to default value \textit{InternalDFTRef} if no VT inputs are available.

Even if the user sets the \textit{AnalogInputType} of a SMAI block to \textquote{Current}, the \textit{MinValFreqMeas} is still visible. However, using the current channel values as base for frequency measurement is \textbf{not recommendable} for a number of reasons, not last among them being the low level of currents that one can have in normal operating conditions.

\textbf{Examples of adaptive frequency tracking}

Preprocessing block shall only be used to feed functions within the same execution cycles (e.g. use preprocessing block with cycle 1 to feed transformer differential protection). The only exceptions are measurement functions (CVMMXN, CMMXU,VMMXU, etc.) which shall be fed by preprocessing blocks with cycle 8.

When two or more preprocessing blocks are used to feed one protection function (e.g. over-power function GOPPDOP), it is of outmost importance that parameter setting \textit{DFTReference} has the same set value for all of the preprocessing blocks involved.
Figure 97: Twelve SMAI instances are grouped within one task time. SMAI blocks are available in three different task times in the IED. Two pointed instances are used in the following examples.

The examples show a situation with adaptive frequency tracking with one reference selected for all instances. In practice each instance can be adapted to the needs of the actual application. The adaptive frequency tracking is needed in IEDs that belong to the protection system of synchronous machines and that are active during run-up and shut-down of the machine. In other applications the usual setting of the parameter DFTReference of SMAI is InternalDFTRef.

Example 1
Figure 98: Configuration for using an instance in task time group 1 as DFT reference

Assume instance SMAI7:7 in task time group 1 has been selected in the configuration to control the frequency tracking. Observe that the selected reference instance (i.e. frequency tracking master) must be a voltage type. Observe that positive sequence voltage is used for the frequency tracking feature.

For task time group 1 this gives the following settings (see Figure 97 for numbering):

SMAI1:1: \(DFTRefExtOut = DFTRefGrp7\) to route SMAI7:7 reference to the SPFCOUT output, \(DFTReference = DFTRefGrp7\) for SMAI1:1 to use SMAI7:7 as reference (see Figure 98) SMAI2:2 – SMAI12:12: \(DFTReference = DFTRefGrp7\) for SMAI2:2 – SMAI12:12 to use SMAI7:7 as reference.

For task time group 2 this gives the following settings:

SMAI1:13 – SMAI12:24: \(DFTReference = ExternalDFTRef\) to use DFTSPFC input of SMAI1:13 as reference (SMAI7:7)

For task time group 3 this gives the following settings:

SMAI1:25 – SMAI12:36: \(DFTReference = ExternalDFTRef\) to use DFTSPFC input as reference (SMAI7:7)

Example 2
Assume instance SMAI4:16 in task time group 2 has been selected in the configuration to control the frequency tracking for all instances. Observe that the selected reference instance (i.e. frequency tracking master) must be a voltage type. Observe that positive sequence voltage is used for the frequency tracking feature.

For task time group 1 this gives the following settings (see Figure 97 for numbering):

SMAI1:1 – SMAI12:12: DFTReference = ExternalDFTRef to use DFTSPFC input as reference (SMAI4:16)

For task time group 2 this gives the following settings:

SMAI1:13: DFTRefExtOut = DFTRefGrp4 to route SMAI4:16 reference to the SPFCOUT output, DFTReference = DFTRefGrp4 for SMAI1:13 to use SMAI4:16 as reference (see Figure 99)


For task time group 3 this gives the following settings:

SMAI1:25 – SMAI12:36: DFTReference = ExternalDFTRef to use DFTSPFC input as reference (SMAI4:16)

17.11 Test mode functionality TESTMODE

17.11.1 Application

The protection and control IEDs may have a complex configuration with many included functions. To make the testing procedure easier, the IEDs include the feature that allows individual blocking of a single-, several-, or all functions.

This means that it is possible to see when a function is activated or trips. It also enables the user to follow the operation of several related functions to check correct functionality and to check parts of the configuration, and to check parts.
17.11.1  IEC 61850 protocol test mode

The function block TESTMODE has implemented the extended testing mode capabilities for IEC 61850 Ed2 systems. Operator commands sent to the function block TESTMODE determine the behavior of the functions. The command can be given remotely from an IEC 61850 client or from the LHMI under the Main menu/Test/Function test modes/Communication/Station Communication/IEC61850 LDO LLN0/LD0LLN0:1. The possible values of the function block TESTMODE are described in Communication protocol manual, IEC 61850 Edition 1 and Edition 2.

There is no setting in PCM600 via PST for the TESTMODE function block.

To be able to set the function block TESTMODE remotely, the setting via path on LHMI and in PST: Main menu/Configuration/Communication/Station Communication/IEC61850-8-1/IEC61850-8-1:RemoteModControl may not be set to Off. The possible values of the parameter RemoteModControl are Off, Maintenance or All levels. The Off value denies all access to function block TESTMODE from remote, Maintenance requires that the category of the originator (orCat) is Maintenance and All levels allow any orCat.

The DataObject Mod of the Root LD.LNN0 can be set on the LHMI under Main menu/Test/Function test modes/Communication/Station communication/IEC61850 LD0 LLN0/LD0LLN0:1 to On, Off, TestBlocked, Test or Blocked.

When the setting of the DataObject Mod is changed at this level, all Logical Nodes inside the logical device update their own behavior according to IEC61850-7-4. The supported values of the function block TESTMODE are described in Communication protocol manual, IEC 61850 Edition 2. When the function block TESTMODE is in test mode the Start LED on the LHMI is turned on with steady light.

The parameter Mod of any specific function block can be configured under Main menu/Test/Function test modes/Communication/Station Communication.

The parameter Mod can be set on the LHMI to the same values as for the DataObject Mod of the Root LD.LNN0 to On, Off, TestBlocked, Test or Blocked. For Example, Main menu/ Test/Function test modes/ Differential protection/GeneratorDiff(87G,3Id/I>,GENPDIF(87G,3Id/I>):-1.

It is possible that the behavior of the function block TESTMODE is also influenced by other sources as well, independent of the mode communicated via the IEC61850-8-1 station bus. For example the insertion of the test handle into the test switch with its auxiliary contact is connected to a BI on the IED and further inside the configuration to the input IED_TEST on the function block TESTMODE. Another example is when loss of Service Values appears, or as explained above the setting via the LHMI.

When setting via PST or LHMI the parameter Operation of any function in an IED is set to Off, the function is not executed and the behavior (beh) is set to Off and it is not possible to override it. When a behavior of a function is Off the function will not execute. The related Mod keeps its current state.

When IEC 61850 Mod of a function is set to Off or Blocked, the Start LED on the LHMI will be set to flashing to indicate the abnormal operation of the IED.

The IEC 61850-7-4 gives a detailed overview over all aspects of the test mode and other states of mode and behavior. The status of a function block behavior Beh is shown on the LHMI under...
the Main menu/Test/Function status/Function group/Function block descriptive name/LN name/Outputs.

- When the Beh of a function block is set to Test, the function block is not blocked and all control commands with a test bit are accepted.
- When the Beh of a function block is set to Test/blocked, all control commands with a test bit are accepted. Outputs to the process via a non-IEC 61850 link data are blocked by the function block. Only process-related outputs on function blocks related to primary equipment are blocked. If there is an XCBR function block used, the outputs EXC_Open and EXC_Close are blocked.
- When the Beh of a function block is set to Blocked, all control commands with a test bit are accepted. Outputs to the process via a non-IEC 61850 link data are blocked by the function block. In addition, the function block can be blocked when their Beh is blocked. This can be done if the function block has a block input.

The block status of a component is shown on the LHMI as the Blk output under the same path as for Beh: Main menu/Test/Function status/Function group/Function block descriptive name/LN name/Outputs. If the Blk output is not shown, the component cannot be blocked.

17.11.2 Setting guidelines

Remember always that there are two possible ways to place the IED in the TestMode= On state. If the IED is set to normal operation (TestMode = Off), but the functions are still shown being in the test mode, the input signal IED_TEST on the TESTMODE function block is activated in the configuration.

Forcing of binary input and output signals is only possible when the IED is in IED test mode.

17.12 Time synchronization TIMESYNCHGEN

17.12.1 Application

Use time synchronization to achieve a common time base for the IEDs in a protection and control system. This makes it possible to compare events and disturbance data between all IEDs in the system.

Time-tagging of internal events and disturbances are an excellent help when evaluating faults. Without time synchronization, only the events within one IED can be compared with each other. With time synchronization, events and disturbances within the whole network, can be compared and evaluated.

In the IED, the internal time can be synchronized from the following sources:

- BIN (Binary Minute Pulse)
- DNP
- IEC103
- SNTP
- IRIG-B
- SPA
- LON
- PPS
- IEEE 1588 (PTP)

Out of these, LON and SPA contains two types of synchronization messages:
• Coarse time messages are sent every minute and contain complete date and time, that is year, month, day, hour, minute, second and millisecond.
• Fine time messages are sent every second and comprise only seconds and milliseconds.

The selection of the time source is done via the corresponding setting.

If PTP is activated, the device with the best accuracy within the synchronizing group will be selected as the source. For more information about PTP, see the Technical manual.

**IEEE 1588 (PTP)**

PTP according to IEEE 1588-2008 and specifically its profile IEC/IEEE 61850-9-3 for power utility automation is a synchronization method that can be used to maintain a common time within a station. This time can be synchronized to the global time using, for instance, a GPS receiver. If PTP is enabled on the IEDs and the switches that connect the station are compatible with IEEE 1588, the station will become synchronized to one common time with an accuracy of under 1us. Using an IED as a boundary clock between several networks will keep 1us accuracy on three levels or when using an HSR, 15 IEDs can be connected in a ring without losing a single microsecond in accuracy.

### 17.12.2 Setting guidelines

All the parameters related to time are divided into two categories: System time and Synchronization.

#### 17.12.2.1 System time

The time is set with years, month, day, hour, minute, second and millisecond.

#### 17.12.2.2 Synchronization

The setting parameters for the real-time clock with external time synchronization are set via local HMI or PCM600. The path for Time Synchronization parameters on local HMI is **Main menu/Configuration/Time/Synchronization**. The parameters are categorized as Time Synchronization (TIMESYNCHGEN) and IRIG-B settings (IRIG-B:1) in case that IRIG-B is used as the external time synchronization source.

**TimeSynch**

When the source of the time synchronization is selected on the local HMI, the parameter is called *TimeSynch*. The time synchronization source can also be set from PCM600. The setting alternatives are:

- FineSyncSource can have the following values:
  - **Off**
  - **SPA**
  - **LON**
  - **BIN** (Binary Minute Pulse)
  - **SNTP**
  - **IRIG-B**
  - **PPS**

- CoarseSyncSrc which can have the following values:
The function input to be used for minute-pulse synchronization is called BININPUT. For a description of the BININPUT settings, see the Technical Manual.

The system time can be set manually, either via the local HMI or via any of the communication ports. The time synchronization fine tunes the clock (seconds and milliseconds).

The parameter SyncMaster defines if the IED is a master, or not a master for time synchronization within a Substation Automation System, for IEDs connected in a communication network (IEC 61850-8-1). The SyncMaster can have the following values:

- Off
- SNTP -Server

All protection functions will be blocked if the AppSynch parameter is set to Synch while there is no 9-2 synchronization source. For more information please refer to the "IEC/UCA 61850-9-2LE communication protocol" section.

IEEE 1588 (PTP)

Precision Time Protocol (PTP) is enabled/disabled using the Ethernet configuration tool /ECT) in PCM600.

PTP can be set to On, Off or Slave only. When set to Slave only the IED is connected to the PTP-group and will synchronize to the grandmaster but cannot function as the grandmaster.

A PTP-group is set up by connecting the IEDs to a network and enabling PTP. To set one IED as the grandmaster change Priority2 to 127 instead of the default 128.

The PTP VLAN tag must have the same value in station clock and in the IED. The default value is set to 0.

The PTP VLAN tag does not need to be the same on all access points in one IED. It is possible to mix as long as they are the same for all devices on each subnet.
Figure 101: Example system

Figure 101 describes an example system. The REC and REL are both using the 9-2 stream from the SAM600, and gets its synch from the GPS. Moreover, the REL and REC both acts as a boundary clock to provide synch to the SAM600.

On all access points, the PTP parameter is “ON”.

17.12.2.3 Process bus IEC/UCA 61850-9-2LE synchronization

When process bus communication (IEC/UCA 61850-9-2LE protocol) is used, it is essential that the merging units are synchronized with the hardware time of the IED (see Technical manual, section Design of the time system (clock synchronization)). To achieve this, PTP, PPS or IRIG-B can be used depending on the facilities of the merging unit.
If the merging unit supports PTP, use PTP. If PTP is used in the IED and the merging unit cannot be synchronized from the IED, then use GPS-based clocks to provide PTP synch as well as sync to the merging unit.

If synchronization of the IED and the merging unit is based on GPS, set the parameter SyncLostMode to BlockOnLostUTC in order to provide a block of protection functions whenever the global common time is lost.

If PTP is not used, use the same synchronization method for the HwSyncSrc as the merging unit provides. For instance, if the merging unit provides PPS as synchronization, use PPS as HwSyncSrc. If LDCM in GPS-mode is used, that is, the hardware and software clocks are connected to each other, HwSyncSrc is not used and other means to synchronize the merging unit to the IED is required. For instance, FineSyncSource is set to the same source that the merging unit uses.

If the IED is used together with a merging unit and no time synchronization is available, for example, in the laboratory test, the IED will synchronize to the SV data stream. During the re-synchronization, the protection functions will be blocked once a second for about 45 ms, and this will continue for up to 10 minutes. To avoid this, configure PTP (IEEE 1588) to On for the access point where the merging unit is configured.
Section 18  Requirements

18.1  Current transformer requirements

The performance of a protection function will depend on the quality of the measured current signal. Saturation of the current transformers (CTs) will cause distortion of the current signals and can result in a failure to operate or cause unwanted operations of some functions. Consequently CT saturation can have an influence on both the dependability and the security of the protection. This protection IED has been designed to permit heavy CT saturation with maintained correct operation.

18.1.1  Current transformer basic classification and requirements

To guarantee correct operation, the current transformers (CTs) must be able to correctly reproduce the current for a minimum time before the CT will begin to saturate. To fulfill the requirement on a specified time to saturation the CTs must fulfill the requirements of a minimum secondary e.m.f. that is specified below.

CTs are specified according to many different classes and standards. In principle, there are three different types of protection CTs. These types are related to the design of the iron core and the presence of airgaps. Airgaps affects the properties of the remanent flux.

The following three different types of protection CTs have been specified:

- The High Remanence type with closed iron core and no specified limit of the remanent flux
- The Low Remanence type with small airgaps in the iron core and the remanent flux limit is specified to be maximum 10% of the saturation flux
- The Non Remanence type with big airgaps in the iron core and the remanent flux can be neglected

Even though no limit of the remanent flux is specified in the IEC standard for closed core CTs, it is a common opinion that the remanent flux is normally limited to maximum 75 - 80 % of the saturation flux.

Since approximately year 2000 some CT manufactures have introduced new core materials that gradually have increased the possible maximum levels of remanent flux even up to 95 % related to the hysteresis curve. Corresponding level of actual remanent flux is 90 % of the saturation flux ($\Psi_{sat}$). As the present CT standards have no limitation of the level of remanent flux, these CTs are also classified as for example, class TPX, P and PX according to IEC. The IEC TR 61869-100, Edition 1.0 2017-01, Instrument transformers – Guidance for application of current transformers in power system protection, is the first official document that highlighted this development. So far remanence factors of maximum 80% have been considered when CT requirements have been decided for ABB IEDs. Even in the future this level of remanent flux probably will be the maximum level that will be considered when decided the CT requirements. If higher remanence levels should be considered, it should often lead to unrealistic CT sizes.

Thus, now there is a need to limit the acceptable level of remanent flux. To be able to guarantee the performance of protection IEDs, we need to introduce the following classification of CTs.

There are many different standards and a lot of classes but fundamentally there are four different types of CTs:
• Very High Remanence type CT
• High Remanence type CT
• Low Remanence type CT
• Non Remanence type CT

The Very High Remanence (VHR) type is a CT with closed iron core (for example, protection classes TPX, P, PX according to IEC, class C, K according to ANSI/IEEE) and with an iron core material (new material, typically new alloy based magnetic materials) that gives a remanent flux higher than 80 % of the saturation flux.

The High Remanence (HR) type is a CT with closed iron core (for example, protection classes TPX, P, PX according to IEC, class C, K according to ANSI/IEEE) but with an iron core material (traditional material) that gives a remanent flux that is limited to maximum 80 % of the saturation flux.

The Low Remanence (LR) type is a CT with small airgaps in the iron core (for example, TPY, PR, PXR according to IEC) and the remanent flux limit is specified to be maximum 10% of the saturation flux.

The Non Remanence (NR) type is a CT with big airgaps in the core (for example, TPZ according to IEC) and the remanent flux can be neglected.

It is also possible that different CT classes of HR and LR type may be mixed.

CT type VHR (using new material) should not be used for protection CT cores. This means that it is important to specify that the remanence factor must not exceed 80 % when ordering for example, class P, PX or TPX CTs. If CT manufacturers are using new core material and are not able to fulfill this requirement, the CTs shall be specified with small airgaps and therefore will be CTs of LR type (for example, class PR, TPY or PXR). Very high remanence level in a protection core CT can cause the following problems for protection IEDs:

1. Unwanted operation of differential (i.e. unit) protections for external faults
2. Unacceptably delayed or even missing operation of all types of protections (for example, distance, differential, overcurrent, etc.) which can result in loosing protection selectivity in the network

No information is available about how frequent the use of the new iron core material is for protection CT cores, but it is known that some CT manufacturers are using the new material while other manufacturers continue to use the old traditional core material for protection CT cores. In a case where VHR type CTs have been already installed, the calculated values of $E_{al}$ for HR type CTs, for which the formulas are given in this document, must be multiplied by factor two-and-a-half in order for VHR type CTs (i.e. with new material) to be used together with ABB protection IEDs. However, this may result in unacceptably big CT cores, which can be difficult to manufacture and fit in available space.

Different standards and classes specify the saturation e.m.f. in different ways but it is possible to approximately compare values from different classes. The rated equivalent limiting secondary e.m.f. $E_{al}$ according to the IEC 61869–2 standard is used to specify the CT requirements for the IED. The requirements are also specified according to other standards.

### 18.1.2 Conditions

The requirements are a result of investigations performed in our network simulator. The current transformer models are representative for current transformers of high remanence and low remanence type. The results may not always be valid for non remanence type CTs (TPZ).

The performances of the protection functions have been checked in the range from symmetrical to fully asymmetrical fault currents. Primary time constants of at least 120 ms
have been considered at the tests. The current requirements below are thus applicable both for symmetrical and asymmetrical fault currents.

Depending on the protection function phase-to-earth, phase-to-phase and three-phase faults have been tested for different relevant fault positions for example, close in forward and reverse faults, zone 1 reach faults, internal and external faults. The dependability and security of the protection was verified by checking for example, time delays, unwanted operations, directionality, overreach and stability.

The remanence in the current transformer core can cause unwanted operations or minor additional time delays for some protection functions. As unwanted operations are not acceptable at all maximum remanence has been considered for fault cases critical for the security, for example, faults in reverse direction and external faults. Because of the almost negligible risk of additional time delays and the non-existent risk of failure to operate the remanence have not been considered for the dependability cases. The requirements below are therefore fully valid for all normal applications.

It is difficult to give general recommendations for additional margins for remanence to avoid the minor risk of an additional time delay. They depend on the performance and economy requirements. When current transformers of low remanence type (for example, TPY, PR) are used, normally no additional margin is needed. For current transformers of high remanence type (for example, P, PX, TPX) the small probability of fully asymmetrical faults, together with high remanence in the same direction as the flux generated by the fault, has to be kept in mind at the decision of an additional margin. Fully asymmetrical fault current will be achieved when the fault occurs at approximately zero voltage (0°). Investigations have shown that 95% of the faults in the network will occur when the voltage is between 40° and 90°. In addition fully asymmetrical fault current will not exist in all phases at the same time.

### 18.1.3 Fault current

The current transformer requirements are based on the maximum fault current for faults in different positions. Maximum fault current will occur for three-phase faults or single phase-to-earth faults. The current for a single phase-to-earth fault will exceed the current for a three-phase fault when the zero sequence impedance in the total fault loop is less than the positive sequence impedance.

When calculating the current transformer requirements, maximum fault current for the relevant fault position should be used and therefore both fault types have to be considered.

### 18.1.4 Secondary wire resistance and additional load

The voltage at the current transformer secondary terminals directly affects the current transformer saturation. This voltage is developed in a loop containing the secondary wires and the burden of all relays in the circuit. For earth faults the loop includes the phase and neutral wire, normally twice the resistance of the single secondary wire. For three-phase faults the neutral current is zero and it is just necessary to consider the resistance up to the point where the phase wires are connected to the common neutral wire. The most common practice is to use four wires secondary cables so it normally is sufficient to consider just a single secondary wire for the three-phase case.

The conclusion is that the loop resistance, twice the resistance of the single secondary wire, must be used in the calculation for phase-to-earth faults and the phase resistance, the resistance of a single secondary wire, may normally be used in the calculation for three-phase faults.

As the burden can be considerable different for three-phase faults and phase-to-earth faults it is important to consider both cases. Even in a case where the phase-to-earth fault current is smaller than the three-phase fault current the phase-to-earth fault can be dimensioning for the CT depending on the higher burden.
In isolated or high impedance earthed systems the phase-to-earth fault is not the dimensioning case. Therefore, the resistance of the single secondary wire can always be used in the calculation for this kind of power systems.

### 18.1.5 General current transformer requirements

The current transformer ratio is mainly selected based on power system data for example, maximum load and/or maximum fault current. It should be verified that the current to the protection is higher than the minimum operating value for all faults that are to be detected with the selected CT ratio. It should also be verified that the maximum possible fault current is within the limits of the IED.

The current error of the current transformer can limit the possibility to use a very sensitive setting of a sensitive residual overcurrent protection. If a very sensitive setting of this function will be used it is recommended that the current transformer should have an accuracy class which have an current error at rated primary current that is less than ±1% (for example, 5P). If current transformers with less accuracy are used it is advisable to check the actual unwanted residual current during the commissioning.

### 18.1.6 Rated equivalent secondary e.m.f. requirements

With regard to saturation of the current transformer all current transformers of high remanence and low remanence type that fulfill the requirements on the rated equivalent limiting secondary e.m.f. $E_{al}$ below can be used. The characteristic of the non remanence type CT (TPZ) is not well defined as far as the phase angle error is concerned. If no explicit recommendation is given for a specific function we therefore recommend contacting ABB to confirm that the non remanence type can be used.

The CT requirements for the different functions below are specified as a rated equivalent limiting secondary e.m.f. $E_{al}$ according to the IEC 61869-2 standard. Requirements for CTs specified according to other classes and standards are given at the end of this section.

#### 18.1.6.1 Breaker failure protection

The CTs must have a rated equivalent limiting secondary e.m.f. $E_{al}$ that is larger than or equal to the required equivalent limiting secondary e.m.f. $E_{alreq}$ below:

$$E_{al} \geq E_{alreq} = 5 \cdot I_{op} \cdot \frac{I_{sr}}{I_{pr}} \cdot \left( R_{ct} + R_{L} + \frac{S_R}{I_r^2} \right)$$

(Equation 45)

where:
- $I_{op}$: The primary operate value (A)
- $I_{pr}$: The rated primary CT current (A)
- $I_{sr}$: The rated secondary CT current (A)
- $I_r$: The rated current of the protection IED (A)
- $R_{ct}$: The secondary resistance of the CT (Ω)
- $R_{L}$: The resistance of the secondary cable and additional load (Ω). The loop resistance containing the phase and neutral wires, must be used for faults in solidly earthed systems. The resistance of a single secondary wire should be used for faults in high impedance earthed systems.
- $S_R$: The burden of an IED current input channel (VA). $S_R = 0.020$ VA/channel for $I_r = 1$ A and $S_R = 0.150$ VA/channel for $I_r = 5$ A
18.1.6.2 Non-directional instantaneous and definitive time, phase and residual overcurrent protection

The CTs must have a rated equivalent limiting secondary e.m.f. \( E_{al} \) that is larger than or equal to the required rated equivalent limiting secondary e.m.f. \( E_{alreq} \) below:

\[
E_{al} \geq E_{alreq} = 1,5 \cdot I_{op} \cdot \frac{I_{sr}}{I_{pr}} \left( R_{ct} + R_{L} + \frac{S_{R}}{I_{r}^2} \right)
\]

(Equation 46)

where:
- \( I_{op} \) The primary operate value (A)
- \( I_{pr} \) The rated primary CT current (A)
- \( I_{sr} \) The rated secondary CT current (A)
- \( I_{r} \) The rated current of the protection IED (A)
- \( R_{ct} \) The secondary resistance of the CT (\( \Omega \))
- \( R_{L} \) The resistance of the secondary cable and additional load (\( \Omega \)). The loop resistance containing the phase and neutral wires, must be used for faults in solidly earthed systems. The resistance of a single secondary wire should be used for faults in high impedance earthed systems.
- \( S_{R} \) The burden of an IED current input channel (VA). \( S_{R} = 0.020 \text{ VA/channel for } I_{r} = 1 \text{ A and } S_{R} = 0.150 \text{ VA/channel for } I_{r} = 5 \text{ A} \)

18.1.6.3 Non-directional inverse time delayed phase and residual overcurrent protection

The requirement according to Equation 47 and Equation 48 does not need to be fulfilled if the high set instantaneous or definitive time stage is used. In this case Equation is the only necessary requirement.

If the inverse time delayed function is the only used overcurrent protection function the CTs must have a rated equivalent limiting secondary e.m.f. \( E_{al} \) that is larger than or equal to the required rated equivalent limiting secondary e.m.f. \( E_{alreq} \) below:

\[
E_{al} \geq E_{alreq} = 20 \cdot I_{op} \cdot \frac{I_{sr}}{I_{pr}} \left( R_{ct} + R_{L} + \frac{S_{R}}{I_{r}^2} \right)
\]

(Equation 47)

where:
- \( I_{op} \) The primary current set value of the inverse time function (A)
- \( I_{pr} \) The rated primary CT current (A)
- \( I_{sr} \) The rated secondary CT current (A)
- \( I_{r} \) The rated current of the protection IED (A)

Table continues on next page
The secondary resistance of the CT ($R_{ct}$)

The resistance of the secondary cable and additional load ($R_L$). The loop resistance containing the phase and neutral wires, must be used for faults in solidly earthed systems. The resistance of a single secondary wire should be used for faults in high impedance earthed systems.

$S_R$ The burden of an IED current input channel (VA). $S_R=0.020$ VA/channel for $I_r = 1$ A and $S_R = 0.150$ VA/channel for $I_r = 5$ A

Independent of the value of $I_{op}$ the maximum required $E_{al}$ is specified according to the following:

$$E_{al} \geq E_{alreq max} = I_{k max} \cdot \frac{I_r}{I_{pr}} \cdot \left( R_{ct} + R_L + \frac{S_R}{I_r^2} \right)$$

(Equation 48)

where

$I_{k max}$ Maximum primary fundamental frequency current for close-in faults (A)

### 18.1.7 Current transformer requirements for CTs according to other standards

All kinds of conventional magnetic core CTs are possible to use with the IEDs if they fulfill the requirements corresponding to the above specified expressed as the rated equivalent limiting secondary e.m.f. $E_{al}$ according to the IEC 61869-2 standard. From different standards and available data for relaying applications it is possible to approximately calculate a secondary e.m.f. of the CT comparable with $E_{al}$. By comparing this with the required rated equivalent limiting secondary e.m.f. $E_{alreq}$ it is possible to judge if the CT fulfills the requirements. The requirements according to some other standards are specified below.

#### 18.1.7.1 Current transformers according to IEC 61869-2, class P, PR

A CT according to IEC 61869-2 is specified by the secondary limiting e.m.f. $E_{ALF}$. The value of the $E_{ALF}$ is approximately equal to the corresponding $E_{al}$. Therefore, the CTs according to class P and PR must have a secondary limiting e.m.f. $E_{ALF}$ that fulfills the following:

$$E_{ALF} > \max E_{alreq}$$

(Equation 49)

#### 18.1.7.2 Current transformers according to IEC 61869-2, class PX, PXR (and old IEC 60044-6, class TPS and old British Standard, class X)

CTs according to these classes are specified approximately in the same way by a rated knee point e.m.f. $E_{knee}$ ($E_k$ for class PX and PXR, $E_{knee BS}$ for class X and the limiting secondary voltage $U_{al}$ for TPS). The value of the $E_{knee}$ is lower than the corresponding $E_{al}$ according to IEC 61869-2. It is not possible to give a general relation between the $E_{knee}$ and the $E_{al}$ but normally...
the \( E_{\text{knee}} \) is approximately 80% of the \( E_{\text{al}} \). Therefore, the CTs according to class PX, PXR, X and TPS must have a rated knee point e.m.f. \( E_{\text{knee}} \) that fulfills the following:

\[
E_{\text{knee}} \approx E_k \approx E_{\text{kneelS}} \approx U_{\text{al}} > 0.8 \cdot \left( \text{maximum of } E_{\text{alreq}} \right)
\]

(Equation 50)

### 18.1.7.3 Current transformers according to ANSI/IEEE

Current transformers according to ANSI/IEEE are partly specified in different ways. A rated secondary terminal voltage \( U_{\text{ANSI}} \) is specified for a CT of class C. \( U_{\text{ANSI}} \) is the secondary terminal voltage the CT will deliver to a standard burden at 20 times rated secondary current without exceeding 10% ratio correction. There are a number of standardized \( U_{\text{ANSI}} \) values for example, \( U_{\text{ANSI}} \) is 400 V for a C400 CT. A corresponding rated equivalent limiting secondary e.m.f. \( E_{\text{alANSI}} \) can be estimated as follows:

\[
E_{\text{alANSI}} = \left| 20 \cdot I_{\text{sr}} \cdot R_{\text{ct}} + U_{\text{ANSI}} \right| = \left| 20 \cdot I_{\text{sr}} \cdot R_{\text{ct}} + 20 \cdot I_{\text{sr}} \cdot Z_{\text{bANSI}} \right|
\]

(Equation 51)

where:

- \( Z_{\text{bANSI}} \) The impedance (that is, with a complex quantity) of the standard ANSI burden for the specific C class (Ω)
- \( U_{\text{ANSI}} \) The secondary terminal voltage for the specific C class (V)

The CTs according to class C must have a calculated rated equivalent limiting secondary e.m.f. \( E_{\text{alANSI}} \) that fulfills the following:

\[
E_{\text{alANSI}} > \text{maximum of } E_{\text{alreq}}
\]

(Equation 52)

A CT according to ANSI/IEEE is also specified by the knee point voltage \( U_{\text{kneeANSI}} \) that is graphically defined from an excitation curve. The knee point voltage \( U_{\text{kneeANSI}} \) normally has a lower value than the knee-point e.m.f. according to IEC and BS. \( U_{\text{kneeANSI}} \) can approximately be estimated to 75% of the corresponding \( E_{\text{al}} \) according to IEC 61869-2. Therefore, the CTs according to ANSI/IEEE must have a knee point voltage \( U_{\text{kneeANSI}} \) that fulfills the following:

\[
U_{\text{kneeANSI}} > 0.75 \cdot \left( \text{maximum of } E_{\text{alreq}} \right)
\]

(Equation 53)

### 18.2 Voltage transformer requirements

The performance of a protection function will depend on the quality of the measured input signal. Transients caused by capacitive voltage transformers (CVTs) can affect some protection functions.

Magnetic or capacitive voltage transformers can be used.
The capacitive voltage transformers (CVTs) should fulfill the requirements according to the IEC 61869-5 standard regarding ferro-resonance and transients. The ferro-resonance requirements of the CVTs are specified in chapter 6.502 of the standard.

The transient responses for three different standard transient response classes, T1, T2 and T3 are specified in chapter 6.503 of the standard. CVTs according to all classes can be used.

The protection IED has effective filters for these transients, which gives secure and correct operation with CVTs.

18.3 SNTP server requirements

The SNTP server to be used is connected to the local network, that is not more than 4-5 switches or routers away from the IED. The SNTP server is dedicated for its task, or at least equipped with a real-time operating system, that is not a PC with SNTP server software. The SNTP server should be stable, that is, either synchronized from a stable source like GPS, or local without synchronization. Using a local SNTP server without synchronization as primary or secondary server in a redundant configuration is not recommended.

18.4 PTP requirements

For PTP to perform properly, the Ethernet equipment that is used needs to be compliant with IEEE1588. The clocks used must follow the IEEE1588 standard BMC (Best Master Algorithm) and shall, for instance, not claim class 7 for a longer time than it can guarantee 1us absolute accuracy.

18.5 IEC/UCA 61850-9-2LE Merging unit requirements

The merging units that supply the IED with measured values via the process bus must fulfill the IEC/UCA 61850-9-2LE standard.

This part of the IEC 61850 is specifying “Communication Service Mapping (SCSM) – Sampled values over ISO/IEC 8802”, in other words – sampled data over Ethernet. The 9-2 part of the IEC 61850 protocol uses also definitions from 7-2, “Basic communication structure for substation and feeder equipment – Abstract communication service interface (ACSI)”. The set of functionality implemented in the IED (IEC/UCA 61850-9-2LE) is a subset of the IEC 61850-9-2. For example the IED covers the client part of the standard, not the server part.

The standard does not define the sample rate for data, but in the UCA users group recommendations there are indicated sample rates that are adopted, by consensus, in the industry.

There are two sample rates defined: 80 samples/cycle (4000 samples/sec. at 50Hz or 4800 samples/sec. at 60 Hz) for a merging unit “type1” and 256 samples/cycle for a merging unit “type2”. The IED can receive data rates of 80 samples/cycle.

Note that the IEC/UCA 61850-9-2LE standard does not specify the quality of the sampled values, only the transportation. Thus, the accuracy of the current and voltage inputs to the merging unit and the inaccuracy added by the merging unit must be coordinated with the requirement for actual type of protection function.

Factors influencing the accuracy of the sampled values from the merging unit are for example anti aliasing filters, frequency range, step response, truncating, A/D conversion inaccuracy, time tagging accuracy etc.
In principle the accuracy of the current and voltage transformers, together with the merging unit, shall have the same quality as direct input of currents and voltages.
### Section 19  Glossary

<p>| AC       | Alternating current |
| ACC      | Actual channel      |
| ACT      | Application configuration tool within PCM600 |
| A/D converter | Analog-to-digital converter |
| ADBS     | Amplitude deadband supervision |
| ADM      | Analog digital conversion module, with time synchronization |
| AI       | Analog input        |
| ANSI     | American National Standards Institute |
| AR       | Autoreclosing       |
| ASCT     | Auxiliary summation current transformer |
| ASD      | Adaptive signal detection |
| ASDU     | Application service data unit |
| AWG      | American Wire Gauge standard |
| BBP      | Busbar protection   |
| BFOC/2,5 | Bayonet fiber optic connector |
| BFP      | Breaker failure protection |
| BI       | Binary input        |
| BIM      | Binary input module |
| BOM      | Binary output module |
| BOS      | Binary outputs status |
| BR       | External bistable relay |
| BS       | British Standards   |
| BSR      | Binary signal transfer function, receiver blocks |
| BST      | Binary signal transfer function, transmit blocks |
| C37.94   | IEEE/ANSI protocol used when sending binary signals between IEDs |
| CAN      | Controller Area Network. ISO standard (ISO 11898) for serial communication |
| CB       | Circuit breaker     |
| CBM      | Combined backplane module |
| CCM      | CAN carrier module  |
| CCVT     | Capacitive Coupled Voltage Transformer |
| Class C  | Protection Current Transformer class as per IEEE/ ANSI |
| CMPPPS   | Combined megapulses per second |
| CMT      | Communication Management tool in PCM600 |</p>
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO cycle</td>
<td>Close-open cycle</td>
</tr>
<tr>
<td>Codirectional</td>
<td>Way of transmitting G.703 over a balanced line. Involves two twisted pairs</td>
</tr>
<tr>
<td></td>
<td>making it possible to transmit information in both directions</td>
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<tr>
<td>COM</td>
<td>Command</td>
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<tr>
<td>COMTRADE</td>
<td>Standard Common Format for Transient Data Exchange format for Disturbance</td>
</tr>
<tr>
<td></td>
<td>recorder according to IEEE/ANSI C37.111, 1999 / IEC 60255-24</td>
</tr>
<tr>
<td>Contra-directional</td>
<td>Way of transmitting G.703 over a balanced line. Involves four twisted pairs, two of which are used for transmitting data in both directions and two for transmitting clock signals</td>
</tr>
<tr>
<td>COT</td>
<td>Cause of transmission</td>
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<tr>
<td>CPU</td>
<td>Central processing unit</td>
</tr>
<tr>
<td>CR</td>
<td>Carrier receive</td>
</tr>
<tr>
<td>CRC</td>
<td>Cyclic redundancy check</td>
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<tr>
<td>CROB</td>
<td>Control relay output block</td>
</tr>
<tr>
<td>CS</td>
<td>Carrier send</td>
</tr>
<tr>
<td>CT</td>
<td>Current transformer</td>
</tr>
<tr>
<td>CU</td>
<td>Communication unit</td>
</tr>
<tr>
<td>CVT or CCVT</td>
<td>Capacitive voltage transformer</td>
</tr>
<tr>
<td>DAR</td>
<td>Delayed autoreclosing</td>
</tr>
<tr>
<td>DARPA</td>
<td>Defense Advanced Research Projects Agency (The US developer of the TCP/IP</td>
</tr>
<tr>
<td></td>
<td>protocol etc.)</td>
</tr>
<tr>
<td>DBDL</td>
<td>Dead bus dead line</td>
</tr>
<tr>
<td>DBLL</td>
<td>Dead bus live line</td>
</tr>
<tr>
<td>DC</td>
<td>Direct current</td>
</tr>
<tr>
<td>DFC</td>
<td>Data flow control</td>
</tr>
<tr>
<td>DFT</td>
<td>Discrete Fourier transform</td>
</tr>
<tr>
<td>DHCP</td>
<td>Dynamic Host Configuration Protocol</td>
</tr>
<tr>
<td>DIP-switch</td>
<td>Small switch mounted on a printed circuit board</td>
</tr>
<tr>
<td>DI</td>
<td>Digital input</td>
</tr>
<tr>
<td>DLLB</td>
<td>Dead line live bus</td>
</tr>
<tr>
<td>DNP</td>
<td>Distributed Network Protocol as per IEEE Std 1815-2012</td>
</tr>
<tr>
<td>DR</td>
<td>Disturbance recorder</td>
</tr>
<tr>
<td>DRAM</td>
<td>Dynamic random access memory</td>
</tr>
<tr>
<td>DRH</td>
<td>Disturbance report handler</td>
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<tr>
<td>DSP</td>
<td>Digital signal processor</td>
</tr>
<tr>
<td>DTT</td>
<td>Direct transfer trip scheme</td>
</tr>
<tr>
<td>ECT</td>
<td>Ethernet configuration tool</td>
</tr>
<tr>
<td>EHV network</td>
<td>Extra high voltage network</td>
</tr>
<tr>
<td>EIA</td>
<td>Electronic Industries Association</td>
</tr>
<tr>
<td>EMC</td>
<td>Electromagnetic compatibility</td>
</tr>
<tr>
<td>EMF</td>
<td>Electromotive force</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMI</td>
<td>Electromagnetic interference</td>
</tr>
<tr>
<td>EnFP</td>
<td>End fault protection</td>
</tr>
<tr>
<td>EPA</td>
<td>Enhanced performance architecture</td>
</tr>
<tr>
<td>ESD</td>
<td>Electrostatic discharge</td>
</tr>
<tr>
<td>F-SMA</td>
<td>Type of optical fiber connector</td>
</tr>
<tr>
<td>FAN</td>
<td>Fault number</td>
</tr>
<tr>
<td>FCB</td>
<td>Flow control bit; Frame count bit</td>
</tr>
<tr>
<td>FOX 20</td>
<td>Modular 20 channel telecommunication system for speech, data and protection signals</td>
</tr>
<tr>
<td>FOX 512/515</td>
<td>Access multiplexer</td>
</tr>
<tr>
<td>FOX 6Plus</td>
<td>Compact time-division multiplexer for the transmission of up to seven duplex channels of digital data over optical fibers</td>
</tr>
<tr>
<td>FPN</td>
<td>Flexible product naming</td>
</tr>
<tr>
<td>FTP</td>
<td>File Transfer Protocol</td>
</tr>
<tr>
<td>FUN</td>
<td>Function type</td>
</tr>
<tr>
<td>G.703</td>
<td>Electrical and functional description for digital lines used by local telephone companies. Can be transported over balanced and unbalanced lines</td>
</tr>
<tr>
<td>GCM</td>
<td>Communication interface module with carrier of GPS receiver module</td>
</tr>
<tr>
<td>GDE</td>
<td>Graphical display editor within PCM600</td>
</tr>
<tr>
<td>GI</td>
<td>General interrogation command</td>
</tr>
<tr>
<td>GIS</td>
<td>Gas-insulated switchgear</td>
</tr>
<tr>
<td>GOOSE</td>
<td>Generic object-oriented substation event</td>
</tr>
<tr>
<td>GPS</td>
<td>Global positioning system</td>
</tr>
<tr>
<td>GSAL</td>
<td>Generic security application</td>
</tr>
<tr>
<td>GSE</td>
<td>Generic substation event</td>
</tr>
<tr>
<td>HDLC protocol</td>
<td>High-level data link control, protocol based on the HDLC standard</td>
</tr>
<tr>
<td>HFBR connector type</td>
<td>Plastic fiber connector</td>
</tr>
<tr>
<td>HLV circuit</td>
<td>Hazardous Live Voltage according to IEC60255-27</td>
</tr>
<tr>
<td>HMI</td>
<td>Human-machine interface</td>
</tr>
<tr>
<td>HSAR</td>
<td>High speed autoreclosing</td>
</tr>
<tr>
<td>HSR</td>
<td>High-availability Seamless Redundancy</td>
</tr>
<tr>
<td>HV</td>
<td>High-voltage</td>
</tr>
<tr>
<td>HVDC</td>
<td>High-voltage direct current</td>
</tr>
<tr>
<td>IDBS</td>
<td>Integrating deadband supervision</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electrical Committee</td>
</tr>
<tr>
<td>IEC 60044-6</td>
<td>IEC Standard, Instrument transformers – Part 6: Requirements for protective current transformers for transient performance</td>
</tr>
<tr>
<td>IEC 60870-5-103</td>
<td>Communication standard for protection equipment. A serial master/slave protocol for point-to-point communication</td>
</tr>
<tr>
<td>IEC 61850</td>
<td>Substation automation communication standard</td>
</tr>
<tr>
<td>IEC 61850–8–1</td>
<td>Communication protocol standard</td>
</tr>
</tbody>
</table>
IEEE Institute of Electrical and Electronics Engineers

IEEE 802.12 A network technology standard that provides 100 Mbits/s on twisted-pair or optical fiber cable

IEEE P1386.1 PCI Mezzanine Card (PMC) standard for local bus modules. References the CMC (IEEE P1386, also known as Common Mezzanine Card) standard for the mechanics and the PCI specifications from the PCI SIG (Special Interest Group) for the electrical EMF (Electromotive force).

IEEE 1686 Standard for Substation Intelligent Electronic Devices (IEDs) Cyber Security Capabilities

IED Intelligent electronic device

IET600 Integrated engineering tool

I-GIS Intelligent gas-insulated switchgear

IOM Binary input/output module

Instance When several occurrences of the same function are available in the IED, they are referred to as instances of that function. One instance of a function is identical to another of the same kind but has a different number in the IED user interfaces. The word “instance” is sometimes defined as an item of information that is representative of a type. In the same way an instance of a function in the IED is representative of a type of function.

IP 1. Internet protocol. The network layer for the TCP/IP protocol suite widely used on Ethernet networks. IP is a connectionless, best-effort packet-switching protocol. It provides packet routing, fragmentation and reassembly through the data link layer.

2. Ingression protection, according to IEC 60529

IP 20 Ingression protection, according to IEC 60529, level 20

IP 40 Ingression protection, according to IEC 60529, level 40

IP 54 Ingression protection, according to IEC 60529, level 54

IRF Internal failure signal

IRIG-B: InterRange Instrumentation Group Time code format B, standard 200

ITU International Telecommunications Union

LAN Local area network

LIB 520 High-voltage software module

LCD Liquid crystal display

LDCM Line data communication module

LDD Local detection device

LED Light-emitting diode

LNT LON network tool

LON Local operating network

MCB Miniature circuit breaker

MCM Mezzanine carrier module

MPM Main processing module

MVAL Value of measurement

MVB Multifunction vehicle bus. Standardized serial bus originally developed for use in trains.

NCC National Control Centre
NOF  Number of grid faults
NUM  Numerical module
OCO cycle  Open-close-open cycle
OCP  Overcurrent protection
OLTC  On-load tap changer
OTEV  Disturbance data recording initiated by other event than start/pick-up
OV  Overvoltage
Overreach  A term used to describe how the relay behaves during a fault condition. For example, a distance relay is overreaching when the impedance presented to it is smaller than the apparent impedance to the fault applied to the balance point, that is, the set reach. The relay “sees” the fault but perhaps it should not have seen it.

PCI  Peripheral component interconnect, a local data bus
PCM  Pulse code modulation
PCM600  Protection and control IED manager
PC-MIP  Mezzanine card standard
PELV circuit  Protected Extra-Low Voltage circuit type according to IEC60255-27
PMC  PCI Mezzanine card
POR  Permissive overreach
POTT  Permissive overreach transfer trip
Process bus  Bus or LAN used at the process level, that is, in near proximity to the measured and/or controlled components
PRP  Parallel redundancy protocol
PSM  Power supply module
PST  Parameter setting tool within PCM600
PTP  Precision time protocol
PT ratio  Potential transformer or voltage transformer ratio
PUTT  Permissive underreach transfer trip
RASC  Synchrocheck relay, COMBIFLEX
RCA  Relay characteristic angle
RISC  Reduced instruction set computer
RMS value  Root mean square value
RS422  A balanced serial interface for the transmission of digital data in point-to-point connections
RS485  Serial link according to EIA standard RS485
RTC  Real-time clock
RTU  Remote terminal unit
SA  Substation Automation
SBO  Select-before-operate
SC  Switch or push button to close
SCL  Short circuit location
SCS  Station control system
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCADA</td>
<td>Supervision, control and data acquisition</td>
</tr>
<tr>
<td>SCT</td>
<td>System configuration tool according to standard IEC 61850</td>
</tr>
<tr>
<td>SDU</td>
<td>Service data unit</td>
</tr>
<tr>
<td>SELV circuit</td>
<td>Safety Extra-Low Voltage circuit type according to IEC60255-27</td>
</tr>
<tr>
<td>SFP</td>
<td>Small form-factor pluggable (abbreviation) Optical Ethernet port (explanation)</td>
</tr>
<tr>
<td>SLM</td>
<td>Serial communication module.</td>
</tr>
<tr>
<td>SMA connector</td>
<td>Subminiature version A, A threaded connector with constant impedance.</td>
</tr>
<tr>
<td>SMT</td>
<td>Signal matrix tool within PCM600</td>
</tr>
<tr>
<td>SMS</td>
<td>Station monitoring system</td>
</tr>
<tr>
<td>SNTP</td>
<td>Simple network time protocol – is used to synchronize computer clocks on local area networks. This reduces the requirement to have accurate hardware clocks in every embedded system in a network. Each embedded node can instead synchronize with a remote clock, providing the required accuracy.</td>
</tr>
<tr>
<td>SOF</td>
<td>Status of fault</td>
</tr>
<tr>
<td>SPA</td>
<td>Strömberg Protection Acquisition (SPA), a serial master/slave protocol for point-to-point and ring communication.</td>
</tr>
<tr>
<td>SRY</td>
<td>Switch for CB ready condition</td>
</tr>
<tr>
<td>ST</td>
<td>Switch or push button to trip</td>
</tr>
<tr>
<td>Starpoint</td>
<td>Neutral point of transformer or generator</td>
</tr>
<tr>
<td>SVC</td>
<td>Static VAr compensation</td>
</tr>
<tr>
<td>TC</td>
<td>Trip coil</td>
</tr>
<tr>
<td>TCS</td>
<td>Trip circuit supervision</td>
</tr>
<tr>
<td>TCP</td>
<td>Transmission control protocol. The most common transport layer protocol used on Ethernet and the Internet.</td>
</tr>
<tr>
<td>TCP/IP</td>
<td>Transmission control protocol over Internet Protocol. The de facto standard Ethernet protocols incorporated into 4.2BSD Unix. TCP/IP was developed by DARPA for Internet working and encompasses both network layer and transport layer protocols. While TCP and IP specify two protocols at specific protocol layers, TCP/IP is often used to refer to the entire US Department of Defense protocol suite based upon these, including Telnet, FTP, UDP and RDP.</td>
</tr>
<tr>
<td>TEF</td>
<td>Time delayed earth-fault protection function</td>
</tr>
<tr>
<td>TLS</td>
<td>Transport Layer Security</td>
</tr>
<tr>
<td>TM</td>
<td>Transmit (disturbance data)</td>
</tr>
<tr>
<td>TNC connector</td>
<td>Threaded Neill-Concelman, a threaded constant impedance version of a BNC connector</td>
</tr>
<tr>
<td>TP</td>
<td>Trip (recorded fault)</td>
</tr>
<tr>
<td>TPZ, TPY, TPX, TPS</td>
<td>Current transformer class according to IEC</td>
</tr>
<tr>
<td>TRM</td>
<td>Transformer Module. This module transforms currents and voltages taken from the process into levels suitable for further signal processing.</td>
</tr>
<tr>
<td>TYP</td>
<td>Type identification</td>
</tr>
</tbody>
</table>
**UMT**
User management tool

**Underreach**
A term used to describe how the relay behaves during a fault condition. For example, a distance relay is underreaching when the impedance presented to it is greater than the apparent impedance to the fault applied to the balance point, that is, the set reach. The relay does not “see” the fault but perhaps it should have seen it. See also Overreach.

**UTC**
Coordinated Universal Time. A coordinated time scale, maintained by the Bureau International des Poids et Mesures (BIPM), which forms the basis of a coordinated dissemination of standard frequencies and time signals. UTC is derived from International Atomic Time (TAI) by the addition of a whole number of “leap seconds” to synchronize it with Universal Time 1 (UT1), thus allowing for the eccentricity of the Earth's orbit, the rotational axis tilt (23.5 degrees), but still showing the Earth's irregular rotation, on which UT1 is based. The Coordinated Universal Time is expressed using a 24-hour clock, and uses the Gregorian calendar. It is used for aeroplane and ship navigation, where it is also sometimes known by the military name, “Zulu time.” “Zulu” in the phonetic alphabet stands for “Z”, which stands for longitude zero.

**UV**
Undervoltage

**WEI**
Weak end infeed logic

**VT**
Voltage transformer

**3I₀**
Three times zero-sequence current. Often referred to as the residual or the earth-fault current

**3U₀**
Three times the zero sequence voltage. Often referred to as the residual voltage or the neutral point voltage