RELION® 650 SERIES

Line distance protection REL650
Version 2.1
Application manual
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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.

1.2 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, LHMI functions as well as communication engineering for IEC 60870-5-103, IEC 61850, DNP3, LON and SPA.

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

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### 1.3.3 Related documents

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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.

- **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 degraded process performance leading to personal injury or death. It is important that the user fully complies with all warning and cautionary notices.
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 \[\uparrow\] and \[\downarrow\].
- 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 \[\rightarrow\].
- 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

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Section 2 Application

2.1 General IED application

REL650 is used for the protection, control and monitoring of overhead lines and cables in solidly or impedance earthed networks. It is suitable for the protection of heavily loaded lines and multi-terminal lines where the requirement for fast one- and/or three-phase tripping is wanted. Backup protection and apparatus control for 1 circuit breaker is included.

The full scheme distance protection provides protection of power lines with high sensitivity and low requirement on remote end communication. The 6 zones have fully independent measuring and setting ranges which gives high flexibility for all types of lines. Load encroachment and adaptive reach compensation are included.

The multi-shot autoreclose includes priority features for double-breaker arrangements. It cooperates with the synchrocheck function with high-speed or delayed reclosing.

Breaker failure, high set instantaneous phase and earth overcurrent, four step directional or non-directional delayed phase and earth overcurrent and two step under voltage protection are included and configured as back-up protection.

The impedance protection and the directional overcurrent protection can communicate with a remote end in any teleprotection communication scheme. The advanced logic capability, where the user logic is prepared with a graphical tool, allows special applications.

Disturbance recording and fault locator are available to allow independent post-fault analysis after primary disturbances.

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

- Six zone distance protection with quadrilateral and mho characteristic, for single and three-pole tripping (A11)

The package is configured and ready for direct use. Analog and control circuits have been predefined and other signals need to be applied as required for each application. The pre-configured IED can be changed and adapted to suit specific applications with the graphical 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 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.
2.2 Main protection functions

Table 2: Example of quantities

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2.3 Back-up protection functions

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Voltage protection

| UV2PTUV | 27 | Two step undervoltage protection | 1 |

Multipurpose protection

| CVGAPC | General current and voltage protection | 2 |

1) 67 requires voltage
2) 67N requires voltage
# 2.4 Control and monitoring functions

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<td>BTIGAPC</td>
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<td>Boolean 16 to Integer conversion with Logic Node representation</td>
<td>16</td>
</tr>
<tr>
<td>IB16</td>
<td></td>
<td>Integer to Boolean 16 conversion</td>
<td>18</td>
</tr>
</tbody>
</table>

Table continues on next page
<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
<th>Line distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITBGAPC</td>
<td>Integer to Boolean 16 conversion with Logic Node representation</td>
<td>16</td>
</tr>
<tr>
<td>TEIGAPC</td>
<td>Elapsed time integrator with limit transgression and overflow supervision</td>
<td>12</td>
</tr>
<tr>
<td>INTCOMP</td>
<td>Comparator for integer inputs</td>
<td>12</td>
</tr>
<tr>
<td>REALCOMP</td>
<td>Comparator for real inputs</td>
<td>12</td>
</tr>
</tbody>
</table>

**Monitoring**

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
<th>Line distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVMMXN,</td>
<td>Measurements</td>
<td>6</td>
</tr>
<tr>
<td>VMMXU,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMSQI,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VMSQI,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VNMMXU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMMXU</td>
<td>Measurements</td>
<td>10</td>
</tr>
<tr>
<td>AISVBAS</td>
<td>Function block for service value presentation of secondary analog inputs</td>
<td>1</td>
</tr>
<tr>
<td>SSIMG</td>
<td>Gas medium supervision</td>
<td>21</td>
</tr>
<tr>
<td>SSIML</td>
<td>Liquid medium supervision</td>
<td>3</td>
</tr>
<tr>
<td>SSCBR</td>
<td>Circuit breaker condition monitoring</td>
<td>3</td>
</tr>
<tr>
<td>EVENT</td>
<td>Event function</td>
<td>20</td>
</tr>
<tr>
<td>DRPRDRE,</td>
<td>Disturbance report</td>
<td>1</td>
</tr>
<tr>
<td>A1RADR-A4ADR, B1RBDR-B8RBDR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPGAPC</td>
<td>Generic communication function for Single Point indication</td>
<td>64</td>
</tr>
<tr>
<td>SP16GAPC</td>
<td>Generic communication function for Single Point indication 16 inputs</td>
<td>16</td>
</tr>
<tr>
<td>MVGAPC</td>
<td>Generic communication function for Measured Value</td>
<td>24</td>
</tr>
<tr>
<td>BINSTATREP</td>
<td>Logical signal status report</td>
<td>3</td>
</tr>
<tr>
<td>RANGE_XP</td>
<td>Measured value expander block</td>
<td>66</td>
</tr>
<tr>
<td>LMBRFLO</td>
<td>Fault locator</td>
<td>1</td>
</tr>
<tr>
<td>I103MEAS</td>
<td>Measurands for IEC 60870-5-103</td>
<td>1</td>
</tr>
<tr>
<td>I103MEASUSR</td>
<td>Measurands user defined signals for IEC 60870-5-103</td>
<td>3</td>
</tr>
<tr>
<td>I103AR</td>
<td>Function status auto-recloser for IEC 60870-5-103</td>
<td>1</td>
</tr>
<tr>
<td>I103EF</td>
<td>Function status earth-fault for IEC 60870-5-103</td>
<td>1</td>
</tr>
<tr>
<td>I103FLTPROT</td>
<td>Function status fault protection for IEC 60870-5-103</td>
<td>1</td>
</tr>
<tr>
<td>I103IED</td>
<td>IED status for IEC 60870-5-103</td>
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</tr>
<tr>
<td>I103SUPERV</td>
<td>Supervision status for IEC 60870-5-103</td>
<td>1</td>
</tr>
<tr>
<td>I103USRDEF</td>
<td>Status for user defined signals for IEC 60870-5-103</td>
<td>20</td>
</tr>
<tr>
<td>L4UFCONT</td>
<td>Event counter with limit supervision</td>
<td>30</td>
</tr>
<tr>
<td>TEILGAPC</td>
<td>Running hour-meter</td>
<td>6</td>
</tr>
</tbody>
</table>

**Metering**

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
<th>Line distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCFCNT</td>
<td>Pulse-counter logic</td>
<td>16</td>
</tr>
<tr>
<td>ETPMMTR</td>
<td>Function for energy calculation and demand handling</td>
<td>6</td>
</tr>
</tbody>
</table>
Table 3: Total number of instances for basic configurable logic blocks

<table>
<thead>
<tr>
<th>Basic configurable logic block</th>
<th>Total number of instances</th>
</tr>
</thead>
<tbody>
<tr>
<td>AND</td>
<td>280</td>
</tr>
<tr>
<td>GATE</td>
<td>40</td>
</tr>
<tr>
<td>INV</td>
<td>420</td>
</tr>
<tr>
<td>LLD</td>
<td>40</td>
</tr>
<tr>
<td>OR</td>
<td>280</td>
</tr>
<tr>
<td>PULSETIMER</td>
<td>40</td>
</tr>
<tr>
<td>RSMEMORY</td>
<td>40</td>
</tr>
<tr>
<td>SRMEMORY</td>
<td>40</td>
</tr>
<tr>
<td>TIMERSET</td>
<td>60</td>
</tr>
<tr>
<td>XOR</td>
<td>40</td>
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</table>

2.5 Communication

<table>
<thead>
<tr>
<th>IEC 61850</th>
<th>ANSI</th>
<th>Function description</th>
<th>Line distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>LONSPA, SPA</td>
<td></td>
<td>SPA communication protocol</td>
<td>1</td>
</tr>
<tr>
<td>ADE</td>
<td></td>
<td>LON communication protocol</td>
<td>1</td>
</tr>
<tr>
<td>HORIZCOMM</td>
<td></td>
<td>Network variables via LON</td>
<td>1</td>
</tr>
<tr>
<td>PROTOCOL</td>
<td></td>
<td>Operation selection between SPA and IEC 60870-5-103 for SLM</td>
<td>1</td>
</tr>
<tr>
<td>RS485PROT</td>
<td></td>
<td>Operation selection for RS485</td>
<td>1</td>
</tr>
<tr>
<td>RS485GEN</td>
<td></td>
<td>RS485</td>
<td>1</td>
</tr>
<tr>
<td>DNPGEN</td>
<td></td>
<td>DNP3.0 communication general protocol</td>
<td>1</td>
</tr>
<tr>
<td>DNPGENTCP</td>
<td></td>
<td>DNP3.0 communication general TCP protocol</td>
<td>1</td>
</tr>
<tr>
<td>CHSERRS485</td>
<td></td>
<td>DNP3.0 for EIA-485 communication protocol</td>
<td>1</td>
</tr>
<tr>
<td>CH1TCP, CH2TCP, CH3TCP, CH4TCP</td>
<td></td>
<td>DNP3.0 for TCP/IP communication protocol</td>
<td>1</td>
</tr>
<tr>
<td>CHSEROPT</td>
<td></td>
<td>DNP3.0 for TCP/IP and EIA-485 communication protocol</td>
<td>1</td>
</tr>
<tr>
<td>MSTSER</td>
<td></td>
<td>DNP3.0 for serial communication protocol</td>
<td>1</td>
</tr>
<tr>
<td>MST1TCP, MST2TCP, MST3TCP, MST4TCP</td>
<td></td>
<td>DNP3.0 for TCP/IP communication protocol</td>
<td>1</td>
</tr>
<tr>
<td>DNPFREC</td>
<td></td>
<td>DNP3.0 fault records for TCP/IP and EIA-485 communication protocol</td>
<td>1</td>
</tr>
<tr>
<td>IEC 61850-8-1</td>
<td></td>
<td>Parameter setting function for IEC 61850</td>
<td>1</td>
</tr>
<tr>
<td>GOOSEINTLKRCV</td>
<td></td>
<td>Horizontal communication via GOOSE for interlocking</td>
<td>59</td>
</tr>
<tr>
<td>GOOSEBINRCV</td>
<td></td>
<td>GOOSE binary receive</td>
<td>16</td>
</tr>
<tr>
<td>GOOSEDPRCV</td>
<td></td>
<td>GOOSE function block to receive a double point value</td>
<td>64</td>
</tr>
<tr>
<td>GOOSEINTRCV</td>
<td></td>
<td>GOOSE function block to receive an integer value</td>
<td>32</td>
</tr>
<tr>
<td>GOOSEMVRVC</td>
<td></td>
<td>GOOSE function block to receive a measurand value</td>
<td>60</td>
</tr>
<tr>
<td>GOOSESPRCV</td>
<td></td>
<td>GOOSE function block to receive a single point value</td>
<td>64</td>
</tr>
<tr>
<td>MULTICMDRCV/ MULTICMDSND</td>
<td></td>
<td>Multiple command and transmit</td>
<td>60/10</td>
</tr>
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</table>

Table continues on next page
<table>
<thead>
<tr>
<th>IEC 61850 or function name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTERRSIG</td>
<td>Self supervision with internal event list</td>
</tr>
<tr>
<td>SELFSSUPEVLST</td>
<td>Self supervision with internal event list</td>
</tr>
<tr>
<td>TIMESYNCHGEN</td>
<td>Time synchronization module</td>
</tr>
<tr>
<td>BININPUT, SYNCHCAN, SYNCHGPS, SYNCHCMPPS, SYNCHLON, SYNCHPPH, SYNCHPPS, SNTP, SYNCHSPA, SYNCHCMPPS</td>
<td>Time synchronization</td>
</tr>
<tr>
<td>TIMEZONE</td>
<td>Time synchronization</td>
</tr>
<tr>
<td>DSTBEGIN, DSTENABLE, DSTEND</td>
<td>GPS time synchronization module</td>
</tr>
<tr>
<td>IRIG-B</td>
<td>Time synchronization</td>
</tr>
<tr>
<td>SETGRPS</td>
<td>Number of setting groups</td>
</tr>
</tbody>
</table>

### 2.6 Basic IED functions

#### Table 4: Basic IED functions
### IEC 61850 or function name

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter setting groups</td>
</tr>
<tr>
<td>Test mode functionality</td>
</tr>
<tr>
<td>Change lock function</td>
</tr>
<tr>
<td>Signal matrix for binary inputs</td>
</tr>
<tr>
<td>Signal matrix for binary outputs</td>
</tr>
<tr>
<td>Signal matrix for analog inputs</td>
</tr>
<tr>
<td>Summation block 3 phase</td>
</tr>
<tr>
<td>Authority status</td>
</tr>
<tr>
<td>Authority check</td>
</tr>
<tr>
<td>Authority management</td>
</tr>
<tr>
<td>FTP access with password</td>
</tr>
<tr>
<td>SPA communication mapping</td>
</tr>
<tr>
<td>Date and time via SPA protocol</td>
</tr>
<tr>
<td>Denial of service, frame rate control for front port</td>
</tr>
<tr>
<td>Denial of service, frame rate control for OEM port AB</td>
</tr>
<tr>
<td>Denial of service, frame rate control for OEM port CD</td>
</tr>
<tr>
<td>Denial of service, socket flow control</td>
</tr>
<tr>
<td>Global base values for settings</td>
</tr>
<tr>
<td>Primary system values</td>
</tr>
<tr>
<td>Time master supervision</td>
</tr>
<tr>
<td>Time management</td>
</tr>
<tr>
<td>DNP3.0 for serial communication protocol</td>
</tr>
</tbody>
</table>

### Table 5: Local HMI functions

<table>
<thead>
<tr>
<th>IEC 61850 or function name</th>
<th>ANSI</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHMICTRL</td>
<td></td>
<td>Local HMI signals</td>
</tr>
<tr>
<td>LANGUAGE</td>
<td></td>
<td>Local human machine language</td>
</tr>
<tr>
<td>SCREEN</td>
<td></td>
<td>Local HMI Local human machine screen behavior</td>
</tr>
<tr>
<td>FNKEYTY1–FNKEYTY5</td>
<td></td>
<td>Parameter setting function for HMI in PCM600</td>
</tr>
<tr>
<td>FNKEYMD1–FNKEYMD5</td>
<td></td>
<td>Parameter setting function for HMI in PCM600</td>
</tr>
<tr>
<td>LEDGEN</td>
<td></td>
<td>General LED indication part for LHMI</td>
</tr>
<tr>
<td>OPENCLOSE_LED</td>
<td></td>
<td>LHMI LEDs for open and close keys</td>
</tr>
<tr>
<td>GRP1_LED1–GRP1_LED15</td>
<td></td>
<td>Basic part for CP HW LED indication module</td>
</tr>
<tr>
<td>GRP2_LED1–GRP2_LED15</td>
<td></td>
<td>Basic part for CP HW LED indication module</td>
</tr>
<tr>
<td>GRP3_LED1–GRP3_LED15</td>
<td></td>
<td>Basic part for CP HW LED indication module</td>
</tr>
</tbody>
</table>
Section 3    Configuration

3.1    Description of configuration REL650

3.1.1    Introduction

The basic delivery includes one binary input module and one binary output module, which is sufficient for the default configured IO to trip and close circuit breaker. All IEDs can be reconfigured with the help of the ACT configuration tool in the PCM600 engineering platform. 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, mimic 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 IO 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 IO 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 A11

Six zone distance protection with quadrilateral and mho characteristic, for single and three-pole tripping.
Figure 2: Configuration diagram for configuration A11
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 and 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.

A reference PhaseAngleRef can be defined to facilitate service values reading. This analog channels phase angle will always be fixed to zero degrees and all other 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 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

Usually the L1 phase-to-earth voltage connected to the first VT channel number of the transformer input module (TRM) is selected as the phase reference. The first VT channel number depends on the type of transformer input module.

For a TRM with 6 current and 6 voltage inputs the first VT channel is 7. The setting PhaseAngleRef=7 shall be used if the phase reference voltage is connected to that channel.
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 has a direction towards the object. A negative value of current, power, and so on (reverse) means a direction away from the object. See figure 3.

![Diagram of current direction](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 object and a direction defined as Forward always is looking towards the object. The following examples show the principle.

4.2.2.1 Example 1

Two IEDs used for protection of two objects.
**Figure 4:** Example how to set CTStarPoint parameters in the IED

The 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 the 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.
Figure 6: Example how to set CTStarPoint parameters in the IED

In this example one IED includes both transformer and line protection 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 a 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.
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 Transformer as reference object. Correct setting is "ToObject".

IED
Transformer and Line protection

Forward
Reverse
Definition of direction for directional line functions

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

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

Figure 8 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 8: 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 9 gives an example about the wiring of a star connected three-phase CT set to the IED. It gives also 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 9: 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 9:

- CTprim=600A
- CTsec=5A
- CTStarPoint=ToObject

Inside the IED only the ratio of the first two parameters is used. 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 10:

Figure 10: Star connected three-phase CT set with its star point away from the protected object

In the example in figure 10 case everything is done in a similar way as in the above described example (figure 9). The only difference is the setting of the parameter CTStarPoint of the used current inputs on the TRM (item 2 in figure 10 and 9):
Section 4  
Analog inputs

- $CT_{prim}=600\text{A}$
- $CT_{sec}=5\text{A}$
- $CTStarPoint=\text{FromObject}$

Inside the IED only the ratio of the first two parameters is used. 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 10.

![Diagram](image)

**Figure 11:** 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) 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) shows how to connect residual/neutral current from the three-phase CT set to the fourth inputs 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.

- $CT_{prim}=800\text{A}$
- $CT_{sec}=1\text{A}$
- $CTStarPoint=\text{FromObject}$
- $ConnectionType=\text{Ph-N}$

Inside the IED only the ratio of the first two parameters is used. The third parameter as set in this example will have no influence on the 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), 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), 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. In that case the pre-processing block will calculate it by vectorial summation of the three individual phase currents.

6) 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.

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

Figure 12 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 12: 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.

\[ CT_{prim} = 600A \]
\[ CT_{sec} = 5A \]

- `CTStarPoint= ToObject`
- `ConnectionType= Ph-Ph`

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 then 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:

- 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 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 13:

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:

- $CT_{\text{prim}} = 800\text{A}$
- $CT_{\text{sec}} = 1\text{A}$
- $CTStarPoint = \text{ToObject}$
- $ConnectionType = \text{Ph-Ph}$

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$^\circ$ by setting $\text{ToObject}$.

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

Figure 14 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 14: 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 14:
\[ CT_{prim} = 1000 \text{ A} \]
\[ CT_{sec} = 1 \text{ A} \]
\[ CTStarPoint= ToObject \]

For connection (b) shown in figure 14:
\[ CT_{prim} = 1000 \text{ A} \]
\[ CT_{sec} = 1 \text{ A} \]
\[ CTStarPoint= FromObject \]

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. IBase 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 \( I_{Base} \) 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 \( I_{Base} \) 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 \( VT_{sec} \) and \( VT_{prim} \) 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: \( VT_{prim}=132 \) (value in kV) \( VT_{sec}=110 \) (value in V)

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

Figure 15 defines the marking of voltage transformer terminals commonly used around the world.
Figure 15: Commonly used markings of VT terminals

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 16 gives an example on how to connect a three phase-to-earth connected VT to the IED. It as well 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.

For correct terminal designations, see the connection diagrams valid for the delivered IED.
Figure 16: A Three 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:
   \[ \frac{VT_{\text{prim}}}{VT_{\text{sec}}} = \frac{66}{110} \]
   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.

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

(Equation 2)

Table continues on next page
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.

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 3Uo 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 18.

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. However the following settings shall be set as shown here:

- UBase=66 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 17 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 as well. It shall be noted that this VT connection is only used on lower voltage levels (that is, rated primary voltage below 40 kV).
**Figure 17: 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:

   \[ \text{VT}_{\text{prim}} = 13.8 \text{ kV} \]
   \[ \text{VT}_{\text{sec}} = 120 \text{ V} \]

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{ConnectionType=Ph-Ph}
   - \text{UBase=13.8 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.
### 4.2.4.5 Example on how to connect an open delta VT to the IED for high impedance earthed or unearthed networks

Figure 18 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 $3U_0$ to the IED.

In case of a solid earth fault close to the VT location the primary value of $3U_0$ will be equal to:

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

(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 18 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 18: 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)

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

(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.

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

(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 19 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 3Uo 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 19 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.

![Diagram](IEC06000602-4-en.vsdx)

**Figure 19:** 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.

\[ +3U_0 \text{ shall be connected to the IED.} \]

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:

\[ VT_{prim} = \sqrt{3} \cdot \frac{138}{\sqrt{3}} = 138kV \]  
(Equation 8)

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

\[ \frac{138}{115} = \frac{138/\sqrt{3}}{115/\sqrt{3}} \]  
(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 DFTReference shall be set accordingly.

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

Figure 20 gives an example on how to connect a neutral point VT to the IED. This type of VT connection presents secondary voltage proportional to \( U_0 \) to the IED.
In case of a solid earth fault in high impedance earthed or ungrounded systems, the primary value of $U_0$ voltage will be equal to:

$$U_0 = \frac{U_{ph} - p_n}{\sqrt{3}} = U_{ph} - E$$

(Equation 11)

Figure 20 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 20: 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 the 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).

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.
Section 5  Local HMI

Figure 21:  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.

![Display layout](image)

**Figure 22: 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.
The indication LED panel shows on request the alarm text labels for the indication LEDs. Three indication LED pages are available.

Figure 23:  Function button panel

The function button and indication LED panels are not visible at the same time. Each panel is shown by pressing one of the function buttons or the Multipage button. Pressing the ESC button clears the panel from the display. Both panels have a dynamic width that depends on the label string length.

Figure 24:  Indication LED panel

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 . They can,
for example, represent the status of a circuit breaker. The LEDs are controlled by the function
block OPENCLOSE_LED which must be configured to show the status of the breaker.

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 25: 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 start and trip LEDs are configured via the disturbance recorder. 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.</td>
</tr>
<tr>
<td></td>
<td>The start indication is latching and must be reset via communication, LHMI or</td>
</tr>
<tr>
<td></td>
<td>binary input on the LEDGEN component. To open the reset menu on the LHMI,</td>
</tr>
<tr>
<td></td>
<td>press .</td>
</tr>
<tr>
<td>Flashing</td>
<td>The IED is in test mode and protection functions are blocked, or the IEC61850</td>
</tr>
<tr>
<td></td>
<td>protocol is blocking one or more functions. The indication disappears when</td>
</tr>
<tr>
<td></td>
<td>the IED is no longer in test mode and blocking is removed. The blocking of</td>
</tr>
<tr>
<td></td>
<td>functions through the IEC61850 protocol can be reset in Main menu/Test/Reset</td>
</tr>
<tr>
<td></td>
<td>IEC61850 Mod. The yellow LED changes to either On or Off state depending on</td>
</tr>
<tr>
<td></td>
<td>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 <img src="button_image" alt="button" />.</td>
</tr>
<tr>
<td>Flasing</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 9: Alarm indications

<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.
Figure 26: RJ-45 communication port and green indicator LED

1  RJ-45 connector
2  Green indicator LED

The default IP address for the IED front port is 10.150.3 and the corresponding subnetwork mask is 255.255.255.0. It can be set through the local HMI path **Main menu/Configuration/Communication/Ethernet configuration/Front:**1.

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  Impedance protection

6.1  Distance protection ZMFPDIS

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>Distance protection zone</td>
<td>ZMFPDIS</td>
<td></td>
<td>21</td>
</tr>
</tbody>
</table>

6.1.2  Application

The distance protection function in the IED is designed to meet basic requirements for application on transmission and sub-transmission lines (solid earthed systems) although it can also be used on distribution levels.

Sub-transmission networks are being extended and often become more and more complex, consisting of a high number of multi-circuit and/or multi terminal lines of very different lengths. These changes in the network will normally impose more stringent demands on the fault clearing equipment in order to maintain an unchanged or increased security level of the power system.

6.1.2.1  System earthing

The type of system earthing plays an important role when designing the protection system. Some hints with respect to distance protection are highlighted below.

**Solidly earthed networks**

In solidly earthed systems, the transformer neutrals are connected directly to earth without any impedance between the transformer neutral and earth.

![Solidly earthed network](image)

*Figure 27:  Solidly earthed network*

The earth-fault current is as high or even higher than the short-circuit current. The series impedances determine the magnitude of the fault current. The shunt admittance has very limited influence on the earth-fault current. The shunt admittance may, however, have some marginal influence on the earth-fault current in networks with long transmission lines.
The earth-fault current at single phase-to-earth in phase L1 can be calculated as equation 14:

\[ I_{\text{L1}} = \frac{3 \cdot U_{\text{L1}}}{Z_1 + Z_2 + Z_0 + 3Z_f} = \frac{U_{\text{L1}}}{Z_1 + Z_0 + Z_f} \]

(Equation 14)

Where:
- \( U_{\text{L1}} \) is the phase-to-earth voltage (kV) in the faulty phase before fault
- \( Z_1 \) is the positive sequence impedance (Ω/phase)
- \( Z_2 \) is the negative sequence impedance (Ω/phase)
- \( Z_0 \) is the zero sequence impedance (Ω/phase)
- \( Z_f \) is the fault impedance (Ω), often resistive
- \( Z_N \) is the earth-return impedance defined as \((Z_0 - Z_1)/3\)

The high zero-sequence current in solidly earthed networks makes it possible to use impedance measuring techniques to detect earth faults. However, distance protection has limited possibilities to detect high resistance faults and should therefore always be complemented with other protection function(s) that can carry out the fault clearance in those cases.

**Effectively earthed networks**

A network is defined as effectively earthed if the earth-fault factor \( f_e \) is less than 1.4. The earth-fault factor is defined according to equation 15.

\[ f_e = \frac{U_{\text{max}}}{U_{\text{pn}}} \]

(Equation 15)

Where:
- \( U_{\text{max}} \) is the highest fundamental frequency voltage on one of the healthy phases at single phase-to-earth fault.
- \( U_{\text{pn}} \) is the phase-to-earth fundamental frequency voltage before fault.

Another definition for effectively earthed network is when the following relationships between the symmetrical components of the network impedances are valid, see equation 16 and 17.

\[ X_0 < 3 \cdot X_1 \]

(Equation 16)

\[ R_0 \leq R_f \]

(Equation 17)

Where
- \( R_0 \) is the resistive zero sequence of the source
- \( X_0 \) is the reactive zero sequence of the source
R₁ is the resistive positive sequence of the source
X₁ is the reactive positive sequence of the source

The magnitude of the earth-fault current in effectively earthed networks is high enough for impedance measuring elements to detect earth faults. However, in the same way as for solidly earthed networks, distance protection has limited possibilities to detect high resistance faults and should therefore always be complemented with other protection function(s) that can carry out the fault clearance in this case.

High impedance earthed networks

In high impedance networks, the neutral of the system transformers are connected to the earth through high impedance, mostly a reactance in parallel with a high resistor.

This type of network is often operated radially, but can also be found operating as a meshed network.

What is typical for this type of network is that the magnitude of the earth-fault current is very low compared to the short circuit current. The voltage on the healthy phases will get a magnitude of \( \sqrt{3} \) times the phase voltage during the fault. The zero sequence voltage (3U₀) will have the same magnitude in different places in the network due to low voltage drop distribution.

The magnitude of the total fault current can be calculated according to equation **18**.

\[
3I₀ = \sqrt{1R^2 + (1L - 1C)^2}
\]

(Equation 18)

Where:

- \( 3I₀ \) is the earth-fault current (A)
- \( IR \) is the current through the neutral point resistor (A)
- \( IL \) is the current through the neutral point reactor (A)
- \( IC \) is the total capacitive earth-fault current (A)

The neutral point reactor is normally designed so that it can be tuned to a position where the reactive current balances the capacitive current from the network:

\[
\omega L = \frac{1}{3\cdot\omega \cdot C}
\]

(Equation 19)
The operation of high impedance earthed networks is different compared to solid earthed networks, where all major faults have to be cleared very fast. In high impedance earthed networks, some system operators do not clear single phase-to-earth faults immediately; they clear the line later when it is more convenient. In case of cross-country faults, many network operators want to selectively clear one of the two earth faults.

In this type of network, it is mostly not possible to use distance protection for detection and clearance of earth faults. The low magnitude of the earth-fault current might not give start of the zero-sequence measurement elements or the sensitivity will be too low for acceptance. For this reason a separate high sensitive earth-fault protection is necessary to carry out the fault clearance for single phase-to-earth fault.

### 6.1.2.2 Fault infeed from remote end

All transmission and most all sub-transmission networks are operated meshed. Typical for this type of network is that fault infeed from remote end will happen when fault occurs on the protected line. The fault current infeed will enlarge the fault impedance seen by the distance protection. This effect is very important to keep in mind when both planning the protection system and making the settings.

With reference to figure 29, the equation for the bus voltage $U_A$ at A side is:

$$U_A = I_A \cdot p \cdot Z_L + (I_A + I_B) \cdot R_f$$

(Equation 20)

If we divide $U_A$ by $I_A$ we get $Z$ present to the IED at A side.

$$Z_A = \frac{U_A}{I_A} = \frac{I_A}{I_A} \cdot \frac{I_A + I_B}{I_A} \cdot R_f$$

(Equation 21)

The infeed factor $(I_A + I_B)/I_A$ can be very high, 10-20 depending on the differences in source impedances at local and remote end.
The effect of fault current infeed from the remote line end is one of the most driving factors to justify complementary protection for distance protection.

When the line is heavily loaded, the distance protection at the exporting end will have a tendency to overreach. To handle this phenomenon, the IED has an adaptive built-in algorithm, which compensates the overreach tendency of zone 1 at the exporting end. No settings are required for this feature.

6.1.2.3 Load encroachment

In some cases the measured load impedance might enter the set zone characteristic without any fault on the protected line. This phenomenon is called load encroachment and it might occur when an external fault is cleared and high emergency load is transferred onto the protected line. The effect of load encroachment is illustrated on the left in figure 30. The entrance of the load impedance inside the characteristic is of course not desirable and the way to handle this with conventional distance protection is to consider this with the resistive reach settings, that is, to have a security margin between the distance zone characteristic and the minimum load impedance. Such a solution has the drawback that it will reduce the sensitivity of the distance protection, that is, the ability to detect resistive faults.

The IED has a built in feature which shapes the characteristic according to the characteristic shown in figure 30. The load encroachment algorithm will increase the possibility to detect high fault resistances, especially for phase-to-earth faults at the remote line end. For example, for a given setting of the load angle $ArgLd$, the resistive blinder for the zone measurement can be set according to figure 30 affording higher fault resistance coverage without risk for unwanted operation due to load encroachment. Separate resistive blinder settings are available in forward and reverse direction.

The use of the load encroachment feature is essential for long heavily loaded lines, where there might be a conflict between the necessary emergency load transfer and necessary sensitivity of the distance protection. The function can also preferably be used on heavy loaded, medium long lines. For short lines, the major concern is to get sufficient fault resistance coverage. Load encroachment is not a major problem. See section III.
6.1.2.4 Short line application

In short line applications, the major concern is to get sufficient fault resistance coverage. Load encroachment is not such a common problem. The line length that can be recognized as a short line is not a fixed length; it depends on system parameters such as voltage and source impedance, see table 10.

Table 10: Definition of short and very short line

<table>
<thead>
<tr>
<th>Line category</th>
<th>Un</th>
<th>Un</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>110 kV</td>
<td>500 kV</td>
</tr>
<tr>
<td>Very short line</td>
<td>1.1-5.5 km</td>
<td>5-25 km</td>
</tr>
<tr>
<td>Short line</td>
<td>5.5-11 km</td>
<td>25-50 km</td>
</tr>
</tbody>
</table>

The IED’s ability to set resistive and reactive reach independent for positive and zero sequence fault loops and individual fault resistance settings for phase-to-phase and phase-to-earth fault together with load encroachment algorithm improves the possibility to detect high resistive faults without conflict with the load impedance.

For very short line applications, the underreaching zone 1 cannot be used due to the fact that the voltage drop distribution throughout the line will be too low causing risk for overreaching.

6.1.2.5 Long transmission line application

For long transmission lines, the margin to the load impedance, that is, to avoid load encroachment, will normally be a major concern. It is well known that it is difficult to achieve high sensitivity for phase-to-earth fault at remote line end of long lines when the line is heavy loaded.

What can be recognized as long lines with respect to the performance of distance protection can generally be described as in table 11. Long lines have Source impedance ratio (SIR’s) less than 0.5.

Figure 30: Load encroachment phenomena and shaped load encroachment characteristic

[1] RLdRv = RLdRvFactor * RLdFw
Table 11: Definition of long and very long lines

<table>
<thead>
<tr>
<th>Line category</th>
<th>Un</th>
<th>Un</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>110 kV</td>
<td>500 kV</td>
</tr>
<tr>
<td>Long lines</td>
<td>77 km - 99 km</td>
<td>350 km - 450 km</td>
</tr>
<tr>
<td>Very long lines</td>
<td>&gt; 99 km</td>
<td>&gt; 450 km</td>
</tr>
</tbody>
</table>

The IED's ability to set resistive and reactive reach independent for positive and zero sequence fault loops and individual fault resistance settings for phase-to-phase and phase-to-earth fault together with load encroachment algorithm improves the possibility to detect high resistive faults at the same time as the security is improved (risk for unwanted trip due to load encroachment is eliminated), see figure 30.

6.1.2.6 Parallel line application with mutual coupling

General
Introduction of parallel lines in the network is increasing due to difficulties to get necessary land to build new lines.

Parallel lines introduce an error in the measurement due to the mutual coupling between the parallel lines. The lines need not be of the same voltage level in order to experience mutual coupling, and some coupling exists even for lines that are separated by 100 meters or more. The mutual coupling does influence the zero sequence impedance to the fault point but it does not normally cause voltage inversion.

It can be shown from analytical calculations of line impedances that the mutual impedances for positive and negative sequence are very small (< 1-2%) of the self impedance and it is a common practice to neglect them.

From an application point of view there exists three types of network configurations (classes) that must be considered when making the settings for the protection function.

The different network configuration classes are:

1. Parallel line with common positive and zero sequence network
2. Parallel circuits with common positive but isolated zero sequence network
3. Parallel circuits with positive and zero sequence sources isolated.

One example of class 3 networks could be the mutual coupling between a 400 kV line and rail road overhead lines. This type of mutual coupling is not so common although it exists and is not treated any further in this manual.

For each type of network class, there are three different topologies; the parallel line can be in service, out of service, out of service and earthed at both ends.

The reach of the distance protection zone 1 shall be different depending on the operation condition of the parallel line. This can be handled by the use of different setting groups for handling the cases when the parallel line is in operation and out of service and earthed at both ends.

The distance protection within the IED can compensate for the influence of a zero sequence mutual coupling on the measurement at single phase-to-earth faults in the following ways, by using:
• The possibility of different setting values that influence the earth-return compensation for different distance zones within the same group of setting parameters.
• Different groups of setting parameters for different operating conditions of a protected multi circuit line.

Most multi circuit lines have two parallel operating circuits.

**Parallel line applications**
This type of networks is defined as those networks where the parallel transmission lines terminate at common nodes at both ends.

The three most common operation modes are:

1. Parallel line in service.
2. Parallel line out of service and earthed.
3. Parallel line out of service and not earthed.

**Parallel line in service**
This type of application is very common and applies to all normal sub-transmission and transmission networks.

Let us analyze what happens when a fault occurs on the parallel line see figure 31.

From symmetrical components, we can derive the impedance \( Z \) at the relay point for normal lines without mutual coupling according to equation 22.

\[
Z = \frac{U_{ph}}{I_{ph} + 3I_0} = \frac{U_{ph}}{I_{ph} + 3I_0 \cdot K_N}
\]

(Equation 22)

Where:

- \( U_{ph} \) is phase to earth voltage at the relay point
- \( I_{ph} \) is phase current in the faulty phase
- \( 3I_0 \) is earth fault current
- \( Z_1 \) is positive sequence impedance
- \( Z_0 \) is zero sequence impedance

**Figure 31: Class 1, parallel line in service**
The equivalent circuit of the lines can be simplified, see figure 32.
When mutual coupling is introduced, the voltage at the relay point A will be changed according to equation 23.

\[
U_{ph} = Z_{1l} \left( I_{ph} + 3I_0 \cdot \frac{Z_0 - Z_{1l}}{3Z_{1l}} + 3I_{0p} \cdot \frac{Z_{0p}}{3Z_{1l}} \right)
\]

(Equation 23)

By dividing equation 23 by equation 22 and after some simplification we can write the impedance present to the relay at A side as:

\[
Z = \frac{Z_{1l}}{\left( 1 + \frac{3I_0 \cdot KNm}{I_{ph} + 3I_0 \cdot KN} \right)}
\]

(Equation 24)

Where:

\[
KNm = Z_{0m}/(3 \cdot Z_{1l})
\]

The second part in the parentheses is the error introduced to the measurement of the line impedance.

If the current on the parallel line has negative sign compared to the current on the protected line, that is, the current on the parallel line has an opposite direction compared to the current on the protected line, the distance function will overreach. If the currents have the same direction, the distance protection will underreach.

Maximum overreach will occur if the fault current infeed from remote line end is weak. If considering a single phase-to-earth fault at ‘p’ unit of the line length from A to B on the parallel line for the case when the fault current infeed from remote line end is zero, the voltage \( U_A \) in the faulty phase at A side as in equation 25.

\[
\bar{U}_A = p \cdot Z_{1l} \left( I_{ph} + K_N \cdot 3I_0 + K_{Nim} \cdot 3I_{0p} \right)
\]

(Equation 25)

One can also notice that the following relationship exists between the zero sequence currents:

\[
3I_0 \cdot Z_{0l} = 3I_{0p} \cdot Z_{0l} \left( 2 - p \right)
\]

(Equation 26)
Simplification of equation 26, solving it for $3I_0$, and substitution of the result into equation 25 gives that the voltage can be drawn as:

$$\overline{U}_A = p \cdot ZI_L \left( \frac{I_{ph} + K_N \cdot 3I_0 + K_{N_m} \cdot 3I_0 \cdot p}{2 - p} \right)$$

(Equation 27)

If we finally divide equation 27 with equation 22 we can draw the impedance present to the IED as

$$\overline{Z} = p \cdot ZI_L \left( \frac{I_{ph} + KN \cdot 3I_0 + K_{N_m} \cdot 3I_0 \cdot p}{I_{ph} + 3I_0 \cdot KN} \right)$$

(Equation 28)

Calculation for a 400 kV line, where we for simplicity have excluded the resistance, gives with $X_{1L}=0.303 \, \Omega/km$, $X_{0L}=0.88 \, \Omega/km$, zone 1 reach is set to 90% of the line reactance $p=71\%$ that is, the protection is underreaching with approximately 20%.

The zero sequence mutual coupling can reduce the reach of distance protection on the protected circuit when the parallel line is in normal operation. The reduction of the reach is most pronounced with no current infeed in the IED closest to the fault. This reach reduction is normally less than 15%. But when the reach is reduced at one line end, it is proportionally increased at the opposite line end. So this 15% reach reduction does not significantly affect the operation of a permissive underreaching scheme.

**Parallel line out of service and earthed**

![Figure 33: The parallel line is out of service and earthed](IEC09000251_1_en.vsd)

When the parallel line is out of service and earthed at both line ends on the bus bar side of the line CTs so that zero sequence current can flow on the parallel line, the equivalent zero sequence circuit of the parallel lines will be according to figure 34.

![Figure 34: Equivalent zero sequence impedance circuit for the double-circuit line that operates with one circuit disconnected and earthed at both ends](IEC09000252_1_en.vsd)

Here the equivalent zero-sequence impedance is equal to $Z_0 \cdot Z_{0m}$ in parallel with $(Z_0 \cdot Z_{0m})/Z_0 + Z_{0m}^2$ which is equal to equation 29.
The influence on the distance measurement will be a considerable overreach, which must be considered when calculating the settings. It is recommended to use a separate setting group for this operation condition since it will reduce the reach considerably when the line is in operation.

All expressions below are proposed for practical use. They assume the value of zero sequence, mutual resistance $R_{0m}$ equals to zero. They consider only the zero sequence, mutual reactance $X_{0m}$. Calculate the equivalent $X_{0E}$ and $R_{0E}$ zero sequence parameters according to equation 30 and equation 31 for each particular line section and use them for calculating the reach for the underreaching zone.

$$Z_E = \frac{Z_0^2 - Z_{0m}^2}{Z_0}$$

(Equation 29)

$$R_{0E} = R_0 \left( 1 + \frac{X_{0m}^2}{R_0^2 + X_0^2} \right)$$

(Equation 30)

$$X_{0E} = X_0 \left( 1 - \frac{X_{0m}^2}{R_0^2 + X_0^2} \right)$$

(Equation 31)

**Parallel line out of service and not earthed**

When the parallel line is out of service and not earthed, the zero sequence on that line can only flow through the line admittance to the earth. The line admittance is high which limits the zero-sequence current on the parallel line to very low values. In practice, the equivalent zero-sequence impedance circuit for faults at the remote bus bar can be simplified to the circuit shown in figure 35.

The line zero sequence mutual impedance does not influence the measurement of the distance protection in a faulty circuit. This means that the reach of the underreaching distance protection zone is reduced if, due to operating conditions, the equivalent zero sequence impedance is set according to the conditions when the parallel system is out of operation and earthed at both ends.
Figure 36: Equivalent zero-sequence impedance circuit for a double-circuit line with one circuit disconnected and not earthed

The reduction of the reach is equal to equation 32.

\[
\overline{K_U} = \frac{1}{3} \left( 2 \cdot \overline{Z_1} + \overline{Z_0} + R_f \right) = 1 - \frac{Z_{m0}^2}{Z_0 \cdot \left( 2 \cdot \overline{Z_1} + \overline{Z_0} + 3R_f \right)}
\]

(Equation 32)

This means that the reach is reduced in reactive and resistive directions. If the real and imaginary components of the constant \(A\) are equal to equation 33 and equation 34.

\[
\text{Re}(\overline{A}) = R_0 \cdot (2 \cdot R_1 + R_0 + 3 \cdot R_f) - X_0 \cdot (X_0 + 2 \cdot X_1)
\]

(Equation 33)

\[
\text{Im}(\overline{A}) = X_0 \cdot (2 \cdot R_1 + R_0 + 3 \cdot R_f) + R_0 \cdot (2 \cdot X_1 + X_0)
\]

(Equation 34)

The real component of the \(K_U\) factor is equal to equation 35.

\[
\text{Re}(\overline{K_U}) = 1 + \frac{\text{Re}(\overline{A}) \cdot X_{m0}^2}{\left[ \text{Re}(\overline{A}) \right]^2 + \left[ \text{Im}(\overline{A}) \right]^2}
\]

(Equation 35)

The imaginary component of the same factor is equal to equation 36.

\[
\text{Im}(\overline{K_U}) = \frac{\text{Im}(\overline{A}) \cdot X_{m0}^2}{\left[ \text{Re}(\overline{A}) \right]^2 + \left[ \text{Im}(\overline{A}) \right]^2}
\]

(Equation 36)

Ensure that the underreaching zones from both line ends will overlap a sufficient amount (at least 10%) in the middle of the protected circuit.

6.1.2.7 Tapped line application
This application gives rise to similar problem that was highlighted in section "Fault infeed from remote end", that is increased measured impedance due to fault current infeed. For example, for faults between the T point and B station the measured impedance at A and C will be

\[
Z_A = Z_{AT} + \frac{I_A + I_C}{I_A} \cdot Z_{TF}
\]

(Equation 37)

\[
Z_C = Z_{Trf} + \left( Z_{CT} + \frac{I_A + I_C}{I_C} \cdot Z_{TF} \right) \cdot \left( \frac{U_2}{U_1} \right)^2
\]

(Equation 38)

Where:
- \( Z_{AT} \) and \( Z_{CT} \) is the line impedance from the A respective C station to the T point.
- \( I_A \) and \( I_C \) is fault current from A respective C station for fault between T and B.
- \( U_2/U_1 \) Transformation ratio for transformation of impedance at U1 side of the transformer to the measuring side U2 (it is assumed that current and voltage distance function is taken from U2 side of the transformer).
- \( Z_{TF} \) is the line impedance from the T point to the fault (F).
- \( Z_{Trf} \) transformer impedance

For this example with a fault between T and B, the measured impedance from the T point to the fault will be increased by a factor defined as the sum of the currents from T point to the
fault divided by the IED current. For the IED at C, the impedance on the high voltage side U1 has to be transferred to the measuring voltage level by the transformer ratio.

Another complication that might occur depending on the topology is that the current from one end can have a reverse direction for fault on the protected line. For example, for faults at T the current from B might go in reverse direction from B to C depending on the system parameters (see the dotted line in figure 37), given that the distance protection in B to T will measure wrong direction.

In three-end application, depending on the source impedance behind the IEDs, the impedances of the protected object and the fault location, it might be necessary to accept zone 2 trip in one end or sequential trip in one end.

Generally for this type of application it is difficult to select settings of zone 1 that both gives overlapping of the zones with enough sensitivity without interference with other zone 1 settings, that is, without selectivity conflicts. Careful fault calculations are necessary to determine suitable settings and selection of proper scheme communication.

**Fault resistance**
The performance of distance protection for single phase-to-earth faults is very important, because normally more than 70% of the faults on transmission lines are single phase-to-earth faults. At these faults, the fault resistance is composed of three parts: arc resistance, resistance of a tower construction, and tower-footing resistance. The resistance is also depending on the presence of earth shield conductor at the top of the tower, connecting tower-footing resistance in parallel. The arc resistance can be calculated according to Warrington's formula:

\[
R_{arc} = \frac{28707 \cdot L}{I^{1.4}}
\]

(Equation 39)

where:
- \( L \) represents the length of the arc (in meters). This equation applies for the distance protection zone 1.
- Consider approximately three times arc foot spacing for the zone 2 and wind speed of approximately 50 km/h
- \( I \) is the actual fault current in A.

In practice, the setting of fault resistance for both phase-to-earth \( RFPE \) and phase-to-phase \( RFPP \) should be as high as possible without interfering with the load impedance in order to obtain reliable fault detection.

### 6.1.3 Setting guidelines

#### 6.1.3.1 General

The settings for Distance measuring zones, quadrilateral characteristic (ZMFPDIS) are done in primary values. The instrument transformer ratio that has been set for the analog input card is used to automatically convert the measured secondary input signals to primary values used in ZMFPDIS.

The following basics must be considered, depending on application, when doing the setting calculations:
• Errors introduced by current and voltage instrument transformers, particularly under transient conditions.
• Inaccuracies in the line zero-sequence impedance data, and their effect on the calculated value of the earth-return compensation factor.
• The effect of infeed between the IED and the fault location, including the influence of different $Z_0/Z_1$ ratios of the various sources.
• The phase impedance of non transposed lines is not identical for all fault loops. The difference between the impedances for different phase-to-earth loops can be as large as 5-10% of the total line impedance.
• The effect of a load transfer between the IEDs of the protected fault resistance is considerable, the effect must be recognized.
• Zero-sequence mutual coupling from parallel lines.

6.1.3.2 Setting of zone 1

The different errors mentioned earlier usually require a limitation of the underreaching zone (normally zone 1) to 75 - 90% of the protected line.

In case of parallel lines, consider the influence of the mutual coupling according to section “Parallel line application with mutual coupling” and select the case(s) that are valid in the particular application. By proper setting it is possible to compensate for the cases when the parallel line is in operation, out of service and not earthed and out of service and earthed in both ends. The setting of earth-fault reach should be selected to be <95% also when parallel line is out of service and earthed at both ends (worst case).

6.1.3.3 Setting of overreaching zone

The first overreaching zone (normally zone 2) must detect faults on the whole protected line. Considering the different errors that might influence the measurement in the same way as for zone 1, it is necessary to increase the reach of the overreaching zone to at least 120% of the protected line. The zone 2 reach can be even higher if the fault infeed from adjacent lines at remote end is considerably higher than the fault current at the IED location.

The setting shall generally not exceed 80% of the following impedances:

• The impedance corresponding to the protected line, plus the first zone reach of the shortest adjacent line.
• The impedance corresponding to the protected line, plus the impedance of the maximum number of transformers operating in parallel on the bus at the remote end of the protected line.

Larger overreach than the mentioned 80% can often be acceptable due to fault current infeed from other lines. This requires however analysis by means of fault calculations.

If any of the above gives a zone 2 reach less than 120%, the time delay of zone 2 must be increased by approximately 200ms to avoid unwanted operation in cases when the telecommunication for the short adjacent line at remote end is down during faults. The zone 2 must not be reduced below 120% of the protected line section. The whole line must be covered under all conditions.

The requirement that the zone 2 shall not reach more than 80% of the shortest adjacent line at remote end is highlighted in the example below.

If a fault occurs at point F see figure 38, the IED at point A senses the impedance:
\[
Z_{AF} = \frac{V_A}{I_A} = \frac{I_A + I_C}{I_A} Z_{CF} + \frac{I_A + I_C + I_B}{I_A} R_f = \frac{Z_{AC}}{I_A} Z_{CF} + \left( 1 + \frac{I_C + I_B}{I_A} \right) R_f
\]

(Equation 40)

---

6.1.3.4 Setting of reverse zone

The reverse zone is applicable for purposes of scheme communication logic, current reversal logic, weak-end infeed logic, and so on. The same applies to the back-up protection of the bus bar or power transformers. It is necessary to secure, that it always covers the overreaching zone, used at the remote line IED for the telecommunication purposes.

Consider the possible enlarging factor that might exist due to fault infeed from adjacent lines. Equation 41 can be used to calculate the reach in reverse direction when the zone is used for blocking scheme, weak-end infeed, and so on.

\[
Z_{rev} \geq 1.2 \cdot \left( Z_L - Z_{2rem} \right)
\]

(Equation 41)

Where:

- \(Z_L\) is the protected line impedance
- \(Z_{2rem}\) is zone 2 setting at remote end of protected line.

In many applications it might be necessary to consider the enlarging factor due to fault current infeed from adjacent lines in the reverse direction in order to obtain certain sensitivity.

6.1.3.5 Setting of zones for parallel line application

Parallel line in service – Setting of zone 1

With reference to section "Parallel line applications", the zone reach can be set to 85% of the protected line.

However, influence of mutual impedance has to be taken into account.

Parallel line in service – setting of zone 2

Overreaching zones (in general, zones 2 and 3) must overreach the protected circuit in all cases. The greatest reduction of a reach occurs in cases when both parallel circuits are in service with a single phase-to-earth fault located at the end of a protected line. The equivalent
zero sequence impedance circuit for this case is equal to the one in figure 32 in section Parallel line in service.

The components of the zero sequence impedance for the overreaching zones must be equal to at least:

\[
R_{OE} = R_0 + R_{m0}
\]  
(Equation 42)

\[
X_{OE} = X_0 + X_{m0}
\]  
(Equation 43)

Check the reduction of a reach for the overreaching zones due to the effect of the zero sequence mutual coupling. The reach is reduced for a factor:

\[
K_0 = 1 - \frac{Z_{0m}}{2 \cdot Z_1 + Z_0 + R_f}
\]  
(Equation 44)

If the denominator in equation 44 is called B and Z0m is simplified to X0m, then the real and imaginary part of the reach reduction factor for the overreaching zones can be written as:

\[
\text{Re}(K_0) = 1 - \frac{X_{0m} \cdot \text{Re}(B)}{\text{Re}(B)^2 + \text{Im}(B)^2}
\]  
(Equation 45)

\[
\text{Im}(K_0) = \frac{X_{0m} \cdot \text{Im}(B)}{\text{Re}(B)^2 + \text{Im}(B)^2}
\]  
(Equation 46)

**Parallel line is out of service and earthed in both ends**

Apply the same measures as in the case with a single set of setting parameters. This means that an underreaching zone must not overreach the end of a protected circuit for the single phase-to-earth faults.

Set the values of the corresponding zone (zero-sequence resistance and reactance) equal to:

\[
R_{OE} = R_0 \cdot \left(1 + \frac{X_{m0}^2}{R_0^2 + X_0^2}\right)
\]  
(Equation 47)

\[
X_{OE} = X_0 \cdot \left(1 - \frac{X_{m0}^2}{R_0^2 + X_0^2}\right)
\]  
(Equation 48)
6.1.3.6 Setting the reach with respect to load

Set separately the expected fault resistance for phase-to-phase faults $RFPP$ and for the phase-to-earth faults $RFPE$ for each zone. For each distance zone, set all remaining reach setting parameters independently of each other.

The final reach in the resistive direction for phase-to-earth fault loop measurement automatically follows the values of the line-positive and zero-sequence resistance, and at the end of the protected zone is equal to equation 49.

\[
R = \frac{1}{3} \left( 2 \cdot R1 + R0 \right) + RFPE
\]

(Equation 49)

\[
\phi_{loop} = \arctan \left( \frac{2 \cdot X1 + X0}{2 \cdot R1 + R0} \right)
\]

(Equation 50)

Setting of the resistive reach for the underreaching zone 1 should follow the condition to minimize the risk for overreaching:

\[
RFPE \leq 4.5 \cdot X1
\]

(Equation 51)

The fault resistance for phase-to-phase faults is normally quite low compared to the fault resistance for phase-to-earth faults. To minimize the risk for overreaching, limit the setting of the zone1 reach in the resistive direction for phase-to-phase loop measurement based on equation 52.

\[
RFPP \leq 6 \cdot X1
\]

(Equation 52)

The setting $XLd$ is primarily there to define the border between what is considered a fault and what is just normal operation. See figure 39. In this context, the main examples of normal operation are reactive load from reactive power compensation equipment or the capacitive charging of a long high-voltage power line. $XLd$ needs to be set with some margin towards normal apparent reactance; not more than 90% of the said reactance or just as much as is needed from a zone reach point of view.

As with the settings $RLdFw$ and $RLdRv$\[2\], $XLd$ is representing a per-phase load impedance of a symmetrical star-coupled representation. For a symmetrical load or three-phase and phase-to-phase faults, this means per-phase, or positive-sequence, impedance. During a phase-to-earth fault, it means the per-loop impedance, including the earth return impedance.

6.1.3.7 Zone reach setting lower than minimum load impedance

Even if the resistive reach of all protection zones is set lower than the lowest expected load impedance and there is no risk for load encroachment, it is still necessary to set $RLdFw$, $RLdRv$ \[3\] and $ArgLd$ according to the expected load situation, since these settings are used internally in the function as reference points to improve the performance of the phase selection.

---

\[2\] $RLdRv = RLdRvFactor \cdot RLdFw$

\[3\] $RLdRv = RLdRvFactor \cdot RLdFw$
The maximum permissible resistive reach for any zone must be checked to ensure that there is a sufficient setting margin between the boundary and the minimum load impedance. The minimum load impedance (Ω/phase) is calculated with equation 53.

\[ Z_{\text{load min}} = \frac{U^2}{S} \]  

(Equation 53)

Where:
- \( U \) the minimum phase-to-phase voltage in kV
- \( S \) the maximum apparent power in MVA.

The load impedance [Ω/phase] is a function of the minimum operation voltage and the maximum load current:

\[ Z_{\text{load}} = \frac{U_{\text{min}}}{\sqrt{3} \cdot I_{\text{max}}} \]  

(Equation 54)

Minimum voltage \( U_{\text{min}} \) and maximum current \( I_{\text{max}} \) are related to the same operating conditions. Minimum load impedance occurs normally under emergency conditions.

As a safety margin, it is required to avoid load encroachment under three-phase conditions. To guarantee correct, healthy phase IED operation under combined heavy three-phase load and earth faults, both phase-to-phase and phase-to-earth fault operating characteristics should be considered.

To avoid load encroachment for the phase-to-earth measuring elements, the set resistive reach of any distance protection zone must be less than 80% of the minimum load impedance.

\[ RFPE \leq 0.8 \cdot Z_{\text{load}} \]  

(Equation 55)

Equation 55 is applicable only when the loop characteristic angle for the single phase-to-earth faults is more than three times as large as the maximum expected load-impedance angle. For the case when the loop characteristic angle is less than three times the load-impedance angle, more accurate calculations are necessary according to equation 56.

\[ RFPE \leq 0.8 \cdot Z_{\text{load min}} \cdot \left[ \cos \vartheta - \frac{2 \cdot (R1 + R0)}{2 \cdot (X1 + X0)} \cdot \sin \vartheta \right] \]  

(Equation 56)

Where:
- \( \vartheta \) is a maximum load-impedance angle, related to the maximum load power.

To avoid load encroachment for the phase-to-phase measuring elements, the set resistive reach of any distance protection zone must be less than 160% of the minimum load impedance.
\[ RFPP \leq 1.6 \cdot Z_{\text{load}} \]

(Equation 57)

Equation 57 is applicable only when the loop characteristic angle for the phase-to-phase faults is more than three times as large as the maximum expected load-impedance angle. For other cases a more accurate calculations are necessary according to equation 58.

\[ RFPP \leq 1.6 \cdot Z_{\text{load min}} \left( \cos \theta - \frac{R_1}{X_1} \sin \theta \right) \]

(Equation 58)

### 6.1.3.8 Zone reach setting higher than minimum load impedance

The impedance zones are enabled as soon as the (symmetrical) load impedance crosses the vertical boundaries defined by \( RLdFw \) and \( RLdRv \)[4] or the lines defined by \( ArgLd \). So, it is necessary to consider some margin. It is recommended to set \( RLdFw \) and \( RLdRv \) to 90% of the per-phase resistance that corresponds to maximum load.

\[ RLdFw < 0.9 \cdot R_{\text{load min}} \]

(Equation 59)

\[ RLdRv < 0.9 \cdot R_{\text{load min}} \]

(Equation 60)

The absolute value of the margin to the closest \( ArgLd \) line should be of the same order, that is, at least \( 0.1 \cdot Z_{\text{load min}} \).

The load encroachment settings are related to a per-phase load impedance in a symmetrical star-coupled representation. For symmetrical load or three-phase and phase-to-phase faults, this corresponds to the per-phase, or positive-sequence, impedance. For a phase-to-earth fault, it corresponds to the per-loop impedance, including the earth return impedance.

---

[4] \( RLdRv = RLdRvFactor \cdot RLdFw \)
During the initial current change for phase-to-phase and for phase-to-earth faults, operation may be allowed also when the apparent impedance of the load encroachment element is located in the load area. This improves the dependability for fault at the remote end of the line during high load. Although it is not associated to any standard event, there is one potentially hazardous situation that should be considered. Should one phase of a parallel circuit open a single pole, even though there is no fault, and the load current of that phase increase, there is actually no way of distinguish this from a real fault with similar characteristics. Should this accidental event be given precaution, the phase-to-earth reach (RFPE) of all instantaneous zones has to be set below the emergency load for the pole-open situation. Again, this is only for the application where there is a risk that one breaker pole would open without a preceding fault. If this never happens, for example when there is no parallel circuit, there is no need to change any phase-to-earth reach according to the pole-open scenario.

### 6.1.3.9 Other settings

#### IMinOpPE and IMinOpPP

The ability for a specific loop and zone to issue a start or a trip is inhibited if the magnitude of the input current for this loop falls below the threshold value defined by these settings. The output of a phase-to-earth loop Ln is blocked if ILn < \( I_{\text{minOpPE}}(Zx) \). \( I_{\text{minOpPE}} \) is the RMS value of the fundamental current in phase n.

The output of a phase-to-phase loop LmLn is blocked if ILmLn < \( I_{\text{minOpPP}}(Zx) \). \( I_{\text{minOpPP}} \) is the RMS value of the vector difference between phase currents Lm and Ln.

Both current limits \( I_{\text{minOpPE}} \) and \( I_{\text{minOpPP}} \) are automatically reduced to 75% of regular set values if the zone is set to operate in reverse direction, that is, \( \text{OperationDir} \) is set to Reverse.

#### OpModePPZx and OpModePEZx

These settings, two per zone (\( x=1,2..5&RV \)), with options \{Off, Quadrilateral, Mho, Offset\}, are used to set the operation and characteristic for phase-to-earth and phase-to-phase faults, respectively.

For example, in one zone it is possible to choose Mho characteristic for the three Ph-Ph measuring loops and Quadrilateral characteristic for the three Ph-E measuring loops.

#### DirModeZx

This setting defines the operating direction for zones Z3, Z4 and Z5 (the directionality of zones Z1, Z2 and ZRV is fixed). The options are \textit{Non-directional, Forward or Reverse}. The result from
respective set value is illustrated in figure 40, where the positive impedance corresponds to the direction out on the protected line.

![Diagram showing non-directional, forward, and reverse directions.]

**Figure 40:** Directional operating modes of the distance measuring zones 3 to 5 
*tpPZX, tPEx, TimerModeZx, ZoneLinkStart and TimerLinksZx*

The logic for the linking of the timer settings can be described with a module diagram. The figure 41 shows only the case when *TimerModeZx* is selected to *Ph-Ph* and *Ph-E.*
Figure 41: Logic for linking of timers

CVTtype

If possible, the type of capacitive voltage transformer (CVT) used for measurement should be identified. The alternatives are strongly related to the type of ferro-resonance suppression circuit included in the CVT. There are two main choices:

- **Passive type**
  For CVTs that use a nonlinear component, like a saturable inductor, to limit overvoltages (caused by ferro-resonance). This component is practically idle during normal load and fault conditions, hence the name “passive.” CVTs that have a high resistive burden to mitigate ferro-resonance also fall into this category.

- **Any**
  This option is primarily related to the so-called active type CVT, which uses a set of reactive components to form a filter circuit that essentially attenuates frequencies other than the nominal to restrain the ferro-resonance. The name “active” refers to this circuit always being involved during transient conditions, regardless of the voltage level. This option should also be used for the types that do not fall under the other two categories, for example, CVTs with power electronic damping devices, or if the type cannot be identified at all.

- **None** (Magnetic)
  This option should be selected if the voltage transformer is fully magnetic.

INReleasePE

This setting opens an opportunity to enable phase-to-earth measurement for phase-to-phase-earth faults. It determines the level of residual current (3I0) above which phase-to-earth measurement is activated (and phase-to-phase measurement is blocked). The relations are defined with the equation.
\[ 3 \cdot I_a \geq \frac{IN\, ReleasePE}{100} \cdot I_{ph\, max} \] 

(Equation 61)

Where:

- \( IN\, ReleasePE \) the setting for the minimum residual current needed to enable operation in the phase-to-earth fault loops in %
- \( I_{ph\, max} \) the maximum phase current in any of the three phases

By default, this setting is set excessively high to always enable phase-to-phase measurement for phase-to-phase-earth faults. This default setting value must be maintained unless there are very specific reasons to enable phase-to-earth measurement. Even with the default setting value, phase-to-earth measurement is activated whenever appropriate, like in the case of simultaneous faults: two earth faults at the same time, one each on the two circuits of a double line.

6.2 Automatic switch onto fault logic ZCVPSOF

6.2.1 Identification

<table>
<thead>
<tr>
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<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
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</thead>
<tbody>
<tr>
<td>Automatic switch onto fault logic</td>
<td>ZCVPSOF</td>
<td>-</td>
<td>-</td>
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6.2.2 Application

Automatic switch onto fault logic, voltage- and current-based function ZCVPSOF is a complementary function to impedance measuring functions, but may use the information from such functions.

With ZCVPSOF, a fast trip is achieved for a fault on the whole line when the line is being energized. The ZCVPSOF tripping is generally non-directional to secure a trip at fault situations where directional information cannot be established, for example, due to lack of polarizing voltage when a line potential transformer is used.

Automatic activation based on dead-line detection can only be used when the voltage transformer is situated on the line side of a circuit breaker.

When line side voltage transformers are used, the use of the nondirectional distance zones secures switch onto fault tripping for close-in three-phase short circuits. The use of the nondirectional distance zones also gives a fast fault clearance when energizing a bus from the line with a short circuit fault on the bus.

Other protection functions like time-delayed phase and zero-sequence overcurrent function can be connected to ZCVPSOF to increase the dependability in the scheme.

When the voltage transformers are situated on the bus side, the automatic switch onto fault detection based on dead-line detection is not possible. In such cases the deadline detection is bypassed using the breaker closing status and the switch onto fault logic is activated.
6.2.3 Setting guidelines

The parameters for automatic switch onto fault logic, voltage- and current-based function ZCVPSOF are set via the local HMI or Protection and Control Manager PCM600.

The distance protection zone used for instantaneous trip by ZCVPSOF has to be set to cover the entire protected line with a safety margin of minimum 20%.

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

GlobalBaseSel is used to select GBASVAL for reference of base values.

Operation: The operation of ZCVPSOF is by default set to On. The parameter must be set to Off if ZCVPSOF is not to be used.

IPh< is used to set the current level for the detection of a dead line. IPh< is, by default, set to 20% of IBase. It shall be set with a sufficient margin (15–20%) below the minimum expected load current. In many cases, the minimum load current of a line is close to zero and even can be zero. The operating value must exceed the maximum charging current of an overhead line when only one phase is disconnected (mutual coupling in the other phases).

UPh< is used to set the voltage level for the detection of a dead line. UPh< is, by default, set to 70% of UBase. This is a suitable setting in most cases, but it is recommended to check the suitability in the actual application.

AutoInitMode: automatic activating of ZCVPSOF is, by default, set to DLD disabled, which means the dead-line logic detection is disabled. If an automatic activation of the dead-line detection is required, the parameter AutoInitMode has to be set to either Voltage, Current or Current & Voltage.

When AutoInitMode is set to Voltage, the dead-line detection logic checks that the three-phase voltages are lower than the set UPh< level.

When AutoInitMode is set to Current, the dead-line detection logic checks if the three-phase currents are lower than the set IPh< level.

When AutoInitMode is set to Current & Voltage, the dead-line detection logic checks that both three-phase currents and three-phase voltages are lower than the set IPh< and UPh< levels.

Otherwise, the logic is activated by an external BC input.

tSOTF: the drop delay of ZCVPSOF is, by default, set to 1.0 seconds, which is suitable for most applications.

tDLD: The time delay for activating ZCVPSOF by the internal dead-line detection is, by default, set to 0.2 seconds. It is suitable in most applications. The delay shall not be set too short to avoid unwanted activations during transients in the system.

Mode: The operation of ZCVPSOF has three modes for defining the criteria for tripping. The setting of Mode is, by default, UlLevel, which means that the tripping criterion is based on the setting of IPh< and UPh<. The choice of UlLevel gives a faster and more sensitive operation of the function, which is important for reducing the stress that might occur when energizing onto a fault. However, the voltage recovery can be slow in some systems when energizing the line. Therefore, if the timer tDuration is set too short, ZCVPSOF can interpret this as a fault and release a trip.

When Mode is set to Impedance, the operate criterion is based on the BC input (breaker closing), which can be the start of the overreaching zone from the impedance zone measurement or a tOperate-delayed input. A nondirectional output signal should
be used from an overreaching zone. The selection of the Impedance mode gives increased security.

When Mode is set to UlLvl&Imp, the condition for tripping is an ORed between UlLevel and Impedance.

tDuration: The setting of the timer for the release of UlLevel is, by default, 0.02 seconds, which has proven to be suitable in most cases from field experience. If a shorter time delay is to be set, it is necessary to consider the voltage recovery time during line energization.

tOperate: The time delay for the START_DLYD input to activate TRIP when Mode is set to Impedance or UlLvl&Imp is, by default, set to 0.03 seconds.
Section 7 Current protection

7.1 Instantaneous phase overcurrent protection PHPIOC

7.1.1 Identification

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<tr>
<td>Instantaneous phase overcurrent protection 3-phase output</td>
<td>PHPIOC</td>
<td>3I&gt;&gt;</td>
<td>50</td>
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7.1.2 Application

Long transmission lines often transfer great quantities of electric power from production to consumption areas. The unbalance of the produced and consumed electric power at each end of the transmission line is very large. This means that a fault on the line can easily endanger the stability of a complete system.

The transient stability of a power system depends mostly on three parameters (at constant amount of transmitted electric power):

- The type of the fault. Three-phase faults are the most dangerous, because no power can be transmitted through the fault point during fault conditions.
- The magnitude of the fault current. A high fault current indicates that the decrease of transmitted power is high.
- The total fault clearing time. The phase angles between the EMFs of the generators on both sides of the transmission line increase over the permitted stability limits if the total fault clearing time, which consists of the protection operating time and the breaker opening time, is too long.

The fault current on long transmission lines depends mostly on the fault position and decreases with the distance from the generation point. For this reason the protection must operate very quickly for faults very close to the generation (and relay) point, for which very high fault currents are characteristic.

The instantaneous phase overcurrent protection 3-phase output PHPIOC can operate in 10 ms for faults characterized by very high currents.

7.1.3 Setting guidelines

The parameters for instantaneous phase overcurrent protection 3-phase output PHPIOC are set via the local HMI or PCM600.

This protection function must operate only in a selective way. So check all system and transient conditions that could cause its unwanted operation.
Only detailed network studies can determine the operating conditions under which the highest possible fault current is expected on the line. In most cases, this current appears during three-phase fault conditions. But also examine single-phase-to-earth and two-phase-to-earth conditions.

Also study transients that could cause a high increase of the line current for short times. A typical example is a transmission line with a power transformer at the remote end, which can cause high inrush current when connected to the network and can thus also cause the operation of the built-in, instantaneous, overcurrent protection.

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

OpMode: This parameter can be set to 2 out of 3 or 1 out of 3. The setting controls the minimum number of phase currents that must be larger than the set operate current IP>> for operation. Normally this parameter is set to 1 out of 3 and will thus detect all fault types. If the protection is to be used mainly for multi phase faults, 2 out of 3 should be chosen.

IP>>: Set operate current in % of IBase.

StValMult: The operate current can be changed by activation of the binary input ENMULT to the set factor StValMult.

IP>>MinEd2Set: Minimum settable operate phase current level in % of IBase, for IEC 61850 Ed. 2 settings.

IP>>MaxEd2Set: Maximum settable operate phase current level in % of IBase, for IEC 61850 Ed. 2 settings.

### 7.1.3.1 Meshed network without parallel line

The following fault calculations have to be done for three-phase, single-phase-to-earth and two-phase-to-earth faults. With reference to figure 42, apply a fault in B and then calculate the current through-fault phase current \( I_{fB} \). The calculation should be done using the minimum source impedance values for \( Z_A \) and the maximum source impedance values for \( Z_B \) in order to get the maximum through fault current from A to B.

![Diagram of a meshed network without parallel line]

**Figure 42:** Through fault current from A to B: \( I_{fB} \)

Then a fault in A has to be applied and the through fault current \( I_{fA} \) has to be calculated, figure 43. In order to get the maximum through fault current, the minimum value for \( Z_B \) and the maximum value for \( Z_A \) have to be considered.
**Figure 43:** Through fault current from B to A: $I_{fA}$

The IED must not trip for any of the two through-fault currents. Hence the minimum theoretical current setting ($I_{min}$) will be:

$$I_{min} \geq \text{MAX}(I_{fA}, I_{fB})$$

(Equation 62)

A safety margin of 5% for the maximum protection static inaccuracy and a safety margin of 5% for the maximum possible transient overreach have to be introduced. An additional 20% is suggested due to the inaccuracy of the instrument transformers under transient conditions and inaccuracy in the system data.

The minimum primary setting ($I_s$) for the instantaneous phase overcurrent protection 3-phase output is then:

$$I_s \geq 1.3 \cdot I_{min}$$

(Equation 63)

The protection function can be used for the specific application only if this setting value is equal to or less than the maximum fault current that the IED has to clear, $I_F$ in figure 44.

**Figure 44:** Fault current: $I_F$

$$IP \gg \frac{I_s}{I_{Base}} \cdot 100$$

(Equation 64)
7.1.3.2 Meshed network with parallel line

In case of parallel lines, the influence of the induced current from the parallel line to the protected line has to be considered. One example is given in figure 45 where the two lines are connected to the same busbars. In this case, the influence of the induced fault current from the faulty line (line 1) to the healthy line (line 2) is considered together with the two through fault currents $I_{fA}$ and $I_{fB}$ mentioned previously. The maximal influence from the parallel line for the IED in figure 45 will be with a fault at the C point with the C breaker open.

A fault in C has to be applied, and then the maximum current seen from the IED ($I_M$) on the healthy line (this applies for single-phase-to-earth and two-phase-to-earth faults) is calculated.

\[ I_{min} \geq \max(I_{fA}, I_{fB}, I_M) \]  

(Equation 65)

Where $I_{fA}$ and $I_{fB}$ have been described in the previous paragraph. Considering the safety margins mentioned previously, the minimum setting ($I_s$) for the instantaneous phase overcurrent protection 3-phase output is then:

\[ I_s \geq 1.3 \cdot I_{min} \]  

(Equation 66)

The protection function can be used for the specific application only if this setting value is equal or less than the maximum phase fault current that the IED has to clear.

The IED setting value $IP>>$ is given in percentage of the primary base current value, $IBase$. The value for $IP>>$ is given from this formula:

\[ IP >> = \frac{I_s}{IBase} \cdot 100 \]  

(Equation 67)
7.2 Four step phase overcurrent protection OC4PTOC

7.2.1 Identification

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<thead>
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<tr>
<td>Four step phase overcurrent protection 3-phase output</td>
<td>OC4PTOC</td>
<td></td>
<td>51_67</td>
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</tbody>
</table>

7.2.2 Application

The Four step phase overcurrent protection 3-phase output 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 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.

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

In many applications several steps with different current pick up levels and time delays are needed. OC4PTOC can have up to four different, individual settable, steps. The flexibility of each step of OC4PTOC is great. 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.

Choice of delay time characteristics: There are several types of delay time 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: 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 2nd harmonic content. This can be used to avoid unwanted operation of the protection. Therefore, OC4PTOC have a possibility of 2nd harmonic restrain if the level of this harmonic current reaches a value above a set percentage of the fundamental current.

The phase overcurrent protection is often used as 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.

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

The following settings can be done for OC4PTOC.

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

- **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 46.

- **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.

- **2ndHarmStab**: 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%.
Figure 46: Directional function characteristic

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

7.2.3.1 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.

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

<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>
</tbody>
</table>

Table continues on next page
The different characteristics are described in *Technical manual*.

\( \text{Ix}_x \): Operate phase current level for step \( x \) given in % of \( IB \).

\( \text{Ix}_x > \text{MaxEd2Set} \) and \( \text{Ix}_x > \text{MinEd2Set} \) should only be changed if remote setting of operation current level, \( \text{Ix}_x \), is used. The limits are used for decreasing the used range of the \( \text{Ix}_x \) setting. If \( \text{Ix}_x \) is set outside \( \text{Ix}_x > \text{MaxEd2Set} \) and \( \text{Ix}_x > \text{MinEd2Set} \), the closest of the limits to \( \text{Ix}_x \) is used by the function. If \( \text{Ix}_x > \text{MaxEd2Set} \) is smaller than \( \text{Ix}_x > \text{MinEd2Set} \), the limits are swapped.

\( \text{tx} \): Definite time delay for step \( x \). The definite time \( \text{tx} \) 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.

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

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

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

\( \text{txMin} \): 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.

\( \text{IxMult} \): 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
Figure 47: Minimum operate current and operate time for inverse time characteristics

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 $kx$.

$ResetTypeCrv\times$: The reset of the delay timer can be made as shown in Table 13.

Table 13: Reset possibilities

<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.

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

$tPCrx\times$, $tACrx\times$, $tBCrx\times$, $tCCrx\times$: These parameters are used by the customer to create the inverse time characteristic curve. See equation 68 for the time characteristic equation. For more information, refer to Technical manual.
\[ t[s] = \left( \frac{A}{i_{in}} \right)^p + B \cdot l_xMult \]  

(Equation 68)

\( t_{PRCrvx}, t_{TRCrvx}, t_{CRCrvx} \): 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.

### 7.2.3.2 2nd harmonic restrain

If a power transformer is energized there is a risk that the transformer core will saturate during part of the period, resulting in an inrush transformer 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 phase overcurrent function will give an unwanted trip. The inrush current has a relatively large ratio of 2\(^{nd}\) harmonic component. This component can be used to create a restrain signal to prevent this unwanted function.

The settings for the 2nd harmonic restrain are described below.

\( 2ndHarmStab \): The rate of 2nd harmonic current content for activation of the 2nd harmonic restrain signal, to block chosen steps. The setting is given in % of the fundamental frequency residual current. The setting range is 5 - 100% in steps of 1%. The default setting is 20% and can be used if a deeper investigation shows that no other value is needed.

\( HarmRestrainx \): This parameter can be set Off/On, to disable or enable the 2nd harmonic restrain.

The four step phase overcurrent protection 3-phase output 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. Here consideration also has to be taken to the protection reset current, so that a short peak of overcurrent does not cause operation of the protection even when the overcurrent has ceased. This phenomenon is described in figure 48.
Figure 48: Operate and reset current for an overcurrent protection

The lowest setting value can be written according to equation 69.

\[ I_{pu} \geq 1.2 \cdot \frac{I_{\text{max}}}{k} \]

(Equation 69)

where:

1.2 is a safety factor
k is the resetting ratio of the protection
\( I_{\text{max}} \) is the maximum load current

From operation statistics the load current up to the present situation can be found. The current setting must be valid also for some years ahead. It is, in most cases, realistic that the setting values are updated not more often than once every five years. In many cases this time interval is still longer. Investigate the maximum load current that different 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 \( I_{\text{scmin}} \), to be detected by the protection, must be calculated. Taking this value as a base, the highest pick up current setting can be written according to equation 70.
Ipu \leq 0.7 \cdot \text{Isc min} \tag{Equation 70}

where:

- 0.7 is a safety factor
- \text{Isc min} 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 71.

\[
1.2 \cdot \frac{\text{Imax}}{k} \leq \text{Ipu} \leq 0.7 \cdot \text{Isc min} \tag{Equation 71}
\]

The high current function of the overcurrent protection, which only has a short delay of the operation, must be given a current setting so that the protection is selective to other protection in the power system. It is desirable to have a rapid tripping of faults within as large portion as possible of the part of the power system to be protected by the protection (primary protected zone). A fault current calculation gives the largest current of faults, \text{Isc max}, at the most remote part of the primary protected zone. Considerations have to be made to the risk of transient overreach, due to a possible DC component of the short circuit current. The lowest current setting of the most rapid stage, of the phase overcurrent protection, can be written according to

\[
I_{\text{high}} \geq 1.2 \cdot k_t \cdot \text{Isc}_{\text{max}} \tag{Equation 72}
\]

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
- \text{Isc}_{\text{max}} is the largest fault current at a fault at the most remote point of the primary protection zone.

The operate times of the phase overcurrent protection has to be chosen so that the fault time is so short that protected equipment will not be destroyed due to thermal overload, at the same time as 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 49 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 49: Fault time with maintained selectivity

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

To assure selectivity between different protections, in the radial network, there have to be a minimum time difference $\Delta t$ between the time delays of two protections. The minimum time difference can be determined for different cases. 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 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 50. 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 protection will have instantaneous function. The overcurrent protection of IED A1 must have a delayed function. The sequence of events during the fault can be described using a time axis, see figure 50.
The fault occurs
Protection B1 trips
Breaker at B1 opens
Protection A1 resets

Figure 50: Sequence of events during fault

where:
$t=0$ is when the fault occurs
$t=t_1$ is when the trip signal from the overcurrent protection at IED B1 is sent to the circuit breaker. The operation time of this protection is $t_1$
$t=t_2$ is when the circuit breaker at IED B1 opens. The circuit breaker opening time is $t_2 - t_1$
$t=t_3$ is when the overcurrent protection at IED A1 resets. The protection resetting time is $t_3 - t_2$.

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 $t_3$. 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 73.

$$\Delta t \geq 40\,ms + 100\,ms + 40\,ms + 40\,ms = 220\,ms$$

(Equation 73)

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

7.3 Instantaneous residual overcurrent protection EFPIOC
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>Instantaneous residual overcurrent protection</td>
<td>EFPIOC</td>
<td>IN&gt;&gt;</td>
<td>50N</td>
</tr>
</tbody>
</table>

7.3.2 Application

In many applications, when fault current is limited to a defined value by the object impedance, an instantaneous earth-fault protection can provide fast and selective tripping.

The Instantaneous residual overcurrent EFPIOC, which can operate in 15 ms (50 Hz nominal system frequency) for faults characterized by very high currents, is included in the IED.

7.3.3 Setting guidelines

The parameters for the Instantaneous residual overcurrent protection EFPIOC are set via the local HMI or PCM600.

Some guidelines for the choice of setting parameter for EFPIOC is given.

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

The setting of the function is limited to the operate residual current to the protection (IN>>).

The basic requirement is to assure selectivity, that is EFPIOC shall not be allowed to operate for faults at other objects than the protected object (line).

For a normal line in a meshed system single phase-to-earth faults and phase-to-phase-to-earth faults shall be calculated as shown in figure 51 and figure 52. The residual currents (3I\(_0\)) to the protection are calculated. For a fault at the remote line end this fault current is \(I_{fB}\). In this calculation the operational state with high source impedance \(Z_A\) and low source impedance \(Z_B\) should be used. For the fault at the home busbar this fault current is \(I_{fA}\). In this calculation the operational state with low source impedance \(Z_A\) and high source impedance \(Z_B\) should be used.

![Figure 51: Through fault current from A to B: \(I_{fB}\)](EC01200000022-1-en.usd)
The function shall not operate for any of the calculated currents to the protection. The minimum theoretical current setting ($I_{\text{min}}$) will be:

$$I_{\text{min}} \geq \text{MAX}(I_{fA}, I_{fA})$$  \hspace{1cm} (Equation 74)

A safety margin of 5% for the maximum static inaccuracy and a safety margin of 5% for maximum possible transient overreach have to be introduced. An additional 20% is suggested due to inaccuracy of instrument transformers under transient conditions and inaccuracy in the system data.

The minimum primary current setting ($I_s$) is:

$$I_s = 1.3 \times I_{\text{min}}$$  \hspace{1cm} (Equation 75)

In case of parallel lines with zero sequence mutual coupling a fault on the parallel line, as shown in figure 53, should be calculated.

The minimum theoretical current setting ($I_{\text{min}}$) will in this case be:
\[ I_{\text{min}} \geq \text{MAX}(I_{A}, I_{B}, I_{M}) \]  \hspace{1cm} (Equation 76)

Where:
\( I_{A} \) and \( I_{B} \) have been described for the single line case.

Considering the safety margins mentioned previously, the minimum setting (\( I_{s} \)) is:
\[ I_{s} = 1.3 \times I_{\text{min}} \]  \hspace{1cm} (Equation 77)

Transformer inrush current shall be considered.

The setting of the protection is set as a percentage of the base current (\( I_{\text{Base}} \)).

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

**IN>>**: Set operate current in % of \( I_{\text{Base}} \).

**StValMult**: The operate current can be changed by activation of the binary input ENMULT to the set factor \( StValMult \).

### 7.4 Four step residual overcurrent protection EF4PTOC

#### 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>Four step residual overcurrent protection</td>
<td>EF4PTOC</td>
<td></td>
<td>51N_67N</td>
</tr>
</tbody>
</table>

#### 7.4.2 Application

The four step residual overcurrent protection 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 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: 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>
<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>

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 \(IN \cdot Mult\).
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 have residual current components. 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 2ndHarmStab if the level of this harmonic current reaches a value above a
set percentage of the fundamental current.

### 7.4.3 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.

- **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.

### 7.4.3.1 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.
- **Characteristx**: 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.

*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.

*INx>*: Operate residual current level for step *x* given in % of *IB*.

*INx>*MaxEd2Set* and *INx>*MinEd2Set should only be changed if remote setting of operation current level, *INx>* is used. The limits are used for decreasing the used range of the *INx>* setting. If *INx>* is set outside *INx>*MaxEd2Set and *INx>*MinEd2Set, the closest of the limits to *INx>* is used by the function. If *INx>*MaxEd2Set is smaller than *INx>*MinEd2Set, 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 54: 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.
\[ t[s] = \left( \frac{A}{i^{\text{in}}} + B \right) \cdot k \]

(Equation 78)

Further description can be found in the technical reference manual.

7.4.3.2 Common settings for all steps

AngleRCA: Relay characteristic angle given in degree. This angle is defined as shown in figure 55. The angle is defined positive when the residual current lags the reference voltage (Upol = 3U₀ or U₂)

Figure 55: 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 (3U₀ or U₂)
• Current (3I₀ · ZNpol or 3I₂ · ZNpol where ZNpol is RNpol + jXNpol), or
• both currents and voltage, Dual (dual polarizing, (3U₀ + 3I₀ · ZNpol) or (U₂ + I₂ · 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 (3U₀) 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 3U₀> 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 3I₀ · ZNpol. The ZNpol can be defined as (ZS₁-ZS₀)/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/(√3 · 3I₀). Typically, the minimum ZNPol (3 · zero sequence source) is set. Setting is in primary ohms.

When the dual polarizing method is used it is important that the setting/INx> or the product 3I₀ · ZNpol is not greater than 3U₀. 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. Typical setting is 5-10% of IBase.

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

I>Dir: Operate residual current release level in % of IBase for directional comparison scheme. The setting is given in % of IBase 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.

### 7.4.3.3 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. Also here the 2nd harmonic restrain can prevent unwanted operation.

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.

HarmRestrainx: Enable block of step x from the harmonic restrain function.

### 7.4.3.4 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 2nd 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 2nd harmonic current initially. After a short period this current will however be small and the normal 2nd harmonic blocking will reset.

Figure 56: Application for parallel transformer inrush current logic

If the BlkParTransf function is activated the 2nd 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.

Below the settings for the parallel transformer logic are described.

UseStartValue: Gives which current level that should be used for 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.

BlkParTransf: This parameter can be set Off/On, the parallel transformer logic.

7.4.3.5 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 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 2nd 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 operation mode. 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.

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

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

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

### 7.4.3.6 Line application example

The Four step residual overcurrent protection EF4PTOC can be used in different ways. Below is described one application possibility to be used in meshed and effectively earthed systems.

The protection measures the residual current out on the protected line. The protection function has a directional function where the polarizing voltage (zero-sequence voltage) is the polarizing quantity.

The polarizing voltage and current can be internally generated when a three-phase set of voltage transformers and current transformers are used.

![Connection of polarizing voltage from an open delta](xx05000148.vsd)

*Figure 57: Connection of polarizing voltage from an open delta*

The different steps can be described as follows.
**Step 1**

This step has directional instantaneous function. The requirement is that overreaching of the protected line is not allowed.

The residual current out on the line is calculated at a fault on the remote busbar (one- or two-phase-to-earth fault). To assure selectivity it is required that step 1 shall not give a trip at this fault. The requirement can be formulated according to equation 79.

\[
I_{\text{step1}} \geq 1.2 \times 3I_0 \text{ (remote busbar)}
\]

*(Equation 79)*

As a consequence of the distribution of zero sequence current in the power system, the current to the protection might be larger if one line out from the remote busbar is taken out of service, see figure 59.

The requirement is now according to equation 80.

\[
I_{\text{step1}} \geq 1.2 \times 3I_0 \text{ (remote busbar with one line out)}
\]

*(Equation 80)*
A higher value of step 1 might be necessary if a big power transformer (Y0/D) at remote bus bar is disconnected.

A special case occurs at double circuit lines, with mutual zero-sequence impedance between the parallel lines, see figure 60.

![Figure 60: Step 1, third calculation](IEC05000152-en-2.vsd)

The current setting for step 1 is chosen as the largest of the above calculated residual currents, measured by the protection.

**Step 2**

This step has directional function and a short time delay, often about 0.4 s. Step 2 shall securely detect all earth faults on the line, not detected by step 1.

**Figure 61: Step 2, check of reach calculation**

![One- or two-phase earth-fault](IEC05000154-en-2.vsd)
The residual current, out on the line, is calculated at an operational case with minimal earth-fault current. The requirement that the whole line shall be covered by step 2 can be formulated according to equation 82.

\[ I_{step2} \geq 0.7 \cdot 3I_0 \text{ (at remote busbar)} \]

(Equation 82)

To assure selectivity the current setting must be chosen so that step 2 does not operate at step 2 for faults on the next line from the remote substation. Consider a fault as shown in Figure 62.

![Figure 62: Step 2, selectivity calculation](IEC05000155-en-2.vsd)

A second criterion for step 2 is according to equation 83.

\[ I_{step2} \geq 1.2 \cdot \frac{3I_0}{3I_{01}} \cdot I_{step1} \]

(Equation 83)

where:

- \( I_{step1} \) is the current setting for step 1 on the faulted line.

**Step 3**

This step has directional function and a time delay slightly larger than step 2, often 0.8 s. Step 3 shall enable selective trip of earth faults having higher fault resistance to earth, compared to step 2. The requirement on step 3 is selectivity to other earth-fault protections in the network.

One criterion for setting is shown in Figure 63.

![Figure 63: Step 3, Selectivity calculation](IEC05000156-3-en.vsd)
\[ I_{\text{step}3} \geq 1.2 \cdot \frac{3I_0}{3I_{\text{step}2}} \]

(Equation 84)

where:

\( I_{\text{step}2} \) is the chosen current setting for step 2 on the faulted line.

**Step 4**

This step normally has non-directional function and a relatively long time delay. The task for step 4 is to detect and initiate trip for earth faults with large fault resistance, for example tree faults. Step 4 shall also detect series faults where one or two poles, of a breaker or other switching device, are open while the other poles are closed.

Both high resistance earth faults and series faults give zero-sequence current flow in the network. Such currents give disturbances on telecommunication systems and current to earth. It is important to clear such faults both concerning personal security as well as risk of fire.

The current setting for step 4 is often set down to about 100 A (primary 3I_0). In many applications definite time delay in the range 1.2 - 2.0 s is used. In other applications a current dependent inverse time characteristic is used. This enables a higher degree of selectivity also for sensitive earth-fault current protection.

### 7.5 Sensitive directional residual overcurrent and power protection SDEPSDE

#### 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>Sensitive directional residual over current and power protection</td>
<td>SDEPSDE</td>
<td>-</td>
<td>67N</td>
</tr>
</tbody>
</table>

#### 7.5.2 Application

In networks with high impedance earthing, the phase-to-earth fault current is significantly smaller than the short circuit currents. Another difficulty for earth fault protection is that the magnitude of the phase-to-earth fault current is almost independent of the fault location in the network.

Directional residual current can be used to detect and give selective trip of phase-to-earth faults in high impedance earthed networks. The protection uses the residual current component 3I_0 \cdot \cos \phi, where \( \phi \) is the angle between the residual current and the residual voltage (-3U_0), compensated with a characteristic angle. Alternatively, the function can be set to strict 3I_0 level with a check of angle \( \phi \).

Directional residual power can also be used to detect and give selective trip of phase-to-earth faults in high impedance earthed networks. The protection uses the residual power component 3I_0 \cdot 3U_0 \cdot \cos \phi, where \( \phi \) is the angle between the residual current and the reference residual voltage, compensated with a characteristic angle.
A normal non-directional residual current function can also be used with definite or inverse time delay.

A backup neutral point voltage function is also available for non-directional residual overvoltage protection.

In an isolated network, that is, the network is only coupled to earth via the capacitances between the phase conductors and earth, the residual current always has -90º phase shift compared to the residual voltage ($3U_0$). The characteristic angle is chosen to -90º in such a network.

In resistance earthed networks or in Petersen coil earthed, with a parallel resistor, the active residual current component (in phase with the residual voltage) should be used for the earth fault detection. In such networks, the characteristic angle is chosen to 0º.

As the amplitude of the residual current is independent of the fault location, the selectivity of the earth fault protection is achieved by time selectivity.

When should the sensitive directional residual overcurrent protection be used and when should the sensitive directional residual power protection be used? Consider the following:

- Sensitive directional residual overcurrent protection gives possibility for better sensitivity. The setting possibilities of this function are down to 0.25 % of $I_{\text{Base}}$, 1 A or 5 A. This sensitivity is in most cases sufficient in high impedance network applications, if the measuring CT ratio is not too high.
- Sensitive directional residual power protection gives possibility to use inverse time characteristics. This is applicable in large high impedance earthed networks, with large capacitive earth fault currents. In such networks, the active fault current would be small and by using sensitive directional residual power protection, the operating quantity is elevated. Therefore, better possibility to detect earth faults. In addition, in low impedance earthed networks, the inverse time characteristic gives better time-selectivity in case of high zero-resistive fault currents.

Figure 64: Connection of SDEPSDE to analog preprocessing function block

Overcurrent functionality uses true $3I_0$, i.e. sum of $\text{GRP}xL_1$, $\text{GRP}xL_2$ and $\text{GRP}xL_3$. For $3I_0$ to be calculated, connection is needed to all three phase inputs.

Directional and power functionality uses IN and UN. If a connection is made to $\text{GRP}xN$ this signal is used, else if connection is made to all inputs $\text{GRP}xL_1$, $\text{GRP}xL_2$ and $\text{GRP}xL_3$ the internally calculated sum of these inputs ($3I_0$ and $3U_0$) will be used.
### 7.5.3 Setting guidelines

The sensitive earth fault protection is intended to be used in high impedance earthed systems, or in systems with resistive earthing where the neutral point resistor gives an earth fault current larger than what normal high impedance gives but smaller than the phase-to-phase short circuit current.

In a high impedance system the fault current is assumed to be limited by the system zero sequence shunt impedance to earth and the fault resistance only. All the series impedances in the system are assumed to be zero.

In the setting of earth fault protection, in a high impedance earthed system, the neutral point voltage (zero sequence voltage) and the earth fault current will be calculated at the desired sensitivity (fault resistance). The complex neutral point voltage (zero sequence) can be calculated as:

\[
U_0 = \frac{U_{\text{phase}}}{1 + \frac{3 \cdot R_f}{Z_0}}
\]

(Equation 85)

Where
- \(U_{\text{phase}}\) is the phase voltage in the fault point before the fault,
- \(R_f\) is the resistance to earth in the fault point and
- \(Z_0\) is the system zero sequence impedance to earth

The fault current, in the fault point, can be calculated as:

\[
I = 3I_0 = \frac{3 \cdot U_{\text{phase}}}{Z_0 + 3 \cdot R_f}
\]

(Equation 86)

The impedance \(Z_0\) is dependent on the system earthing. In an isolated system (without neutral point apparatus) the impedance is equal to the capacitive coupling between the phase conductors and earth:

\[
Z_0 = -jX_c = -j \frac{3 \cdot U_{\text{phase}}}{I_i}
\]

(Equation 87)

Where
- \(I_i\) is the capacitive earth fault current at a non-resistive phase-to-earth fault
- \(X_c\) is the capacitive reactance to earth

In a system with a neutral point resistor (resistance earthed system) the impedance \(Z_0\) can be calculated as:
Where
\( R_n \) is the resistance of the neutral point resistor

In many systems there is also a neutral point reactor (Petersen coil) connected to one or more transformer neutral points. In such a system the impedance \( Z_0 \) can be calculated as:

\[
Z_0 = -jX_n \frac{3R_n}{3X_n + j3X_n - (3X_n - X_c)}
\]

(Equation 89)

Where
\( X_n \) is the reactance of the Petersen coil. If the Petersen coil is well tuned we have \( 3X_n = X_c \). In this case the impedance \( Z_0 \) will be: \( Z_0 = 3R_n \)

Now consider a system with an earthing via a resistor giving higher earth fault current than the high impedance earthing. The series impedances in the system can no longer be neglected. The system with a single phase to earth fault can be described as in Figure 65.

\[\text{Source impedance} \quad Z_{sc} \text{ (pos. seq)}\]
\[\text{Substation A} \]
\[Z_{T,1} \text{ (pos. seq)} \quad Z_{T,0} \text{ (zero seq)} \quad R_n \]
\[\text{U_{IA}} \quad 3I_0 \]
\[\text{Substation B} \]
\[Z_{sAB,1} \text{ (pos. seq)} \quad Z_{sAB,0} \text{ (zero seq)} \]
\[\text{Phase to earth fault} \]

\[\text{Figure 65: Equivalent of power system for calculation of setting}\]

The residual fault current can be written:
\[ 3I_0 = \frac{3U_{\text{phase}}}{2 \cdot Z_1 + Z_0 + 3 \cdot R_f} \]  
\hspace{1cm} \text{(Equation 90)}

Where
- \( U_{\text{phase}} \) is the phase voltage in the fault point before the fault
- \( Z_1 \) is the total positive sequence impedance to the fault point. \( Z_1 = Z_{sc} + Z_{T,1} + Z_{\text{lineAB,1}} + Z_{\text{lineBC,1}} \)
- \( Z_0 \) is the total zero sequence impedance to the fault point. \( Z_0 = Z_{T,0} + 3R_N + Z_{\text{lineAB,0}} + Z_{\text{lineBC,0}} \)
- \( R_f \) is the fault resistance.

The residual voltages in stations A and B can be written:

\[ U_{0A} = 3I_0 \cdot \left( Z_{T,0} + 3R_N \right) \]  
\hspace{1cm} \text{(Equation 91)}

\[ U_{0B} = 3I_0 \cdot \left( Z_{T,0} + 3R_N + Z_{\text{lineAB,0}} \right) \]  
\hspace{1cm} \text{(Equation 92)}

The residual power, measured by the sensitive earth fault protections in A and B will be:

\[ S_{0A} = 3U_{0A} \cdot 3I_0 \]  
\hspace{1cm} \text{(Equation 93)}

\[ S_{0B} = 3U_{0B} \cdot 3I_0 \]  
\hspace{1cm} \text{(Equation 94)}

The residual power is a complex quantity. The protection will have a maximum sensitivity in the characteristic angle RCA. The apparent residual power component in the characteristic angle, measured by the protection, can be written:

\[ S_{0A,\text{prot}} = 3U_{0A} \cdot 3I_0 \cdot \cos \phi_A \]  
\hspace{1cm} \text{(Equation 95)}

\[ S_{0B,\text{prot}} = 3U_{0B} \cdot 3I_0 \cdot \cos \phi_B \]  
\hspace{1cm} \text{(Equation 96)}

The angles \( \phi_A \) and \( \phi_B \) are the phase angles between the residual current and the residual voltage in the station compensated with the characteristic angle RCA.

The protection will use the power components in the characteristic angle direction for measurement, and as base for the inverse time delay.

The inverse time delay is defined as:
The function can be set On/Off with the setting of Operation.

Common base IED values for primary current (IBase), primary voltage (UBase) and primary power (SBase) are set in a Global base values for settings function GBASVAL.

GlobalBaseSel: It is used to select a GBASVAL function for reference of base values.

RotResU: It is a setting for rotating the polarizing quantity (3U₀) by 0 or 180 degrees. This parameter is set to 180 degrees by default in order to inverse the residual voltage (3U₀) to calculate the reference voltage (-3U₀ e⁻jRCADir). Since the reference voltage is used as the polarizing quantity for directionality, it is important to set this parameter correctly.

With the setting OpMode the principle of directional function is chosen.

With OpMode set to 3I₀cosfi the current component in the direction equal to the characteristic angle RCADir has the maximum sensitivity. The characteristic for RCADir is equal to 0° is shown in Figure 66.

![Diagram](IEC06000648-4-en.vsd)

Figure 66: Characteristic for RCADir equal to 0°

The characteristic is for RCADir equal to -90° is shown in Figure 67.
Figure 67: Characteristic for RCADir equal to -90°

When OpMode is set to $3U03I0cosf\i$ the apparent residual power component in the direction is measured.

When OpMode is set to $3I0$ and $f\i$ the function will operate if the residual current is larger than the setting $INDir>$ and the residual current angle is within the sector $RCADir \pm ROADir$.

The characteristic for this OpMode when $RCADir = 0^\circ$ and $ROADir = 80^\circ$ is shown in figure 68.

Figure 68: Characteristic for $RCADir = 0^\circ$ and $ROADir = 80^\circ$

DirMode is set Forward or Reverse to set the direction of the operation for the directional function selected by the OpMode.

All the directional protection modes have a residual current release level setting $INRel>$ which is set in % of $IBase$. This setting should be chosen smaller than or equal to the lowest fault current to be detected.
All the directional protection modes have a residual voltage release level setting \( UNRel > \) which is set in \% of \( U_{Base} \). This setting should be chosen smaller than or equal to the lowest fault residual voltage to be detected.

\( t_{Def} \) is the definite time delay, given in s, for the directional residual current protection.

\( t_{Reset} \) is the time delay before the definite timer gets reset, given in s. With a \( t_{Reset} \) time of few cycles, there is an increased possibility to clear intermittent earth faults correctly. The setting shall be much shorter than the set trip delay. In case of intermittent earth faults, the fault current is intermittently dropping below the set value during consecutive cycles. Therefore the definite timer should continue for a certain time equal to \( t_{Reset} \) even though the fault current has dropped below the set value.

The characteristic angle of the directional functions \( RCADir \) is set in degrees. \( RCADir \) is normally set equal to 0° in a high impedance earthed network with a neutral point resistor as the active current component is appearing out on the faulted feeder only. \( RCADir \) is set equal to -90° in an isolated network as all currents are mainly capacitive.

\( ROADir \) is Relay Operating Angle. \( ROADir \) is identifying a window around the reference direction in order to detect directionality. \( ROADir \) is set in degrees. For angles differing more than \( ROADir \) from \( RCADir \) the function is blocked. The setting can be used to prevent unwanted operation for non-faulted feeders, with large capacitive earth fault current contributions, due to CT phase angle error.

\( INCosPhi > \) is the operate current level for the directional function when \( OpMode \) is set \( 3I_0Cosfi \). The setting is given in \% of \( I_{Base} \). The setting should be based on calculation of the active or capacitive earth fault current at required sensitivity of the protection.

\( SN > \) is the operate power level for the directional function when \( OpMode \) is set \( 3I_03U_0Cosfi \). The setting is given in \% of \( S_{Base} \). The setting should be based on calculation of the active or capacitive earth fault residual power at required sensitivity of the protection.

The input transformer for the Sensitive directional residual over current and power protection function has the same short circuit capacity as the phase current transformers. Hence, there is no specific requirement for the external CT core, i.e. any CT core can be used.

If the time delay for residual power is chosen the delay time is dependent on two setting parameters. \( S_{Ref} \) is the reference residual power, given in \% of \( S_{Base} \). \( kSN \) is the time multiplier. The time delay will follow the following expression:

\[
 t_{inv} = \frac{kSN \cdot S_{Ref}}{3I_0 \cdot 3U_0 \cdot \cos \phi (\text{measured})} 
\]

(Equation 98)

\( IND > \) is the operate current level for the directional function when \( OpMode \) is set \( 3I_0 \), and \( fi \).

The setting is given in \% of \( I_{Base} \). The setting should be based on calculation of the earth fault current at required sensitivity of the protection.

\( OpINNonDir > \) is set On to activate the non-directional residual current protection.

\( INNonDir > \) is the operate current level for the non-directional function. The setting is given in \% of \( I_{Base} \). This function can be used for detection and clearance of cross-country faults in a shorter time than for the directional function. The current setting should be larger than the maximum single-phase residual current on the protected line.

\( TimeChar \) is the selection of time delay characteristic for the non-directional residual current protection. Definite time delay and different types of inverse time characteristics are available:
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>

See chapter “Inverse time characteristics” in Technical Manual for the description of different characteristics.

tPCrv, tACrv, tBCrv, tCCrv: Parameters for customer creation of inverse time characteristic curve (Curve type = 17). The time characteristic equation is:

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

(Equation 99)

tUNNonDir is the definite time delay for the non directional earth fault current protection, given in s.

OpUN> is set On to activate the trip function of the residual over voltage protection.

tUN is the definite time delay for the trip function of the residual voltage protection, given in s.

7.6 Breaker failure protection CCRBRF
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>Breaker failure protection, 3-phase activation and output</td>
<td>CCRBF</td>
<td>3I&gt;BF</td>
<td>508F</td>
</tr>
</tbody>
</table>

7.6.2 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 component. Instead a breaker failure protection is used.

Breaker failure protection, 3-phase activation and output (CCRBRF) will issue a back-up trip command to adjacent circuit breakers in case of failure to trip of the “normal” circuit breaker for the protected component. The detection of failure to break the current through the breaker is made by means of current measurement or as detection of remaining trip signal (unconditional).

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

7.6.3 Setting guidelines

The parameters for Breaker failure protection 3-phase activation and output 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 (I_Base), (U_Base) and (S_Base).

*Operation:* Off/On

*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 re-trip function shall operate. Retrip Off means that the re-trip 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 re-trip. CB Pos Check (circuit breaker position check) and Contact means re-trip is done when circuit breaker is closed (breaker position is used). No CBPos Check means re-trip is done without check of breaker position.
Table 16: 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 re-trip function is not activated</td>
</tr>
<tr>
<td>CB Pos Check</td>
<td>Current</td>
<td>re-trip is done if phase current is larger than the operate level after re-trip time has elapsed</td>
</tr>
<tr>
<td></td>
<td>Contact</td>
<td>re-trip is done when auxiliary contact position indicates that breaker is still closed after re-trip time has elapsed</td>
</tr>
<tr>
<td></td>
<td>Current&amp;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>re-trip is done without check of current level</td>
</tr>
<tr>
<td></td>
<td>Contact</td>
<td>re-trip is done without check of auxiliary contact position</td>
</tr>
<tr>
<td></td>
<td>Current&amp;Contact</td>
<td>re-trip is done without check of current level or auxiliary contact position</td>
</tr>
</tbody>
</table>

**BuTripMode:** Back-up 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 back-up 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. Typical setting is 10 % of IBase. Set the parameter IP > lower than the parameter I > BlkCont.

**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-earth faults in these 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 is set 1 out of 4. 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 re-trip. The setting can be given within the range 0 – 60s in steps of 0.001 s. Typical setting is 0 – 50ms.

**t2 :** Time delay of the back-up 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 90 – 200ms (also dependent of re-trip timer).
The minimum time delay for the re-trip can be estimated as:

\[ t_2 \geq t_1 + t_{\text{cbopen}} + t_{\text{BFP\_reset}} + t_{\text{margin}} \]

(Equation 100)

where:
- \( t_{\text{cbopen}} \) is the maximum opening time for the circuit breaker
- \( t_{\text{BFP\_reset}} \) is the maximum time for breaker failure protection to detect correct breaker function (the current criteria reset)
- \( t_{\text{margin}} \) 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 on the ability to maintain transient stability in case of a fault close to a power plant.

**Figure 69: Time sequence**

- \( t_{2\text{MPh}} \): Time delay of the back-up 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 back-up trip delay for multi-phase faults. Typical setting is 90 – 150 ms.

- \( t_3 \): Additional time delay to \( t_2 \) for a second back-up trip TRBU2. In some applications there might be a requirement to have separated back-up trip functions, tripping different back-up circuit breakers.

- \( t_{\text{CBAlarm}} \): 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. The time delay for back-up trip is bypassed when the CBFLT is active. Typical setting is 2.0 seconds.
Pulse: Trip pulse duration. This setting must be larger than the critical impulse time of circuit breakers to be tripped from the breaker failure protection. Typical setting is 200 ms.

7.7 Stub protection STBPTOC

7.7.1 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>Stub protection</td>
<td>STBPTOC</td>
<td>3I&gt;STUB</td>
<td>50STB</td>
</tr>
</tbody>
</table>

7.7.2 Application

In a 1½-breaker switchyard the line protection and the busbar protection normally have overlap when a connected object is in service. When an object is taken out of service it is normally required to keep the diagonal of the 1½-breaker switchyard in operation. This is done by opening the disconnector to the protected object. This will, however, disable the normal object protection (for example the distance protection) of the energized part between the circuit breakers and the open disconnector.

Stub protection STBPTOC is a simple phase overcurrent protection, fed from the two current transformer groups feeding the object taken out of service. The stub protection is only activated when the disconnector of the object is open. STBPTOC enables fast fault clearance of faults at the section between the CTs and the open disconnector.
7.7.3 Setting guidelines

The parameters for Stub protection STBPTOC are set via the local HMI or PCM600.

The following settings can be done for the stub protection.

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

*Operation:* Off/On

*ReleaseMode:* This parameter can be set *Release* or *Continuous*. With the *Release* setting the function is only active when a binary release signal RELEASE into the function is activated. This signal is normally taken from an auxiliary contact (normally closed) of the line disconnector and connected to a binary input RELEASE of the IED. With the setting *Continuous* the function is activated independent of presence of any external release signal.

*I*: Current level for the Stub protection, set in % of \(I_{Base}\). This parameter should be set so that all faults on the stub can be detected. The setting should thus be based on fault calculations.

*t*: Time delay of the operation. Normally the function shall be instantaneous.

7.8 Pole discordance protection CCPDSC
7.8.1 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>Pole discordance protection</td>
<td>CCPDSC</td>
<td>PD</td>
<td>52PD</td>
</tr>
</tbody>
</table>

7.8.2 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.

7.8.3 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.

- $\text{GlobalBaseSel}$: Selects the global base value group used by the function to define ($I_{Base}$), ($U_{Base}$) and ($S_{Base}$).
- $\text{Operation}$: Off or On
- $t_{Trip}$: Time delay of the operation.
- $\text{ContSel}$: 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 *IBase*.

### 7.9 Directional underpower protection GUPPDUP

#### 7.9.1 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>Directional underpower protection</td>
<td>GUPPDUP</td>
<td>P &amp;&lt; 2</td>
<td>37</td>
</tr>
</tbody>
</table>

#### 7.9.2 Application

The task of a generator in a power plant is to convert mechanical energy available as a torque on a rotating shaft to electric energy.

Sometimes, the mechanical power from a prime mover may decrease so much that it does not cover bearing losses and ventilation losses. Then, the synchronous generator becomes a synchronous motor and starts to take electric power from the rest of the power system. This operating state, where individual synchronous machines operate as motors, implies no risk for the machine itself. If the generator under consideration is very large and if it consumes lots of electric power, it may be desirable to disconnect it to ease the task for the rest of the power system.

Often, the motoring condition may imply that the turbine is in a very dangerous state. The task of the reverse power protection is to protect the turbine and not to protect the generator itself.

Steam turbines easily become overheated if the steam flow becomes too low or if the steam ceases to flow through the turbine. Therefore, turbo-generators should have reverse power protection. There are several contingencies that may cause reverse power: break of a main steam pipe, damage to one or more blades in the steam turbine or inadvertent closing of the main stop valves. In the last case, it is highly desirable to have a reliable reverse power protection. It may prevent damage to an otherwise undamaged plant.

During the routine shutdown of many thermal power units, the reverse power protection gives the tripping impulse to the generator breaker (the unit breaker). By doing so, one prevents the disconnection of the unit before the mechanical power has become zero. Earlier disconnection would cause an acceleration of the turbine generator at all routine shutdowns. This should have caused overspeed and high centrifugal stresses.
When the steam ceases to flow through a turbine, the cooling of the turbine blades will disappear. Now, it is not possible to remove all heat generated by the windage losses. Instead, the heat will increase the temperature in the steam turbine and especially of the blades. When a steam turbine rotates without steam supply, the electric power consumption will be about 2% of rated power. Even if the turbine rotates in vacuum, it will soon become overheated and damaged. The turbine overheats within minutes if the turbine loses the vacuum.

The critical time to overheating a steam turbine varies from about 0.5 to 30 minutes depending on the type of turbine. A high-pressure turbine with small and thin blades will become overheated more easily than a low-pressure turbine with long and heavy blades. The conditions vary from turbine to turbine and it is necessary to ask the turbine manufacturer in each case.

Power to the power plant auxiliaries may come from a station service transformer connected to the secondary side of the step-up transformer. Power may also come from a start-up service transformer connected to the external network. One has to design the reverse power protection so that it can detect reverse power independent of the flow of power to the power plant auxiliaries.

Hydro turbines tolerate reverse power much better than steam turbines do. Only Kaplan turbine and bulb turbines may suffer from reverse power. There is a risk that the turbine runner moves axially and touches stationary parts. They are not always strong enough to withstand the associated stresses.

Ice and snow may block the intake when the outdoor temperature falls far below zero. Branches and leaves may also block the trash gates. A complete blockage of the intake may cause cavitations. The risk for damages to hydro turbines can justify reverse power protection in unattended plants.

A hydro turbine that rotates in water with closed wicket gates will draw electric power from the rest of the power system. This power will be about 10% of the rated power. If there is only air in the hydro turbine, the power demand will fall to about 3%.

Diesel engines should have reverse power protection. The generator will take about 15% of its rated power or more from the system. A stiff engine may require perhaps 25% of the rated power to motor it. An engine that is good run in might need no more than 5%. It is necessary to obtain information from the engine manufacturer and to measure the reverse power during commissioning.

Gas turbines usually do not require reverse power protection.

Figure 71 illustrates the reverse power protection with underpower protection and with overpowerr protection. The underpower protection gives a higher margin and should provide better dependability. On the other hand, the risk for unwanted operation immediately after synchronization may be higher. One should set the underpower protection (reference angle set to 0) to trip if the active power from the generator is less than about 2%. One should set the overpowerr protection (reference angle set to 180) to trip if the power flow from the network to the generator is higher than 1%.
Underpower protection | Overpower protection
---|---

Figure 71: Reverse power protection with underpower or overpower protection

### 7.9.3 Setting guidelines

**GlobalBaseSel**: Selects the global base value group used by the function to define (I_Base), (U_Base) and (S_Base).

**Operation**: With the parameter *Operation* the function can be set On/Off.

**Mode**: The voltage and current used for the power measurement. The setting possibilities are shown in table 17.

#### Table 17: Complex power calculation

<table>
<thead>
<tr>
<th>Set value Mode</th>
<th>Formula used for complex power calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1, L2, L3</td>
<td>$\bar{S} = \bar{U}<em>{L1} \cdot \bar{T}</em>{L1}^* + \bar{U}<em>{L2} \cdot \bar{T}</em>{L2}^* + \bar{U}<em>{L3} \cdot \bar{T}</em>{L3}^*$</td>
</tr>
<tr>
<td></td>
<td>(Equation 102)</td>
</tr>
<tr>
<td>Arone</td>
<td>$\bar{S} = \bar{U}<em>{L1L2} \cdot \bar{T}</em>{L1}^* - \bar{U}<em>{L2L3} \cdot \bar{T}</em>{L3}^*$</td>
</tr>
<tr>
<td></td>
<td>(Equation 103)</td>
</tr>
<tr>
<td>PosSeq</td>
<td>$\bar{S} = 3 \cdot \bar{U}<em>{PosSeq} \cdot \bar{T}</em>{PosSeq}^*$</td>
</tr>
<tr>
<td></td>
<td>(Equation 104)</td>
</tr>
<tr>
<td>L1L2</td>
<td>$\bar{S} = \bar{U}<em>{L1L2} \cdot (\bar{T}</em>{L1}^* - \bar{T}_{L2}^*)$</td>
</tr>
<tr>
<td></td>
<td>(Equation 105)</td>
</tr>
<tr>
<td>L2L3</td>
<td>$\bar{S} = \bar{U}<em>{L2L3} \cdot (\bar{T}</em>{L2}^* - \bar{T}_{L3}^*)$</td>
</tr>
<tr>
<td></td>
<td>(Equation 106)</td>
</tr>
<tr>
<td>L3L1</td>
<td>$\bar{S} = \bar{U}<em>{L3L1} \cdot (\bar{T}</em>{L3}^* - \bar{T}_{L1}^*)$</td>
</tr>
<tr>
<td></td>
<td>(Equation 107)</td>
</tr>
<tr>
<td>L1</td>
<td>$\bar{S} = 3 \cdot \bar{U}<em>{L1} \cdot \bar{T}</em>{L1}^*$</td>
</tr>
<tr>
<td></td>
<td>(Equation 108)</td>
</tr>
<tr>
<td>L2</td>
<td>$\bar{S} = 3 \cdot \bar{U}<em>{L2} \cdot \bar{T}</em>{L2}^*$</td>
</tr>
<tr>
<td></td>
<td>(Equation 109)</td>
</tr>
<tr>
<td>L3</td>
<td>$\bar{S} = 3 \cdot \bar{U}<em>{L3} \cdot \bar{T}</em>{L3}^*$</td>
</tr>
<tr>
<td></td>
<td>(Equation 110)</td>
</tr>
</tbody>
</table>
The function has two stages that can be set independently.

With the parameter OpMode1(2) the function can be set On/Off.

The function gives trip if the power component in the direction defined by the setting Angle1(2) is smaller than the set pick up power value Power1(2).

![Diagram showing the underpower mode](en00000441.vsd)

**Figure 72: Underpower mode**

The setting Power1(2) gives the power component pick up value in the Angle1(2) direction. The setting is given in p.u. of the generator rated power, see equation 111.

Minimum recommended setting is 0.2% of $S_N$ when metering class CT inputs into the IED are used.

$$S_N = \sqrt{3} \cdot U_{\text{Base}} \cdot I_{\text{Base}}$$

(Equation 111)

The setting Angle1(2) gives the characteristic angle giving maximum sensitivity of the power protection function. The setting is given in degrees. For active power the set angle should be 0° or 180°. 0° should be used for generator low forward active power protection.
For low forward power the set angle should be 0° in the underpower function. TripDelay1(2) is set in seconds to give the time delay for trip of the stage after pick up.

Hysteresis1(2) is given in p.u. of generator rated power according to equation 112:

$$S_N = \sqrt{3} \cdot U_{Base} \cdot I_{Base}$$  

(Equation 112)

The drop out power will be Power1(2) + Hysteresis1(2).

The possibility to have low pass filtering of the measured power can be made as shown in the formula:

$$S = k \cdot S_{Old} + (1-k) \cdot S_{Calculated}$$  

(Equation 113)

Where

- $S$ is a new measured value to be used for the protection function
- $S_{Old}$ is the measured value given from the function in previous execution cycle
- $S_{Calculated}$ is the new calculated value in the present execution cycle
- $k$ is settable parameter

The value of $k=0.92$ is recommended in generator applications as the trip delay is normally quite long.

The calibration factors for current and voltage measurement errors are set % of rated current/voltage:

$I_{AmpComp5}$, $I_{AmpComp30}$, $I_{AmpComp100}$
The angle compensation is given as difference between current and voltage angle errors. The values are given for operating points 5, 30 and 100% of rated current/voltage. The values should be available from instrument transformer test protocols.

7.10 Directional overpower protection GOPPDOP

7.10.1 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>Directional overpower protection</td>
<td>GOPPDOP</td>
<td></td>
<td>32</td>
</tr>
</tbody>
</table>

7.10.2 Application

The task of a generator in a power plant is to convert mechanical energy available as a torque on a rotating shaft to electric energy.

Sometimes, the mechanical power from a prime mover may decrease so much that it does not cover bearing losses and ventilation losses. Then, the synchronous generator becomes a synchronous motor and starts to take electric power from the rest of the power system. This operating state, where individual synchronous machines operate as motors, implies no risk for the machine itself. If the generator under consideration is very large and if it consumes lots of electric power, it may be desirable to disconnect it to ease the task for the rest of the power system.

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Power to the power plant auxiliaries may come from a station service transformer connected to the primary side of the step-up transformer. Power may also come from a start-up service transformer connected to the external network. One has to design the reverse power protection so that it can detect reverse power independent of the flow of power to the power plant auxiliaries.

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Diesel engines should have reverse power protection. The generator will take about 15% of its rated power or more from the system. A stiff engine may require perhaps 25% of the rated power to motor it. An engine that is well run in might need no more than 5%. It is necessary to obtain information from the engine manufacturer and to measure the reverse power during commissioning.

Gas turbines usually do not require reverse power protection.

Figure 74 illustrates the reverse power protection with underpower IED and with overpower IED. The underpower IED gives a higher margin and should provide better dependability. On the other hand, the risk for unwanted operation immediately after synchronization may be higher. One should set the underpower IED to trip if the active power from the generator is less than about 2%. One should set the overpower IED to trip if the power flow from the network to the generator is higher than 1%.

![Figure 74: Reverse power protection with underpower IED and overpower IED](IEC060000315-2-en.vsd)
7.10.3 Setting guidelines

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

*Operation:* With the parameter *Operation* the function can be set On/Off.

*Mode:* The voltage and current used for the power measurement. The setting possibilities are shown in table 18.

<table>
<thead>
<tr>
<th>Set value Mode</th>
<th>Formula used for complex power calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1, L2, L3</td>
<td>$\bar{S} = U_{L1} \cdot I_{L1}^* + U_{L2} \cdot I_{L2}^* + U_{L3} \cdot I_{L3}^*$ (Equation 115)</td>
</tr>
<tr>
<td>Arone</td>
<td>$\bar{S} = U_{L1L2} \cdot I_{L1}^* - U_{L2L3} \cdot I_{L3}^*$ (Equation 116)</td>
</tr>
<tr>
<td>PosSeq</td>
<td>$\bar{S} = 3 \cdot U_{PosSeq} \cdot I_{PosSeq}^*$ (Equation 117)</td>
</tr>
<tr>
<td>L1L2</td>
<td>$\bar{S} = U_{L1L2} \cdot (I_{L1}^* - I_{L2}^*)$ (Equation 118)</td>
</tr>
<tr>
<td>L2L3</td>
<td>$\bar{S} = U_{L2L3} \cdot (I_{L2}^* - I_{L3}^*)$ (Equation 119)</td>
</tr>
<tr>
<td>L3L1</td>
<td>$\bar{S} = U_{L3L1} \cdot (I_{L3}^* - I_{L1}^*)$ (Equation 120)</td>
</tr>
<tr>
<td>L1</td>
<td>$\bar{S} = 3 \cdot U_{L1} \cdot I_{L1}^*$ (Equation 121)</td>
</tr>
<tr>
<td>L2</td>
<td>$\bar{S} = 3 \cdot U_{L2} \cdot I_{L2}^*$ (Equation 122)</td>
</tr>
<tr>
<td>L3</td>
<td>$\bar{S} = 3 \cdot U_{L3} \cdot I_{L3}^*$ (Equation 123)</td>
</tr>
</tbody>
</table>

The function has two stages that can be set independently.

With the parameter *OpMode1(2)* the function can be set On/Off.

The function gives trip if the power component in the direction defined by the setting *Angle1(2)* is larger than the set pick up power value *Power1(2)*.
Figure 75: Overpower mode

The setting Power1(2) gives the power component pick up value in the Angle1(2) direction. The setting is given in p.u. of the generator rated power, see equation 124.

Minimum recommended setting is 0.2% of $S_N$ when metering class CT inputs into the IED are used.

$$S_N = \sqrt{3} \cdot U_{Base} \cdot I_{Base}$$

(Equation 124)

The setting Angle1(2) gives the characteristic angle giving maximum sensitivity of the power protection function. The setting is given in degrees. For active power the set angle should be 0° or 180°. 180° should be used for generator reverse power protection.
Figure 76: For reverse power the set angle should be 180° in the overpower function. TripDelay1(2) is set in seconds to give the time delay for trip of the stage after pick up. Hysteresis1(2) is given in p.u. of generator rated power according to equation 125.

\[ S_N = \sqrt{3} \cdot U_{\text{Base}} \cdot I_{\text{Base}} \]

(Equation 125)

The drop out power will be Power1(2) - Hysteresis1(2).

The possibility to have low pass filtering of the measured power can be made as shown in the formula:

\[ S = k \cdot S_{\text{Old}} + (1-k) \cdot S_{\text{Calculated}} \]

(Equation 126)

Where
- \( S \) is a new measured value to be used for the protection function.
- \( S_{\text{Old}} \) is the measured value given from the function in previous execution cycle.
- \( S_{\text{Calculated}} \) is the new calculated value in the present execution cycle.
- \( k \) is settable parameter.

The value of \( k=0.92 \) is recommended in generator applications as the trip delay is normally quite long.

The calibration factors for current and voltage measurement errors are set % of rated current/voltage:
IAmpComp5, IAmpComp30, IAmpComp100
U AmpComp5, U AmpComp30, U AmpComp100
IAngComp5, IAngComp30, IAngComp100

The angle compensation is given as difference between current and voltage angle errors.

The values are given for operating points 5, 30 and 100% of rated current/voltage. The values should be available from instrument transformer test protocols.

7.11 Broken conductor check BRCPTOC

7.11.1 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>Broken conductor check</td>
<td>BRCPTOC</td>
<td>-</td>
<td>46</td>
</tr>
</tbody>
</table>

7.11.2 Application

Conventional protection functions cannot detect the broken conductor condition. Broken conductor check (BRCPTOC) function, consisting of continuous current unsymmetrical check on the line where the IED connected will give alarm or trip at detecting broken conductors.

7.11.3 Setting guidelines

Broken conductor check BRCPTOC must be set to detect open phase/s (series faults) with different loads on the line. BRCPTOC must at the same time be set to not operate for maximum asymmetry which can exist due to, for example, not transposed power lines.

All settings are in primary values or percentage.

Set $I_{Base}$ (given in GlobalBaseSel) to power line rated current or CT rated current.

Set minimum operating level per phase $I_{P}>$ to typically 10-20% of rated current.

Set the unsymmetrical current, which is relation between the difference of the minimum and maximum phase currents to the maximum phase current to typical $I_{ub}> = 50%$.

Note that it must be set to avoid problem with asymmetry under minimum operating conditions.

Set the time delay $t_{Oper} = 5 - 60$ seconds and reset time $t_{Reset} = 0.010 - 60.000$ seconds.
Section 8  Voltage protection

8.1  Two step undervoltage protection UV2PTUV

8.1.1  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>Two step undervoltage protection UV2PTUV</td>
<td>UV2PTUV</td>
<td></td>
<td>3U&lt;</td>
</tr>
</tbody>
</table>

8.1.2  Application

Two-step undervoltage protection function (UV2PTUV) is applicable in all situations, where reliable detection of low phase voltages is necessary. It is used also as a supervision and fault detection function for other protection functions, to increase the security of a complete protection system.

UV2PTUV is applied to power system elements, such as generators, transformers, motors and power lines in order to detect low voltage conditions. Low voltage conditions are caused by abnormal operation or fault in the power system. 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. Other applications are the detection of “no voltage” condition, for example, before the energization of a HV line or for automatic breaker trip in case of a blackout.

UV2PTUV is also used to initiate voltage correction measures, like insertion of shunt capacitor banks to compensate for reactive load and thereby increasing the voltage. The function has a high measuring accuracy and setting hysteresis to allow applications to control reactive load.

UV2PTUV is used to disconnect apparatuses, like electric motors, which will be damaged when subject to service under low voltage conditions. UV2PTUV deals with low voltage conditions at power system frequency, which can be caused by the following reasons:

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

UV2PTUV prevents sensitive equipment from running under conditions that could cause their overheating 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.

8.1.3  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 settings base voltage $U_{\text{Base}}$, 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 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 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 $U_{\text{Base}}$. When ConnType is set to PhN DFT or PhN RMS then the IED automatically divides set value for $U_{\text{Base}}$ by $\sqrt{3}$. $U_{\text{Base}}$ 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. This means operation for phase-to-earth voltage under:
\[ U < \left( \frac{\% \cdot U_{\text{Base}(kV)}}{\sqrt{3}} \right) \]

(Equation 127)

and operation for phase-to-phase voltage under:

\[ U < (\%) \cdot U_{\text{Base}}(kV) \]

(Equation 128)

The below described setting parameters 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 that 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 of the protection application. It is essential to consider the minimum voltage at non-faulted situations. Normally this voltage is larger than 90% of nominal voltage.

**tn**: time delay of step n, given in s. This setting is dependent of 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 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 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 to Instantaneous, Frozen time, Linearly decreased. The default setting is Instantaneous.

**tIRestn**: 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 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< down 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:
\[ \frac{B \cdot CrvSatn}{100} - C > 0 \]

(Equation 129)

**IntBlkSel**: 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.

**IntBlkStVal**: 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%.

**tBlkUV**: 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.
Section 9 Multipurpose protection

9.1 General current and voltage protection CVGAPC

9.1.1 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>General current and voltage protection</td>
<td>CVGAPC</td>
<td>2(l&gt;/U&lt;)</td>
<td>-</td>
</tr>
</tbody>
</table>

9.1.2 Application

A breakdown of the insulation between phase conductors or a phase conductor and earth results in a short circuit or an earth fault respectively. Such faults can result in large fault currents and may cause severe damage to the power system primary equipment. Depending on the magnitude and type of the fault different overcurrent protections, based on measurement of phase, earth or sequence current components can be used to clear these faults. Additionally it is sometimes required that these overcurrent protections shall be directional and/or voltage controlled/restrained.

The over/under voltage protection is applied on power system elements, such as generators, transformers, motors and power lines in order to detect abnormal voltage conditions. Depending on the type of voltage deviation and type of power system abnormal condition different over/under voltage protections based on measurement of phase-to-earth, phase-to-phase, residual- or sequence- voltage components can be used to detect and operate for such incident.

The IED can be provided with multiple General current and voltage protection (CVGAPC) protection modules. The function is always connected to three-phase current and three-phase voltage input in the configuration tool, but it will always measure only one current and one voltage quantity selected by the end user in the setting tool.

Each CVGAPC function module has got four independent protection elements built into it.

1. Two overcurrent steps with the following built-in features:
   - Definite time delay or Inverse Time Overcurrent TOC/IDMT delay for both steps
   - Second harmonic supervision is available in order to only allow operation of the overcurrent stage(s) if the content of the second harmonic in the measured current is lower than pre-set level
   - Directional supervision is available in order to only allow operation of the overcurrent stage(s) if the fault location is in the pre-set direction (Forward or Reverse). Its behavior during low-level polarizing voltage is settable (Non-Directional, Block, Memory)
   - Voltage restrained/controlled feature is available in order to modify the pick-up level of the overcurrent stage(s) in proportion to the magnitude of the measured voltage
   - Current restrained feature is available in order to only allow operation of the overcurrent stage(s) if the measured current quantity is bigger than the set percentage of the current restrain quantity.

2. Two undercurrent steps with the following built-in features:
3. Two overvoltage steps with the following built-in features
   - Definite time delay or Inverse Time Overcurrent TOC/IDMT delay for both steps

4. Two undervoltage steps with the following built-in features
   - Definite time delay or Inverse Time Overcurrent TOC/IDMT delay for both steps

All these four protection elements within one general protection function works independently from each other and they can be individually enabled or disabled. However it shall be once more noted that all these four protection elements measure one selected current quantity and one selected voltage quantity (see table 19 and table 20). It is possible to simultaneously use all four-protection elements and their individual stages. Sometimes in order to obtain desired application functionality it is necessary to provide interaction between two or more protection elements/stages within one CVGAPC function by appropriate IED configuration (for example, dead machine protection for generators).

9.1.2.1 Current and voltage selection for CVGAPC function

CVGAPC function is always connected to three-phase current and three-phase voltage input in the configuration tool, but it will always measure only the single current and the single voltage quantity selected by the end user in the setting tool (selected current quantity and selected voltage quantity).

The user can select, by a setting parameter CurrentInput, to measure one of the following current quantities shown in table 19.

<table>
<thead>
<tr>
<th>Set value for parameter “CurrentInput”</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 phase1</td>
<td>CVGAPC function will measure the phase L1 current phasor</td>
</tr>
<tr>
<td>2 phase2</td>
<td>CVGAPC function will measure the phase L2 current phasor</td>
</tr>
<tr>
<td>3 phase3</td>
<td>CVGAPC function will measure the phase L3 current phasor</td>
</tr>
<tr>
<td>4 PosSeq</td>
<td>CVGAPC function will measure internally calculated positive sequence current phasor</td>
</tr>
<tr>
<td>5 NegSeq</td>
<td>CVGAPC function will measure internally calculated negative sequence current phasor</td>
</tr>
<tr>
<td>6 3 · ZeroSeq</td>
<td>CVGAPC function will measure internally calculated zero sequence current phasor multiplied by factor 3</td>
</tr>
<tr>
<td>7 MaxPh</td>
<td>CVGAPC function will measure current phasor of the phase with maximum magnitude</td>
</tr>
<tr>
<td>8 MinPh</td>
<td>CVGAPC function will measure current phasor of the phase with minimum magnitude</td>
</tr>
<tr>
<td>9 UnbalancePh</td>
<td>CVGAPC function will measure magnitude of unbalance current, which is internally calculated as the algebraic magnitude difference between the current phasor of the phase with maximum magnitude and current phasor of the phase with minimum magnitude. Phase angle will be set to 0° all the time.</td>
</tr>
<tr>
<td>10 phase1-phase2</td>
<td>CVGAPC function will measure the current phasor internally calculated as the vector difference between the phase L1 current phasor and phase L2 current phasor (IL1-IL2)</td>
</tr>
<tr>
<td>11 phase2-phase3</td>
<td>CVGAPC function will measure the current phasor internally calculated as the vector difference between the phase L2 current phasor and phase L3 current phasor (IL2-IL3)</td>
</tr>
</tbody>
</table>

Table continues on next page
The user can select, by a setting parameter *VoltageInput*, to measure one of the following voltage quantities shown in table 20.

Table 20: Available selection for voltage quantity within CVGAPC function

<table>
<thead>
<tr>
<th>Set value for parameter &quot;VoltageInput&quot;</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 phase1</td>
<td>CVGAPC function will measure the phase L1 voltage phasor</td>
</tr>
<tr>
<td>2 phase2</td>
<td>CVGAPC function will measure the phase L2 voltage phasor</td>
</tr>
<tr>
<td>3 phase3</td>
<td>CVGAPC function will measure the phase L3 voltage phasor</td>
</tr>
<tr>
<td>4 PosSeq</td>
<td>CVGAPC function will measure internally calculated positive sequence voltage phasor</td>
</tr>
<tr>
<td>5 -NegSeq</td>
<td>CVGAPC function will measure internally calculated negative sequence voltage phasor. This voltage phasor will be intentionally rotated for 180° in order to enable easier settings for the directional feature when used.</td>
</tr>
<tr>
<td>6 -3*ZeroSeq</td>
<td>CVGAPC function will measure internally calculated zero sequence voltage phasor multiplied by factor 3. This voltage phasor will be intentionally rotated for 180° in order to enable easier settings for the directional feature when used.</td>
</tr>
<tr>
<td>7 MaxPh</td>
<td>CVGAPC function will measure voltage phasor of the phase with maximum magnitude</td>
</tr>
<tr>
<td>8 MinPh</td>
<td>CVGAPC function will measure voltage phasor of the phase with minimum magnitude</td>
</tr>
<tr>
<td>9 UnbalancePh</td>
<td>CVGAPC function will measure magnitude of unbalance voltage, which is internally calculated as the algebraic magnitude difference between the voltage phasor of the phase with maximum magnitude and voltage phasor of the phase with minimum magnitude. Phase angle will be set to 0° all the time</td>
</tr>
<tr>
<td>10 phase1-phase2</td>
<td>CVGAPC function will measure the voltage phasor internally calculated as the vector difference between the phase L1 voltage phasor and phase L2 voltage phasor (UL1-UL2)</td>
</tr>
<tr>
<td>11 phase2-phase3</td>
<td>CVGAPC function will measure the voltage phasor internally calculated as the vector difference between the phase L2 voltage phasor and phase L3 voltage phasor (UL2-UL3)</td>
</tr>
<tr>
<td>12 phase3-phase1</td>
<td>CVGAPC function will measure the voltage phasor internally calculated as the vector difference between the phase L3 voltage phasor and phase L1 voltage phasor (UL3-UL1)</td>
</tr>
</tbody>
</table>
Set value for parameter "VoltageInput" | Comment
--- | ---
13 MaxPh-Ph | CVGAPC function will measure ph-ph voltage phasor with the maximum magnitude
14 MinPh-Ph | CVGAPC function will measure ph-ph voltage phasor with the minimum magnitude
15 UnbalancePh-Ph | CVGAPC function will measure magnitude of unbalance voltage, which is internally calculated as the algebraic magnitude difference between the ph-ph voltage phasor with maximum magnitude and ph-ph voltage phasor with minimum magnitude. Phase angle will be set to 0° all the time

It is important to notice that the voltage selection from table 20 is always applicable regardless the actual external VT connections. The three-phase VT inputs can be connected to IED as either three phase-to-earth voltages $U_{L1}$, $U_{L2}$ & $U_{L3}$ or three phase-to-phase voltages $U_{L1L2}$, $U_{L2L3}$ & $U_{L3L1}$. VAB, VBC and VCA. This information about actual VT connection is entered as a setting parameter for the pre-processing block, which will then take automatically care about it.

### 9.1.2.2 Base quantities for CVGAPC function

The parameter settings for the base quantities, which represent the base (100%) for pickup levels of all measuring stages shall be entered as setting parameters for every CVGAPC function.

Base current shall be entered as:

1. rated phase current of the protected object in primary amperes, when the measured Current Quantity is selected from 1 to 9, as shown in table 19.
2. rated phase current of the protected object in primary amperes multiplied by $\sqrt{3}$ (1.732 x $I_{\text{phase}}$), when the measured Current Quantity is selected from 10 to 15, as shown in table 19.

Base voltage shall be entered as:

1. rated phase-to-earth voltage of the protected object in primary kV, when the measured Voltage Quantity is selected from 1 to 9, as shown in table 20.
2. rated phase-to-phase voltage of the protected object in primary kV, when the measured Voltage Quantity is selected from 10 to 15, as shown in table 20.

### 9.1.2.3 Application possibilities

Due to its flexibility the general current and voltage protection (CVGAPC) function can be used, with appropriate settings and configuration in many different applications. Some of possible examples are given below:

1. Transformer and line applications:
   - Underimpedance protection (circular, non-directional characteristic)
   - Underimpedance protection (circular mho characteristic)
   - Voltage Controlled/Restrained Overcurrent protection
   - Phase or Negative/Positive/Zero Sequence (Non-Directional or Directional) Overcurrent protection
   - Phase or phase-to-phase or Negative/Positive/Zero Sequence over/under voltage protection
• Special thermal overload protection
• Open Phase protection
• Unbalance protection

2. Generator protection

• 80-95% Stator earth fault protection (measured or calculated 3Uo)
• Rotor earth fault protection (with external COMBIFLEX RXTTE4 injection unit)
• Underimpedance protection
• Voltage Controlled/Restained Overcurrent protection
• Turn-to-Turn & Differential Backup protection (directional Negative Sequence. Overcurrent protection connected to generator HV terminal CTs looking into generator)
• Stator Overload protection
• Rotor Overload protection
• Loss of Excitation protection (directional pos. seq. OC protection)
• Reverse power/Low forward power protection (directional pos. seq. OC protection, 2% sensitivity)
• Dead-Machine/Inadvernt-Energizing protection
• Breaker head flashover protection
• Improper synchronizing detection
• Sensitive negative sequence generator over current protection and alarm
• Phase or phase-to-phase or Negative/Positive/Zero Sequence over/under voltage protection
• Generator out-of-step detection (based on directional pos. seq. OC)
• Inadverntent generator energizing

9.1.2.4 Inadverntent generator energization

When the generator is taken out of service, and non-rotating, there is a risk that the generator circuit breaker is closed by mistake.

Three-phase energizing of a generator, which is at standstill or on turning gear, causes it to behave and accelerate similarly to an induction motor. The machine, at this point, essentially represents the subtransient reactance to the system and it can be expected to draw from one to four per unit current, depending on the equivalent system impedance. Machine terminal voltage can range from 20% to 70% of rated voltage, again, depending on the system equivalent impedance (including the block transformer). Higher quantities of machine current and voltage (3 to 4 per unit current and 50% to 70% rated voltage) can be expected if the generator is connected to a strong system. Lower current and voltage values (1 to 2 per unit current and 20% to 40% rated voltage) are representative of weaker systems.

Since a generator behaves similarly to an induction motor, high currents will develop in the rotor during the period it is accelerating. Although the rotor may be thermally damaged from excessive high currents, the time to damage will be on the order of a few seconds. Of more critical concern, however, is the bearing, which can be damaged in a fraction of a second due to low oil pressure. Therefore, it is essential that high speed tripping is provided. This tripping should be almost instantaneous (< 100 ms).

There is a risk that the current into the generator at inadvertent energization will be limited so that the “normal” overcurrent or underimpedance protection will not detect the dangerous situation. The delay of these protection functions might be too long. The reverse power protection might detect the situation but the operation time of this protection is normally too long.

For big and important machines, fast protection against inadvertent energizing should, therefore, be included in the protective scheme.

The protection against inadvertent energization can be made by a combination of undervoltage, overvoltage and overcurrent protection functions. The undervoltage function
will, with a delay for example 10 s, detect the situation when the generator is not connected to the grid (standstill) and activate the overcurrent function. The overvoltage function will detect the situation when the generator is taken into operation and will disable the overcurrent function. The overcurrent function will have a pick-up value about 50% of the rated current of the generator. The trip delay will be about 50 ms.

9.1.3 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 general current and voltage protection function (CVGAPC) are set via the local HMI or Protection and Control Manager (PCM600).

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

The overcurrent steps has a $I_{Minx}$ ($x=1$ or $2$ depending on step) setting to set the minimum operate current. Set $I_{Minx}$ below $StartCurr\_OCx$ for every step to achieve ANSI reset characteristic according to standard. If $I_{Minx}$ is set above $StartCurr\_OCx$ for any step the ANSI reset works as if current is zero when current drops below $I_{Minx}$.

9.1.3.1 Directional negative sequence overcurrent protection

Directional negative sequence overcurrent protection is typically used as sensitive earth-fault protection of power lines where incorrect zero sequence polarization may result from mutual induction between two or more parallel lines. Additionally, it can be used in applications on underground cables where zero-sequence impedance depends on the fault current return paths, but the cable negative-sequence impedance is practically constant. It shall be noted that directional negative sequence OC element offers protection against all unbalance faults (phase-to-phase faults as well). Care shall be taken that the minimum pickup of such protection function shall be set above natural system unbalance level.

An example will be given, how sensitive-earth-fault protection for power lines can be achieved by using negative-sequence directional overcurrent protection elements within a CVGAPC function.

This functionality can be achieved by using one CVGAPC function. The following shall be done to ensure proper operation of the function:

1. Connect three-phase power line currents and three-phase power line voltages to one CVGAPC instance (for example, GF04)
2. Set CurrentInput to NegSeq (please note that CVGAPC function measures $I_2$ current and NOT $3I_2$ current; this is essential for proper OC pickup level setting)
3. Set VoltageInput to -$NegSeq$ (please note that the negative sequence voltage phasor is intentionally inverted in order to simplify directionality
4. Set base current $IBase$ value equal to the rated primary current of power line CTs
5. Set base voltage $UBase$ value equal to the rated power line phase-to-phase voltage in kV
6. Set RCADir to value +65 degrees ($NegSeq$ current typically lags the inverted $NegSeq$ voltage for this angle during the fault)
7. Set ROADir to value 90 degree
8. Set LowVolt_VM to value 2% ($NegSeq$ voltage level above which the directional element will be enabled)
9. Enable one overcurrent stage (for example, OC1)
10. By parameter CurveType_OC1 select appropriate TOC/IDMT or definite time delayed curve in accordance with your network protection philosophy
11. Set StartCurr_OC1 to value between 3-10% (typical values)
12. Set tDef_OC1 or parameter “k” when TOC/IDMT curves are used to insure proper time coordination with other earth-fault protections installed in the vicinity of this power line
13. Set DirMode_OC1 to Forward
14. Set DirPrinc_OC1 to IcosPhi&U
15. Set ActLowVolt1_VM to Block
   • In order to insure proper restraining of this element for CT saturations during three-phase faults it is possible to use current restraint feature and enable this element to operate only when NegSeq current is bigger than a certain percentage (10% is typical value) of measured PosSeq current in the power line. To do this the following settings within the same function shall be done:
16. Set EnRestrainCurr to On
17. Set RestrCurrInput to PosSeq
18. Set RestrCurrCoeff to value 0.10

If required, this CVGAPC function can be used in directional comparison protection scheme for the power line protection if communication channels to the remote end of this power line are available. In that case typically two NegSeq overcurrent steps are required. One for forward and one for reverse direction. As explained before the OC1 stage can be used to detect faults in forward direction. The built-in OC2 stage can be used to detect faults in reverse direction.

However the following shall be noted for such application:
   • the set values for RCADir and ROADir settings will be as well applicable for OC2 stage
   • setting DirMode_OC2 shall be set to Reverse
   • setting parameter StartCurr_OC2 shall be made more sensitive than pickup value of forward OC1 element (that is, typically 60% of OC1 set pickup level) in order to insure proper operation of the directional comparison scheme during current reversal situations
   • start signals from OC1 and OC2 elements shall be used to send forward and reverse signals to the remote end of the power line
   • the available scheme communications function block within IED shall be used between multipurpose protection function and the communication equipment in order to insure proper conditioning of the above two start signals

Furthermore the other built-in UC, OV and UV protection elements can be used for other protection and alarming purposes.

9.1.3.2 Negative sequence overcurrent protection

Example will be given how to use one CVGAPC function to provide negative sequence inverse time overcurrent protection for a generator with capability constant of 20s, and maximum continuous negative sequence rating of 7% of the generator rated current.

The capability curve for a generator negative sequence overcurrent protection, often used world-wide, is defined by the ANSI standard in accordance with the following formula:
where:

\( t_{op} \) is the operating time in seconds of the negative sequence overcurrent IED
\( k \) is the generator capability constant in seconds
\( I_{NS} \) is the measured negative sequence current
\( I_r \) is the generator rated current

By defining parameter \( x \) equal to maximum continuous negative sequence rating of the generator in accordance with the following formula

\[
x = 7\% = 0.07 \text{ pu}
\]  
(Equation 131)

Equation 130 can be re-written in the following way without changing the value for the operate time of the negative sequence inverse overcurrent IED:

\[
t_{op} = \frac{k \cdot \frac{1}{x^2}}{\left( \frac{I_{NS}}{x \cdot I_r} \right)^2}
\]  
(Equation 132)

In order to achieve such protection functionality with one CVGAPC functions the following must be done:

1. Connect three-phase generator currents to one CVGAPC instance (for example, GF01)
2. Set parameter CurrentInput to value NegSeq
3. Set base current value to the rated generator current in primary amperes
4. Enable one overcurrent step (for example, OC1)
5. Select parameter CurveType_OC1 to value Programmable

\[
t_{op} = k \cdot \left( \frac{A}{M^n - C} + B \right)
\]  
(Equation 133)

where:

\( t_{op} \) is the operating time in seconds of the Inverse Time Overcurrent TOC/IDMT algorithm
\( k \) is time multiplier (parameter setting)
\( M \) is ratio between measured current magnitude and set pickup current level
\( A, B, C \) and \( P \) are user settable coefficients which determine the curve used for Inverse Time Overcurrent TOC/IDMT calculation
When the equation 130 is compared with the equation 132 for the inverse time characteristic of the OC1 it is obvious that if the following rules are followed:

1. set k equal to the generator negative sequence capability value
2. set $A_{OC1}$ equal to the value $1/x^2$
3. set $B_{OC1} = 0.0$, $C_{OC1}=0.0$ and $P_{OC1}=2.0$
4. set $StartCurr_{OC1}$ equal to the value $x$

then the OC1 step of the CVGAPC function can be used for generator negative sequence inverse overcurrent protection.

For this particular example the following settings shall be entered to insure proper function operation:

1. select negative sequence current as measuring quantity for this CVGAPC function
2. make sure that the base current value for the CVGAPC function is equal to the generator rated current
3. set $k_{OC1} = 20$
4. set $A_{OC1}= 1/0.07^2 = 204.0816$
5. set $B_{OC1} = 0.0$, $C_{OC1} = 0.0$ and $P_{OC1} = 2.0$
6. set $StartCurr_{OC1} = 7\%$

Proper timing of the CVGAPC function made in this way can easily be verified by secondary injection. All other settings can be left at the default values. If required delayed time reset for OC1 step can be set in order to ensure proper function operation in case of repetitive unbalance conditions.

Furthermore the other built-in protection elements can be used for other protection and alarming purposes (for example, use OC2 for negative sequence overcurrent alarm and OV1 for negative sequence overvoltage alarm).

9.1.3.3 Generator stator overload protection in accordance with IEC or ANSI standards

Example will be given how to use one CVGAPC function to provide generator stator overload protection in accordance with IEC or ANSI standard if minimum-operating current shall be set to 116% of generator rating.

The generator stator overload protection is defined by IEC or ANSI standard for turbo generators in accordance with the following formula:

$$t_{op} = \frac{k}{\left(\frac{I_m}{I_r}\right)^2 - 1}$$

(Equation 134)

where:

- $t_{op}$ is the operating time of the generator stator overload IED
- $k$ is the generator capability constant in accordance with the relevant standard ($k = 37.5$ for the IEC standard or $k = 41.4$ for the ANSI standard)
- $I_m$ is the magnitude of the measured current
- $I_r$ is the generator rated current
This formula is applicable only when measured current (for example, positive sequence current) exceeds a pre-set value (typically in the range from 105 to 125% of the generator rated current).

By defining parameter \( x \) equal to the per unit value for the desired pickup for the overload IED in accordance with the following formula:

\[
x = 116\% = 1.16 \text{ pu}
\]

(Equation 135)

Formula 3.5 can be re-written in the following way without changing the value for the operate time of the generator stator overload IED:

\[
t_{\text{op}} = \frac{k \cdot \frac{1}{x^2}}{\left( \frac{I_m}{x \cdot I_r} \right)^2 - \frac{1}{x^2}}
\]

(Equation 136)

In order to achieve such protection functionality with one CVGAPC function the following must be done:

1. Connect three-phase generator currents to one CVGAPC instance (for example, GF01)
2. Set parameter CurrentInput to value PosSeq
3. Set base current value to the rated generator current in primary amperes
4. Enable one overcurrent step (for example OC1)
5. Select parameter CurveType_OC1 to value Programmable

\[
t_{\text{op}} = k \cdot \left( \frac{A}{M^2 - C} + B \right)
\]

(Equation 137)

where:
- \( t_{\text{op}} \) is the operating time in seconds of the Inverse Time Overcurrent TOC/IDMT algorithm
- \( k \) is time multiplier (parameter setting)
- \( M \) is ratio between measured current magnitude and set pickup current level
- \( A, B, C \) and \( P \) are user settable coefficients which determine the curve used for Inverse Time Overcurrent TOC/IDMT calculation

When the equation 136 is compared with the equation 137 for the inverse time characteristic of the OC1 step in it is obvious that if the following rules are followed:

1. set \( k \) equal to the IEC or ANSI standard generator capability value
2. set parameter \( A_{\text{OC1}} \) equal to the value \( 1/x^2 \)
3. set parameter \( C_{\text{OC1}} \) equal to the value \( 1/x^2 \)
4. set parameters \( B_{\text{OC1}} = 0.0 \) and \( P_{\text{OC1}}=2.0 \)
5. set \( \text{StartCurr}_{\text{OC1}} \) equal to the value \( x \)

then the OC1 step of the CVGAPC function can be used for generator negative sequence inverse overcurrent protection.
1. select positive sequence current as measuring quantity for this CVGAPC function
2. make sure that the base current value for CVGAPC function is equal to the generator rated current
3. set \( k = 37.5 \) for the IEC standard or \( k = 41.4 \) for the ANSI standard
4. set \( A_{OC1} = \frac{1}{1.162} = 0.7432 \)
5. set \( C_{OC1} = \frac{1}{1.162} = 0.7432 \)
6. set \( B_{OC1} = 0.0 \) and \( P_{OC1} = 2.0 \)
7. set \( StartCurr_{OC1} = 116\% \)

Proper timing of CVGAPC function made in this way can easily be verified by secondary injection. All other settings can be left at the default values. If required delayed time reset for OC1 step can be set in order to insure proper function operation in case of repetitive overload conditions.

Furthermore the other built-in protection elements can be used for other protection and alarming purposes.

In the similar way rotor overload protection in accordance with ANSI standard can be achieved.

9.1.3.4 Open phase protection for transformer, lines or generators and circuit breaker head flashover protection for generators

Example will be given how to use one CVGAPC function to provide open phase protection. This can be achieved by using one CVGAPC function by comparing the unbalance current with a preset level. In order to make such a function more secure it is possible to restrain it by requiring that at the same time the measured unbalance current must be bigger than 97% of the maximum phase current. By doing this it will be insured that function can only pickup if one of the phases is open circuited. Such an arrangement is easy to obtain in CVGAPC function by enabling the current restraint feature. The following shall be done in order to insure proper operation of the function:

1. Connect three-phase currents from the protected object to one CVGAPC instance (for example, GF03)
2. Set CurrentInput to value UnbalancePh
3. Set EnRestrainCurr to On
4. Set RestrCurrInput to MaxPh
5. Set RestrCurrCoeff to value 0.97
6. Set base current value to the rated current of the protected object in primary amperes
7. Enable one overcurrent step (for example, OC1)
8. Select parameter CurveType_OC1 to value IEC Def. Time
9. Set parameter StartCurr_OC1 to value 5%
10. Set parameter tDef_OC1 to desired time delay (for example, 2.0s)

Proper operation of CVGAPC function made in this way can easily be verified by secondary injection. All other settings can be left at the default values. However it shall be noted that set values for restrain current and its coefficient will as well be applicable for OC2 step as soon as it is enabled.

Furthermore the other built-in protection elements can be used for other protection and alarming purposes. For example, in case of generator application by enabling OC2 step with set pickup to 200% and time delay to 0.1s simple but effective protection against circuit breaker head flashover protection is achieved.
9.1.3.5 Voltage restrained overcurrent protection for generator and step-up transformer

Example will be given how to use one CVGAPC function to provide voltage restrained overcurrent protection for a generator. Let us assume that the time coordination study gives the following required settings:

- Inverse Time Over Current TOC/IDMT curve: ANSI very inverse
- Pickup current of 185% of generator rated current at rated generator voltage
- Pickup current 25% of the original pickup current value for generator voltages below 25% of rated voltage

This functionality can be achieved by using one CVGAPC function. The following shall be done in order to ensure proper operation of the function:

1. Connect three-phase generator currents and voltages to one CVGAPC instance (for example, GF05)
2. Set CurrentInput to value MaxPh
3. Set VoltageInput to value MinPh-Ph (it is assumed that minimum phase-to-phase voltage shall be used for restraining. Alternatively, positive sequence voltage can be used for restraining by selecting PosSeq for this setting parameter)
4. Set base current value to the rated generator current primary amperes
5. Set base voltage value to the rated generator phase-to-phase voltage in kV
6. Enable one overcurrent step (for example, OC1)
7. Select CurveType_OC1 to value ANSI Very inv
8. If required set minimum operating time for this curve by using parameter tMin_OC1 (default value 0.05s)
9. Set StartCurr_OC1 to value 185%
10. Set VCntrlMode_OC1 to On
11. Set VDepMode_OC1 to Slope
12. Set VDepFact_OC1 to value 0.25
13. Set UHighLimit_OC1 to value 100%
14. Set ULowLimit_OC1 to value 25%

Proper operation of the CVGAPC function made in this way can easily be verified by secondary injection. All other settings can be left at the default values. Furthermore the other built-in protection elements can be used for other protection and alarming purposes.

9.1.3.6 Loss of excitation protection for a generator

Example will be given how by using positive sequence directional overcurrent protection element within a CVGAPC function, loss of excitation protection for a generator can be achieved. Let us assume that from rated generator data the following values are calculated:

- Maximum generator capability to contentiously absorb reactive power at zero active loading 38% of the generator MVA rating
- Generator pull-out angle 84 degrees

This functionality can be achieved by using one CVGAPC function. The following shall be done in order to insure proper operation of the function:

1. Connect three-phase generator currents and three-phase generator voltages to one CVGAPC instance (for example, GF02)
2. Set parameter CurrentInput to PosSeq
3. Set parameter VoltageInput to PosSeq
4. Set base current value to the rated generator current primary amperes
5. Set base voltage value to the rated generator phase-to-phase voltage in kV
6. Set parameter RCADir to value -84 degree (that is, current lead voltage for this angle)
7. Set parameter *ROADir* to value 90 degree
8. Set parameter *LowVolt_VM* to value 5%
9. Enable one overcurrent step (for example, OC1)
10. Select parameter *CurveType_OC1* to value *IEC Def. Time*
11. Set parameter *StartCurr_OC1* to value 38%
12. Set parameter *tDef_OC1* to value 2.0s (typical setting)
13. Set parameter *DirMode_OC1* to *Forward*
14. Set parameter *DirPrinc_OC1* to *IcosPhi&U*
15. Set parameter *ActLowVolt1_VM* to *Block*

Proper operation of the CVGAPC function made in this way can easily be verified by secondary injection. All other settings can be left at the default values. However it shall be noted that set values for RCA & ROA angles will be applicable for OC2 step if directional feature is enabled for this step as well. Figure 77 shows overall protection characteristic.

Furthermore the other build-in protection elements can be used for other protection and alarming purposes.

*Figure 77: Loss of excitation*
Section 10  Secondary system supervision

10.1  Current circuit supervision CCSSPVC

10.1.1  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>Current circuit supervision</td>
<td>CCSSPVC</td>
<td>-</td>
<td>87</td>
</tr>
</tbody>
</table>

10.1.2  Application

Open or short circuited current transformer cores can cause unwanted operation of many protection functions such as differential, earth-fault current and negative-sequence current functions. When currents from two independent three-phase sets of CTs, or CT cores, measuring the same primary currents are available, reliable current circuit supervision can be arranged by comparing the currents from the two sets. If an error in any CT circuit is detected, the protection functions concerned can be blocked and an alarm given.

In case of large currents, unequal transient saturation of CT cores with different remanence or different saturation factor may result in differences in the secondary currents from the two CT sets. Unwanted blocking of protection functions during the transient stage must then be avoided.

Current circuit supervision CCSSPVC must be sensitive and have short operate time in order to prevent unwanted tripping from fast-acting, sensitive numerical protections in case of faulty CT secondary circuits.

Open CT circuits creates extremely high voltages in the circuits which is extremely dangerous for the personnel. It can also damage the insulation and cause new problems. The application shall, thus, be done with this in consideration, especially if the protection functions are blocked.

10.1.3  Setting guidelines

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

Current circuit supervision CCSSPVC compares the residual current from a three-phase set of current transformer cores with the neutral point current on a separate input taken from another set of cores on the same current transformer.

The minimum operate current, \(I_{MinOp}\), must be set as a minimum to twice the residual current in the supervised CT circuits under normal service conditions and rated primary current.
The parameter $Ip>Block$ is normally set at 150% to block the function during transient conditions.

The FAIL output is connected to the blocking input of the protection function to be blocked at faulty CT secondary circuits.

## 10.2 Fuse failure supervision FUFSPVC

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

### 10.2.2 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 (FUFSPVC).

FUFSPVC 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.
10.2.3 Setting guidelines

10.2.3.1 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.

10.2.3.2 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
UNsINs for selecting negative sequence algorithm or UZsIZs 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 UZsIZs OR UNsINs or OptimZsNs. In
mode UZsIZs OR UNsINs both negative and zero sequence based algorithms are activated and
working in an OR-condition. Also in mode OptimZsNs 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 UZsIZs AND UNsINs 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.

10.2.3.3 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 \ref{eq:3U2}. 

\begin{equation}
3U2 = \frac{3U2}{UBase}\times 100\%\label{eq:3U2}
\end{equation}
$3U_2 := \frac{U_2}{U_{Base}/\sqrt{3}} \cdot 100$

(Equation 138)

where:
- $U_2$ is the maximal negative sequence voltage during normal operation conditions, plus a margin of 10...20%
- $U_{Base}$ is the base voltage for the function according to the setting $GlobalBaseSel$

The setting of the current limit $3I_2<$ is in percentage of parameter $I_{Base}$. The setting of $3I_2<$ must be higher than the normal unbalance current that might exist in the system and can be calculated according to equation 139.

$3I_2 <= \frac{I_2}{I_{Base}} \cdot 100$

(Equation 139)

where:
- $I_2$ is the maximal negative sequence current during normal operating conditions, plus a margin of 10...20%
- $I_{Base}$ is the base current for the function according to the setting $GlobalBaseSel$

### 10.2.3.4 Zero sequence based

The IED setting value $3U_0>$ is given in percentage of the base voltage $U_{Base}$. The setting of $3U_0>$ should not be set lower than the value that is calculated according to equation 140.

$3U_0 >= \frac{3U_{0}}{U_{Base}/\sqrt{3}} \cdot 100$

(Equation 140)

where:
- $3U_{0}$ is the maximal zero sequence voltage during normal operation conditions, plus a margin of 10...20%
- $U_{Base}$ is the base voltage for the function according to the setting $GlobalBaseSel$

The setting of the current limit $3I_0<$ is done in percentage of $I_{Base}$. The setting of $3I_0<$ must be higher than the normal unbalance current that might exist in the system. The setting can be calculated according to equation 141.

$3I_0 = \frac{3I_{0}}{I_{Base}} \cdot 100$

(Equation 141)

where:
- $3I_{0}$ is the maximal zero sequence current during normal operating conditions, plus a margin of 10...20%
- $I_{Base}$ is the base current for the function according to the setting $GlobalBaseSel$
10.2.3.5 Delta U and delta I

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

The setting of $\Delta U >$ should be set high (approximately 60% of $U_{Base}$) and the current threshold $\Delta I <$ low (approximately 10% of $I_{Base}$) 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 $U_{Set\_prim}$ is the primary voltage for operation of $dU/dt$ and $I_{Set\_prim}$ the primary current for operation of $dI/dt$, the setting of $\Delta U >$ and $\Delta I <$ will be given according to equation 142 and equation 143.

\[
\Delta U > = \frac{U_{Set\_prim}}{U_{Base}} \cdot 100
\]

(Equation 142)

\[
\Delta I < = \frac{I_{Set\_prim}}{I_{Base}} \cdot 100
\]

(Equation 143)

The voltage thresholds $U_{Ph >}$ is used to identify low voltage condition in the system. Set $U_{Ph >}$ below the minimum operating voltage that might occur during emergency conditions. A setting of approximately 70% of $U_{Base}$ is recommended.

The current threshold $I_{Ph >}$ shall be set lower than the $I_{MinOp}$ for the distance protection function. A 5...10% lower value is recommended.

10.2.3.6 Dead line detection

The condition for operation of the dead line detection is set by the parameters $I_{DLD <}$ for the current threshold and $U_{DLD <}$ for the voltage threshold.

Set the $I_{DLD <}$ 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 $U_{DLD <}$ with a sufficient margin below the minimum expected operating voltage. A safety margin of at least 15% is recommended.
Section 11  Control

11.1  Synchrocheck, energizing check, and synchronizing SESRSYN

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>Synchrocheck, energizing check, and synchronizing</td>
<td>SESRSYN</td>
<td>sc/vc</td>
<td>25</td>
</tr>
</tbody>
</table>

11.1.2  Application

11.1.2.1  Synchronizing

To allow closing of breakers between asynchronous networks, a synchronizing feature is provided. The breaker close command is issued at the optimum time when conditions across the breaker are satisfied in order to avoid stress on the network and its components.

The systems are defined as asynchronous when the frequency difference between bus and line is larger than an adjustable parameter. If the frequency difference is less than this threshold value the system is defined to have a parallel circuit and the synchrocheck function is used.

The synchronizing function measures the difference between the U-Line and the U-Bus. It operates and enables a closing command to the circuit breaker when the calculated closing angle is equal to the measured phase angle and the following conditions are simultaneously fulfilled:

- The voltages U-Line and U-Bus are higher than the set values for \textit{UHighBusSynch} and \textit{UHighLineSynch} of the respective base voltages \textit{GblBaseSelBus} and \textit{GblBaseSelLine}.
- The difference in the voltage is smaller than the set value of \textit{UDiffSynch}.
- The difference in frequency is less than the set value of \textit{FreqDiffMax} and larger than the set value of \textit{FreqDiffMin}. If the frequency is less than \textit{FreqDiffMin} the synchrocheck is used and the value of \textit{FreqDiffMin} must thus be identical to the value \textit{FreqDiffMrespFreqDiffA} for synchrocheck function. The bus and line frequencies must also be within a range of ±5 Hz from the rated frequency. When the synchronizing option is included also for autoreclose there is no reason to have different frequency setting for the manual and automatic reclosing and the frequency difference values for synchronism check should be kept low.
- The frequency rate of change is less than set value for both U-Bus and U-Line.
- The difference in the phase angle is smaller than the internally preset value of 15 degrees.
- The closing angle is decided by the calculation of slip frequency and required pre-closing time.
The synchronizing function compensates for the measured slip frequency as well as the circuit breaker closing delay. The phase angle advance is calculated continuously. The calculation of the operation pulse sent in advance is using the measured SlipFrequency and the set \( t\text{Breaker} \) time. To prevent incorrect closing pulses, a maximum closing angle between bus and line is preset internally to a value of 15 degrees. Table 21 shows the maximum settable value for \( t\text{Breaker} \) at the preset maximum closing angle of 15 degrees, at different allowed slip frequencies for synchronizing.

Table 21: Dependencies between \( t\text{Breaker} \) and SlipFrequency with maximum closing angle of 15 degrees

<table>
<thead>
<tr>
<th>( t\text{Breaker} ) [s] (max settable value) with the internally preset closing angle of 15 degrees</th>
<th>SlipFrequency [Hz] (BusFrequency - LineFrequency)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.040</td>
<td>1.000</td>
</tr>
<tr>
<td>0.050</td>
<td>0.800</td>
</tr>
<tr>
<td>0.080</td>
<td>0.500</td>
</tr>
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<td>0.050</td>
</tr>
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<td>1.000</td>
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</table>

The reference voltage can be phase-neutral L1, L2, L3 or phase-phase L1-L2, L2-L3, L3-L1 or positive sequence (Require a three phase voltage, that is UL1, UL2 and UL3). By setting the phases used for SESRSYN, with the settings SelPhaseBus1, SelPhaseBus2, SelPhaseLine2 and SelPhaseLine2, a compensation is made automatically for the voltage amplitude difference and the phase angle difference caused if different setting values are selected for the two sides of the breaker. If needed an additional phase angle adjustment can be done for selected line voltage with the PhaseShift setting.

### 11.1.2.2 Synchrocheck

The main purpose of the synchrocheck function is to provide control over the closing of circuit breakers in power networks in order to prevent closing if conditions for synchronism are not detected. It is also used to prevent the re-connection of two systems, which are divided after islanding and after a three pole reclosing.

**Single pole auto-reclosing does not require any synchrocheck since the system is tied together by two phases.**

SESRSYN function block includes both the synchrocheck function and the energizing function to allow closing when one side of the breaker is dead. SESRSYN function also includes a built in voltage selection scheme which allows adoption to various busbar arrangements.

**Figure 78: Two interconnected power systems**

Figure 78 shows two interconnected power systems. The cloud means that the interconnection can be further away, that is, a weak connection through other stations. The
need for a check of synchronization increases if the meshed system decreases since the risk of
the two networks being out of synchronization at manual or automatic closing is greater.

The synchrocheck function measures the conditions across the circuit breaker and compares
them to set limits. Output is generated only when all measured conditions are within their set
limits simultaneously. The check consists of:

- Live line and live bus.
- Voltage level difference.
- Frequency difference (slip). The bus and line frequency must also be within a range of ±5
  Hz from rated frequency.
- Phase angle difference.

A time delay is available to ensure that the conditions are fulfilled for a minimum period of
time.

In very stable power systems the frequency difference is insignificant or zero for manually
initiated closing or closing by automatic restoration. In steady conditions a bigger phase angle
difference can be allowed as this is sometimes the case in a long and loaded parallel power
line. For this application we accept a synchrocheck with a long operation time and high
sensitivity regarding the frequency difference. The phase angle difference setting can be set
for steady state conditions.

Another example is the operation of a power network that is disturbed by a fault event: after
the fault clearance a highspeed auto-reclosing takes place. This can cause a power swing in
the net and the phase angle difference may begin to oscillate. Generally, the frequency
difference is the time derivative of the phase angle difference and will, typically oscillate
between positive and negative values. When the circuit breaker needs to be closed by auto-
reclosing after fault-clearance some frequency difference should be tolerated, to a greater
extent than in the steady condition mentioned in the case above. But if a big phase angle
difference is allowed at the same time, there is some risk that auto-reclosing will take place
when the phase angle difference is big and increasing. In this case it should be safer to close
when the phase angle difference is smaller.

To fulfill the above requirements the synchrocheck function is provided with duplicate
settings, one for steady (Manual) conditions and one for operation under disturbed conditions
(Auto).

![SynchroCheck Diagram](IEC10000079-2-en.vsd)

**Figure 79: Principle for the synchrocheck function**
11.1.2.3 Energizing check

The main purpose of the energizing check function is to facilitate the controlled re-connection of disconnected lines and buses to energized lines and buses.

The energizing check function measures the bus and line voltages and compares them to both high and low threshold values. The output is given only when the actual measured conditions match the set conditions. Figure 80 shows two substations, where one (1) is energized and the other (2) is not energized. The line between CB A and CB B is energized (DLLB) from substation 1 via the circuit breaker A and energization of station 2 is done by CB B energization check device for that breaker DBLL. (or Both).

![Figure 80: Principle for the energizing check function](IEC10000078-4-en.vsd)

**Figure 80: Principle for the energizing check function**

The energizing operation can operate in the dead line live bus (DLLB) direction, dead bus live line (DBLL) direction, or in both directions over the circuit breaker. Energizing from different directions can be different for automatic reclosing and manual closing of the circuit breaker. For manual closing it is also possible to allow closing when both sides of the breaker are dead, Dead Bus Dead Line (DBDL).

The equipment is considered energized (Live) if the voltage is above the set value for \( U_{HighBusEnerg} \) or \( U_{HighLineEnerg} \) of the base voltages \( G_{blBaseSelBus} \) and \( G_{blBaseSelLine} \), which are defined in the Global Base Value groups; in a similar way, the equipment is considered non-energized (Dead) if the voltage is below the set value for \( U_{LowBusEnerg} \) or \( U_{LowLineEnerg} \) of the Global Base Value groups. A disconnected line can have a considerable potential due to factors such as induction from a line running in parallel, or feeding via extinguishing capacitors in the circuit breakers. This voltage can be as high as 50% or more of the base voltage of the line. Normally, for breakers with single breaking elements (<330 kV) the level is well below 30%.

When the energizing direction corresponds to the settings, the situation has to remain constant for a certain period of time before the close signal is permitted. The purpose of the delayed operate time is to ensure that the dead side remains de-energized and that the condition is not due to temporary interference.

11.1.2.4 Voltage selection

The voltage selection function is used for the connection of appropriate voltages to the synchrocheck, synchronizing and energizing check functions. For example, when the IED is used in a double bus arrangement, the voltage that should be selected depends on the status of the breakers and/or disconnectors. By checking the status of the disconnectors auxiliary
contacts, the right voltages for the synchronizing, synchrocheck and energizing check functions can be selected.

Available voltage selection types are for single circuit breaker with double busbars. Single circuit breaker with a single busbar do not need any voltage selection function. Neither does a single circuit breaker with double busbars using external voltage selection need any internal voltage selection.

The voltages from busbars and lines must be physically connected to the voltage inputs in the IED and connected, using the PCM software, to each of the SESRSYN functions available in the IED.

### 11.1.2.5 External fuse failure

Either external fuse-failure signals or signals from a tripped fuse (or miniature circuit breaker) are connected to HW binary inputs of the IED; these signals are connected to inputs of SESRSYN function in the application configuration tool of PCM600. The internal fuse failure supervision function can also be used if a three phase voltage is present. The signal BLKU, from the internal fuse failure supervision function, is then used and connected to the fuse supervision inputs of the SESRSYN function block. In case of a fuse failure, the SESRSYN energizing function is blocked.

The UB1OK/UB2OK and UB1FF/UB2FF inputs are related to the busbar voltage and the ULN1OK/ULN2OK and ULN1FF/ULN2FF inputs are related to the line voltage.

**External selection of energizing direction**

The energizing can be selected by use of the available logic function blocks. Below is an example where the choice of mode is done from a symbol, created in the Graphical Design Editor (GDE) tool on the local HMI, through selector switch function block, but alternatively there can for example, be a physical selector switch on the front of the panel which is connected to a binary to integer function block (B16I).

If the PSTO input is used, connected to the Local-Remote switch on the local HMI, the choice can also be from the station HMI system, typically ABB Microscada through IEC 61850–8–1 communication.

The connection example for selection of the manual energizing mode is shown in figure 81. Selected names are just examples but note that the symbol on the local HMI can only show the active position of the virtual selector.

![Figure 81: Selection of the energizing direction from a local HMI symbol through a selector switch function block.](image-url)
11.1.3 Application examples

The synchronizing function block can also be used in some switchyard arrangements, but with different parameter settings. Below are some examples of how different arrangements are connected to the IED analogue inputs and to the function block SESRSYN. One function block is used per circuit breaker.

The input used below in example are typical and can be changed by use of configuration and signal matrix tools.

The SESRSYN and connected SMAI function block instances must have the same cycle time in the application configuration.

11.1.3.1 Single circuit breaker with single busbar

Figure 82: Connection of SESRSYN function block in a single busbar arrangement

Figure 82 illustrates connection principles for a single busbar. For the SESRSYN function there is one voltage transformer on each side of the circuit breaker. The voltage transformer circuit connections are straightforward; no special voltage selection is necessary.

The voltage from busbar VT is connected to U3PBB1 and the voltage from the line VT is connected to U3PLN1. The conditions of the VT fuses shall also be connected as shown above. The voltage selection parameter CBConfig is set to No voltage sel.
11.1.3.2 Single circuit breaker with double busbar, external voltage selection

**Figure 83:** Connection of SESRSYN function block in a single breaker, double busbar arrangement with external voltage selection

In this type of arrangement no internal voltage selection is required. The voltage selection is made by external relays typically connected according to figure 83. Suitable voltage and VT fuse failure supervision from the two busbars are selected based on the position of the busbar disconnectors. This means that the connections to the function block will be the same as for the single busbar arrangement. The voltage selection parameter \textit{CBConfig} is set to \textit{No voltage sel}.

11.1.3.3 Single circuit breaker with double busbar, internal voltage selection

**Figure 84:** Connection of the SESRSYN function block in a single breaker, double busbar arrangement with internal voltage selection

When internal voltage selection is needed, the voltage transformer circuit connections are made according to figure 84. The voltage from the busbar 1 VT is connected to U3PBB1 and the voltage from busbar 2 is connected to U3PBB2. The voltage from the line VT is connected to U3PLN1. The positions of the disconnectors and VT fuses shall be connected as shown in figure 84. The voltage selection parameter \textit{CBConfig} is set to \textit{Double bus}.
11.1.4 Setting guidelines

The setting parameters for the Synchronizing, synchrocheck and energizing check function SESRSYN are set via the local HMI (LHMI) or PCM600.

This setting guidelines describes the settings of the SESRSYN function via the LHMI.

Common base IED value for primary voltage (UBase) is set in a Global base value function, GBASVAL, found under Main menu//Configuration/Power system/GlobalBaseValue/GBASVAL_X/UBase. The SESRSYN function has one setting for the bus reference voltage (GblBaseSelBus) and one setting for the line reference voltage (GblBaseSelLine) which independently of each other can be set to select one of the twelve GBASVAL functions used for reference of base values. This means that the reference voltage of bus and line can be set to different values. The settings for the SESRSYN function are found under Main menu/Settings/IED Settings/Control/Synchronizing(25,SC/VC)/SESRSYN(25,SC/VC):X has been divided into four different setting groups: General, Synchronizing, Synchrocheck and Energizingcheck.

**General settings**

*Operation:* The operation mode can be set *On* or *Off*. The setting *Off* disables the whole function.

*GblBaseSelBus* and *GblBaseSelLine*

These configuration settings are used for selecting one of twelve GBASVAL functions, which then is used as base value reference voltage, for bus and line respectively.

*SelPhaseBus1* and *SelPhaseBus2*

Configuration parameters for selecting the measuring phase of the voltage for busbar 1 and 2 respectively, which can be a single-phase (phase-neutral), two-phase (phase-phase) or a positive sequence voltage.

*SelPhaseLine1* and *SelPhaseLine2*

Configuration parameters for selecting the measuring phase of the voltage for line 1 and 2 respectively, which can be a single-phase (phase-neutral), two-phase (phase-phase) or a positive sequence voltage.

*CBConfig*

This configuration setting is used to define type of voltage selection. Type of voltage selection can be selected as:

- no voltage selection, *No voltage sel.*
- single circuit breaker with double bus, *Double bus*
- 1 1/2 circuit breaker arrangement with the breaker connected to busbar 1, *1 1/2 bus CB*
- 1 1/2 circuit breaker arrangement with the breaker connected to busbar 2, *1 1/2 bus alt. CB*
- 1 1/2 circuit breaker arrangement with the breaker connected to line 1 and 2, *Tie CB*

*PhaseShift*

This setting is used to compensate the phase shift between the measured bus voltage and line voltage when:

- a. different phase-neutral voltages are selected (for example UL1 for bus and UL2 for line);
- b. one available voltage is phase-phase and the other one is phase-neutral (for example UL1L2 for bus and UL1 for line).
The set value is added to the measured line phase angle. The bus voltage is reference voltage.

**Synchronizing settings**

*OperationSynch*

The setting *Off* disables the Synchronizing function. With the setting *On*, the function is in the service mode and the output signal depends on the input conditions.

*UHighBusSynch* and *UHighLineSynch*

The voltage level settings shall be chosen in relation to the bus/line network voltage. The threshold voltages *UHighBusSynch* and *UHighLineSynch* have to be set lower than the value where the network is expected to be synchronized. A typical value is 80% of the rated voltage.

*UDiffSynch*

Setting of the voltage difference between the line voltage and the bus voltage. The difference is set depending on the network configuration and expected voltages in the two networks running asynchronously. A normal setting is 0.10-0.15 p.u.

*FreqDiffMin*

The setting *FreqDiffMin* is the minimum frequency difference where the systems are defined to be asynchronous. For frequency differences lower than this value, the systems are considered to be in parallel. A typical value for *FreqDiffMin* is 10 mHz. Generally, the value should be low if both synchronizing and synchrocheck functions are provided, and it is better to let the synchronizing function close, as it will close at exactly the right instance if the networks run with a frequency difference.

To avoid overlapping of the synchronizing function and the synchrocheck function the setting *FreqDiffMin* must be set to a higher value than used setting *FreqDiffM*, respective *FreqDiffA* used for synchrocheck.

*FreqDiffMax*

The setting *FreqDiffMax* is the maximum slip frequency at which synchronizing is accepted. $1/\text{FreqDiffMax}$ shows the time for the vector to move 360 degrees, one turn on the synchronoscope, and is called Beat time. A typical value for *FreqDiffMax* is 200-250 mHz, which gives beat times on 4-5 seconds. Higher values should be avoided as the two networks normally are regulated to nominal frequency independent of each other, so the frequency difference shall be small.

*FreqRateChange*

The maximum allowed rate of change for the frequency.

*tBreaker*

The *tBreaker* shall be set to match the closing time for the circuit breaker and should also include the possible auxiliary relays in the closing circuit. It is important to check that no slow logic components are used in the configuration of the IED as there then can be big variations in closing time due to those components. Typical setting is 80-150 ms depending on the breaker closing time.

*tClosePulse*

The setting for the duration of the breaker close pulse.

*tMaxSynch*
The setting \( t_{\text{MaxSynch}} \) is set to reset the operation of the synchronizing function if the operation does not take place within this time. The setting must allow for the setting of \( \text{FreqDiffMin} \), which will decide how long it will take maximum to reach phase equality. At the setting of 10 mHz, the beat time is 100 seconds and the setting would thus need to be at least \( t_{\text{MinSynch}} \) plus 100 seconds. If the network frequencies are expected to be outside the limits from the start, a margin needs to be added. A typical setting is 600 seconds.

\( t_{\text{MinSynch}} \)

The setting \( t_{\text{MinSynch}} \) is set to limit the minimum time at which the synchronizing closing attempt is given. The synchronizing function will not give a closing command within this time, from when the synchronizing is started, even if a synchronizing condition is fulfilled. A typical setting is 200 ms.

**Synchrocheck settings**

**OperationSC**

The \( \text{OperationSC} \) setting \( \text{Off} \) disables the synchrocheck function and sets the outputs \( \text{AUTOSYOK}, \text{MANSYOK}, \text{TSTAUTSY} \) and \( \text{TSTMANSY} \) to low. With the setting \( \text{On} \), the function is in the service mode and the output signal depends on the input conditions.

**UHighBusSC** and **UHighLineSC**

The voltage level settings must be chosen in relation to the bus or line network voltage. The threshold voltages \( \text{UHighBusSC} \) and \( \text{UHighLineSC} \) have to be set lower than the value at which the breaker is expected to close with the synchronism check. A typical value can be 80% of the base voltages.

**UDiffSC**

The setting for voltage difference between line and bus in p.u. This setting in p.u. is defined as \( \left( \frac{\text{U-Bus}}{\text{GblBaseSelBus}} \right) - \left( \frac{\text{U-Line}}{\text{GblBaseSelLine}} \right) \). A normal setting is 0,10-0,15 p.u.

**FreqDiffM** and **FreqDiffA**

The frequency difference level settings, \( \text{FreqDiffM} \) and \( \text{FreqDiffA} \), shall be chosen depending on the condition in the network. At steady conditions a low frequency difference setting is needed, where the \( \text{FreqDiffM} \) setting is used. For autoreclosing a bigger frequency difference setting is preferable, where the \( \text{FreqDiffA} \) setting is used. A typical value for \( \text{FreqDiffM} \) can be 10 mHz, and a typical value for \( \text{FreqDiffA} \) can be 100-200 mHz.

**PhaseDiffM** and **PhaseDiffA**

The phase angle difference level settings, \( \text{PhaseDiffM} \) and \( \text{PhaseDiffA} \), shall also be chosen depending on conditions in the network. The phase angle setting must be chosen to allow closing under maximum load condition. A typical maximum value in heavy-loaded networks can be 45 degrees, whereas in most networks the maximum occurring angle is below 25 degrees. The \( \text{PhaseDiffM} \) setting is a limitation to \( \text{PhaseDiffA} \) setting. Fluctuations occurring at high speed autoreclosing limit \( \text{PhaseDiffA} \) setting.

**tSCM** and **tSCA**

The purpose of the timer delay settings, \( t_{\text{SCM}} \) and \( t_{\text{SCA}} \), is to ensure that the synchrocheck conditions remains constant and that the situation is not due to a temporary interference. Should the conditions not persist for the specified time, the delay timer is reset and the procedure is restarted when the conditions are fulfilled again. Circuit breaker closing is thus not permitted until the synchrocheck situation has remained constant throughout the set delay setting time. Manual closing is normally under more stable conditions and a longer operation time delay setting is needed, where the \( t_{\text{SCM}} \) setting is used. During auto-reclosing, a shorter operation time delay setting is preferable, where the \( t_{\text{SCA}} \) setting is used. A typical value for \( t_{\text{SCM}} \) can be 1 second and a typical value for \( t_{\text{SCA}} \) can be 0.1 seconds.
Energizing check settings

AutoEnerg and ManEnerg

Two different settings can be used for automatic and manual closing of the circuit breaker. The settings for each of them are:

- **Off**, the energizing function is disabled.
- **DLLB**, Dead Line Live Bus, the line voltage is below set value of \( U_{\text{LowLineEnerg}} \) and the bus voltage is above set value of \( U_{\text{HighBusEnerg}} \).
- **DBLL**, Dead Bus Live Line, the bus voltage is below set value of \( U_{\text{LowBusEnerg}} \) and the line voltage is above set value of \( U_{\text{HighLineEnerg}} \).
- **Both**, energizing can be done in both directions, DLLB or DBLL.

ManEnergDBDL

If the parameter is set to **On**, manual closing is also enabled when both line voltage and bus voltage are below \( U_{\text{LowLineEnerg}} \) and \( U_{\text{LowBusEnerg}} \) respectively, and **ManEnerg** is set to DLLB, DBLL or Both.

\( U_{\text{HighBusEnerg}} \) and \( U_{\text{HighLineEnerg}} \)

The voltage level settings must be chosen in relation to the bus or line network voltage. The threshold voltages \( U_{\text{HighBusEnerg}} \) and \( U_{\text{HighLineEnerg}} \) have to be set lower than the value at which the network is considered to be energized. A typical value can be 80% of the base voltages.

\( U_{\text{LowBusEnerg}} \) and \( U_{\text{LowLineEnerg}} \)

The threshold voltages \( U_{\text{LowBusEnerg}} \) and \( U_{\text{LowLineEnerg}} \), have to be set to a value greater than the value where the network is considered not to be energized. A typical value can be 40% of the base voltages.

A disconnected line can have a considerable potential due to, for instance, induction from a line running in parallel, or by being fed via the extinguishing capacitors in the circuit breakers. This voltage can be as high as 30% or more of the base line voltage.

Because the setting ranges of the threshold voltages \( U_{\text{HighBusEnerg}} \) and \( U_{\text{HighLineEnerg}} \) partly overlap each other, the setting conditions may be such that the setting of the non-energized threshold value is higher than that of the energized threshold value. The parameters must therefore be set carefully to avoid overlapping.

\( U_{\text{MaxEnerg}} \)

This setting is used to block the closing when the voltage on the live side is above the set value of \( U_{\text{MaxEnerg}} \).

\( t_{\text{AutoEnerg}} \) and \( t_{\text{ManEnerg}} \)

The purpose of the timer delay settings, \( t_{\text{AutoEnerg}} \) and \( t_{\text{ManEnerg}} \), is to ensure that the dead side remains de-energized and that the condition is not due to a temporary interference. Should the conditions not persist for the specified time, the delay timer is reset and the procedure is restarted when the conditions are fulfilled again. Circuit breaker closing is thus not permitted until the energizing condition has remained constant throughout the set delay setting time.
11.2 Autorecloser for 1 phase, 2 phase and/or 3 phase operation SMBRREC

11.2.1 Identification

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<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
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<td>SMBRREC</td>
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11.2.2 Application

Automatic reclosing is a well-established method for the restoration of service in a power system after a transient line fault. The majority of line faults are flashover arcs, which are transient by nature. When the power line is switched off by the operation of line protection and line breakers, the arc de-ionizes and recovers its ability to withstand voltage at a somewhat variable rate. Thus, a certain dead time with a de-energized line is necessary. Line service can then be resumed by automatic reclosing of the line breakers. The dead time selected should be long enough to ensure a high probability of arc de-ionization and successful reclosing.

For individual line breakers, auto-reclosing equipment, the auto-reclosing open time is used to determine line “dead time”. When simultaneous tripping and reclosing at the two line ends occurs, auto-reclosing open time is approximately equal to the line “dead time”. If the open time and dead time differ then, the line will be energized until the breakers at both ends have opened.
Figure 85: Single-shot automatic reclosing at a permanent fault

Single-phase tripping and single-phase automatic reclosing is a way of limiting the effect of a single-phase line fault on power system operation. Especially at higher voltage levels, the majority of faults are of single-phase type (around 90%). To maintain system stability in power systems with limited meshing or parallel routing single phase auto reclosing is of particular value. During the single phase dead time the system is still capable of transmitting load on the two healthy phases and the system is still synchronized. It requires that each phase breaker operates individually, which is usually the case for higher transmission voltages.

A somewhat longer dead time may be required for single-phase reclosing compared to high-speed three-phase reclosing. This is due to the influence on the fault arc from the voltage and the current in the non-tripped phases.

To maximize the availability of the power system it is possible to choose single pole tripping and automatic reclosing during single-phase faults and three pole tripping and automatic reclosing during multi-phase faults. Three-phase automatic reclosing can be performed with or without the use of a synchronicity check, and an energizing check, such as dead line or dead busbar check.

During the single-pole open time there is an equivalent "series"-fault in the system resulting in a flow of zero sequence current. It is therefore necessary to coordinate the residual current protections (earth fault protection) with the single pole tripping and the auto-reclosing function. Attention shall also be paid to "pole discordance" that arises when circuit breakers are provided with single pole operating devices. These breakers need pole discordance protection. They must also be coordinated with the single pole auto-recloser and blocked during the dead time when a normal discordance occurs. Alternatively, they should use a trip time longer than the set single phase dead time.

For the individual line breakers and auto-reclosing equipment, the "auto-reclosing open time" expression is used. This is the dead time setting for the Auto-Recloser. During simultaneous tripping and reclosing at the two line ends, auto-reclosing open time is approximately equal to
the line dead time. Otherwise these two times may differ as one line end might have a slower trip than the other end which means that the line will not be dead until both ends have opened.

If the fault is permanent, the line protection will trip again when reclosing is attempted in order to clear the fault.

It is common to use one automatic reclosing function per line circuit-breaker (CB). When one CB per line end is used, then there is one auto-reclosing function per line end. If auto-reclosing functions are included in duplicated line protection, which means two auto-reclosing functions per CB, one should take measures to avoid uncoordinated reclosing commands. In 1 1/2 breaker, double-breaker and ring bus arrangements, two CBs per line end are operated. One auto-reclosing function per CB is recommended. Arranged in such a way, sequential reclosing of the two CBs can be arranged with a priority circuit available in the auto-reclose function. In case of a permanent fault and unsuccessful reclosing of the first CB, reclosing of the second CB is cancelled and thus the stress on the power system is limited. Another advantage with the breaker connected auto-recloser is that checking that the breaker closed before the sequence, breaker prepared for an auto-reclose sequence and so on. is much simpler.

The auto-reclosing function can be selected to perform single-phase and/or three-phase automatic-reclosing from several single-shot to multiple-shot reclosing programs. The three-phase auto-reclosing open time can be set to give either High-Speed Automatic Reclosing (HSAR) or Delayed Automatic-Reclosing (DAR). These expressions, HSAR and DAR, are mostly used for three-phase Reclosing as single phase is always high speed to avoid maintaining the unsymmetrical condition. HSAR usually means a dead time of less than 1 second.

In power transmission systems it is common practise to apply single and/or three phase, single-shot Auto-Reclosing. In Sub-transmission and Distribution systems tripping and auto-reclosing are usually three-phase. The mode of automatic-reclosing varies however. Single-shot and multi-shot are in use. The first shot can have a short delay, HSAR, or a longer delay, DAR. The second and following reclosing shots have a rather long delay. When multiple shots are used the dead time must harmonize with the breaker duty-cycle capacity.

Automatic-reclosing is usually started by the line protection and in particular by instantaneous tripping of such protection. The auto-reclosing function can be inhibited (blocked) when certain protection functions detecting permanent faults, such as shunt reactor, cable or busbar protection are in operation. Back-up protection zones indicating faults outside the own line are also connected to inhibit the Auto-Reclose.

Automatic-reclosing should not be attempted when closing a CB and energizing a line onto a fault (SOTF), except when multiple-shots are used where shots 2 etc. will be started at SOTF. Likewise a CB in a multi-breaker busbar arrangement which was not closed when a fault occurred should not be closed by operation of the Auto-Reclosing function. Auto-Reclosing is often combined with a release condition from synchrocheck and dead line or dead busbar check. In order to limit the stress on turbo-generator sets from Auto-Reclosing onto a permanent fault, one can arrange to combine Auto-Reclosing with a synchrocheck on line terminals close to such power stations and attempt energizing from the side furthest away from the power station and perform the synchrocheck at the local end if the energizing was successful.

Transmission protection systems are usually sub-divided and provided with two redundant protection IEDs. In such systems it is common to provide auto-reclosing in only one of the sub-systems as the requirement is for fault clearance and a failure to reclose because of the auto-recloser being out of service is not considered a major disturbance. If two auto-reclosers are provided on the same breaker, the application must be carefully checked and normally one must be the master and be connected to inhibit the other auto-recloser if it has started. This inhibit can for example be done from Autorecloser for 3-phase operation(SMBRREC) in progress.

When Single and/or three phase auto-reclosing is considered, there are a number of cases where the tripping shall be three phase anyway. For example:
Evolving fault where the fault during the dead-time spreads to another phase. The other two phases must then be tripped and a three phase dead-time and auto-reclose initiated

- Permanent fault
- Fault during three phase dead-time
- Auto-reclose out of service or CB not ready for an auto-reclosing cycle

"Prepare three-phase tripping" is then used to switch the tripping to three-phase. This signal is generated by the auto-recloser and connected to the trip function block and also connected outside the IED through IO when a common auto-recloser is provided for two sub-systems. An alternative signal "Prepare 1 Phase tripping" is also provided and can be used as an alternative when the autorecloser is shared with another subsystem. This provides a fail safe connection so that even a failure in the IED with the auto-recloser will mean that the other sub-system will start a three-phase trip.

A permanent fault will cause the line protection to trip again when it recloses in an attempt to energize the line.

The auto-reclosing function allows a number of parameters to be adjusted.

Examples:

- number of auto-reclosing shots
- auto-reclosing program
- auto-reclosing open times (dead time) for each shot

### 11.2.2.1 Auto-reclosing operation OFF and ON

Operation of the automatic reclosing can be set OFF and ON by a setting parameter and by external control. Parameter Operation= Off, or On sets the function OFF and ON. With the settings Operation = On and ExternalCtrl = On, the control is made by input signal pulses to the inputs ON and OFF, for example, from the control system or from the binary input (and other systems).

When the function is set ON, the output SETON is set, and it become operative if other conditions such as CB closed and CB Ready are also fulfilled, the output READY is activated (high). When the function is ready to accept a reclosing start.

### 11.2.2.2 Start auto-reclosing and conditions for start of a reclosing cycle

The usual way to start a reclosing cycle, or sequence, is to start it at selective tripping by line protection by applying a signal to the input START. Starting signals can be either, General Trip signals or, only the conditions for Differential, Distance protection Zone 1 and Distance protection Aided trip. In some cases also Directional Earth fault function Aided trip can be connected to start an Auto-Reclose attempt. If general trip is used to start the auto-recloser it is important to block it from other functions that should not start a reclosing sequence.

In cases where one wants to differentiate three-phase “auto-reclosing open time”, (“dead time”) for different power system configuration or at tripping by different protection stages, one can also use the input STARTHS (Start High-Speed Reclosing). When initiating STARTHS, the auto-reclosing open time for three-phase shot 1, t1 3PhHS is used and the closing is done without checking the synchrocheck condition.

A number of conditions need to be fulfilled for the start to be accepted and a new auto-reclosing cycle to be started. They are linked to dedicated inputs. The inputs are:
• CBREADY, CB ready for a reclosing cycle, for example, charged operating gear.
• CBPOS to ensure that the CB was closed when the line fault occurred and start was applied.
• No signal at input INHIBIT that is, no blocking or inhibit signal present. After the start has been accepted, it is latched in and an internal signal “Started” is set. It can be interrupted by certain events, like an "Inhibit" signal.

11.2.3 Start auto-reclosing from CB open information

If a user wants to initiate auto-reclosing from the "CB open" position instead of from protection trip signals, the function offers such a possibility. This starting mode is selected with the setting parameter StartByCBOpen=On. It is then necessary to block reclosing for all manual trip operations. Typically CBAuxContType=NormClosed\ is also set and a CB auxiliary contact of type NC (normally closed) is connected to inputs CBPOS and START. When the signal changes from “CB closed” to “CB open” an auto-reclosing start pulse is generated and latched in the function, subject to the usual checks. Then the reclosing sequence continues as usual. One needs to connect signals from manual tripping and other functions, which shall not be reclosed automatically to the input INHIBIT.

11.2.4 Blocking of the autorecloser

Auto-Reclose attempts are expected to take place only for faults on the own line. The Auto-Recloser must be blocked by activating the INHIBIT input for the following conditions:

• Tripping from Delayed Distance protection zones
• Tripping from Back-up protection functions
• Tripping from Breaker failure function
• Intertrip received from remote end Breaker failure function
• Busbar protection tripping

Depending of the starting principle (General Trip or only Instantaneous trip) adopted above the delayed and back-up zones might not be required. Breaker failure trip local and remote must however always be connected.

11.2.5 Control of the auto-reclosing open time for shot 1

Up to four different time settings can be used for the first shot, and one extension time. There are separate settings for single-, two- and three-phase auto-reclosing open time, \( t_{1\text{Ph}} \), \( t_{1\text{2Ph}} \), \( t_{1\text{3Ph}} \). If no particular input signal is applied, and an auto-reclosing program with single-phase reclosing is selected, the auto-reclosing open time \( t_{1\text{Ph}} \) will be used. If one of the inputs TR2P or TR3P is activated in connection with the start, the auto-reclosing open time for two-phase or three-phase reclosing is used. There is also a separate time setting facility for three-phase high-speed auto-reclosing without Synchrocheck, \( t_{1\text{3PhHS}} \), available for use when required. It is activated by the STARTHS input.

An auto-reclosing open time extension delay, \( t_{\text{Extended} t_{1}} \), can be added to the normal shot 1 delay. It is intended to come into use if the communication channel for permissive line protection is lost. In such a case there can be a significant time difference in fault clearance at the two ends of the line. A longer “auto-reclosing open time” can then be useful. This extension time is controlled by setting parameter Extended \( t_{1}=\text{On} \) and the input PLCLOST. If this function is used the autorecloser start must also be allowed from distance protection Zone 2 time delayed trip.
11.2.2.6 Long trip signal

In normal circumstances the trip command resets quickly because of fault clearance. The user can set a maximum trip pulse duration $t_{\text{Trip}}$. If $\text{Extended } t_1=\text{Off}$, a long trip signal interrupts the reclosing sequence in the same way as a signal to input INHIBIT. If $\text{Extended } t_1=\text{On}$ the long trip time inhibit is disabled and $\text{Extend } t_1$ is used instead.

11.2.2.7 Maximum number of reclosing shots

The maximum number of reclosing shots in an auto-reclosing cycle is selected by the setting parameter $\text{NoOfShots}$. The type of reclosing used at the first reclosing shot is set by parameter $\text{ARMode}$. The first alternative is three-phase reclosing. The other alternatives include some single-phase or two-phase reclosing. Usually there is no two-phase tripping arranged, and then there will be no two-phase reclosing.

The decision for single and 3 phase trip is also made in the tripping logic (SMPTTRC) function block where the setting $3\text{Ph}, 1/3\text{Ph} (or \text{1/2/3Ph})$ is selected.

11.2.2.8 $\text{ARMode}=3\text{ph}$, (normal setting for a single 3 phase shot)

3-phase reclosing, one to five shots according to setting $\text{NoOfShots}$. The output Prepare three-phase trip $\text{PREP3P}$ is always set (high). A trip operation is made as a three-phase trip at all types of fault. The reclosing is as a three-phase Reclosing as in mode 1/2/3ph described below. All signals, blockings, inhibits, timers, requirements and so on. are the same as in the example described below.

11.2.2.9 $\text{ARMode}=1/2/3\text{ph}$

1-phase, 2-phase or 3-phase reclosing first shot, followed by 3-phase reclosing shots, if selected. Here, the auto-reclosing function is assumed to be "On" and "Ready". The breaker is closed and the operation gear ready (operating energy stored). Input START (or $\text{STARTHS}$) is received and sealed-in. The output $\text{READY}$ is reset (set to false). Output $\text{ACTIVE}$ is set.

- If inputs TR2P is low and TR3P is low (1-phase trip): The timer for 1-phase reclosing open time is started and the output $\text{1PT1}$ (1-phase reclosing in progress) is activated. It can be used to suppress pole disagreement and earth-fault protection trip during the 1-phase open interval.
- If TR2P is high and TR3P is low (2-phase trip): The timer for 2-phase reclosing open time is started and the output $\text{2PT1}$ (2-phase reclosing in progress) is activated.
- If TR3P is high (3-phase trip): The timer for 3-phase auto-reclosing open time, $t_{1 \text{3Ph}}$ is started and output $\text{3PT1}$ (3-phase auto-reclosing shot 1 in progress) is set.
- If $\text{STARTHS}$ is high (3-phase trip): The timer for 3-phase auto-reclosing open time, $t_{1 \text{3phHS}}$ is started and output $\text{3PT1}$ (3-phase auto-reclosing shot 1 in progress) is set.

While any of the auto-reclosing open time timers are running, the output INPROGR is activated. When the "open time" timer runs out, the respective internal signal is transmitted to the output module for further checks and to issue a closing command to the circuit breaker.

When a CB closing command is issued the output $\text{prepare 3-phase trip}$ is set. When issuing a CB closing command a “reclaim” timer $t_{\text{Reclaim}}$ is started. If no tripping takes place during that time the auto-reclosing function resets to the "Ready" state and the signal $\text{ACTIVE}$ resets. If the first reclosing shot fails, a 3-phase trip will be initiated and 3-phase reclosing can follow, if selected.
11.2.2.10  *ARMode*=1/2ph, 1-phase or 2-phase reclosing in the first shot.

In 1-phase or 2-phase tripping, the operation is as in the above described example, program mode 1/2/3ph. If the first reclosing shot fails, a 3-phase trip will be issued and 3-phase reclosing can follow, if selected. In the event of a 3-phase trip, TR3P high, the auto-reclosing will be blocked and no reclosing takes place.

11.2.2.11  *ARMode*=1ph + 1*2ph, 1-phase or 2-phase reclosing in the first shot

The 1-phase reclosing attempt can be followed by 3-phase reclosing, if selected. A failure of a 2-phase reclosing attempt will block the auto-reclosing. If the first trip is a 3-phase trip the auto-reclosing will be blocked. In the event of a 1-phase trip, (TR2P low and TR3P low), the operation is as in the example described above, program mode 1/2/3ph. If the first reclosing shot fails, a 3-phase trip will be initiated and 3-phase reclosing can follow, if selected. A maximum of four additional shots can be done (according to the NoOfShots parameter). At 2-phase trip (TR2P high and TR3P low), the operation is similar to the above. But, if the first reclosing shot fails, a 3-phase trip will be issued and the auto-reclosing will be blocked. No more shots are attempted! The expression 1*2ph should be understood as “Just one shot at 2-phase reclosing” During 3-phase trip (TR2P low and TR3P high) the auto-reclosing will be blocked and no reclosing takes place.

11.2.2.12  *ARMode*=1/2ph + 1*3ph, 1-phase, 2-phase or 3-phase reclosing in the first shot

At 1-phase or 2-phase trip, the operation is as described above. If the first reclosing shot fails, a 3-phase trip will be issued and 3-phase reclosing will follow, if selected. At 3-phase trip, the operation is similar to the above. But, if the first reclosing shot fails, a 3-phase trip command will be issued and the auto-reclosing will be blocked. No more shots take place! 1*3ph should be understood as “Just one shot at 3-phase reclosing”.

11.2.2.13  *ARMode*=1ph + 1*2/3ph, 1-phase, 2-phase or 3-phase reclosing in the first shot

At 1-phase trip, the operation is as described above. If the first reclosing shot fails, a 3-phase trip will be issued and 3-phase reclosing will follow, if selected. At 2-phase or 3-phase trip, the operation is similar as above. But, if the first reclosing shot fails, a 3-phase trip will be issued and the auto-reclosing will be blocked. No more shots take place! “1*2/3ph” should be understood as “Just one shot at 2-phase or 3-phase reclosing”.

Table 22: Type of reclosing shots at different settings of ARMode or integer inputs to MODEINT

<table>
<thead>
<tr>
<th>MODEINT (integer)</th>
<th>ARMode</th>
<th>Type of fault</th>
<th>1st shot</th>
<th>2nd-5th shot</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3ph</td>
<td>1ph</td>
<td>3ph</td>
<td>3ph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2ph</td>
<td>3ph</td>
<td>3ph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3ph</td>
<td>3ph</td>
<td>3ph</td>
</tr>
<tr>
<td>2</td>
<td>1/2/3ph</td>
<td>1ph</td>
<td>1ph</td>
<td>3ph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2ph</td>
<td>2ph</td>
<td>3ph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3ph</td>
<td>3ph</td>
<td>3ph</td>
</tr>
<tr>
<td>3</td>
<td>1/2ph</td>
<td>1ph</td>
<td>1ph</td>
<td>3ph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2ph</td>
<td>2ph</td>
<td>3ph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3ph</td>
<td>.....</td>
<td>.....</td>
</tr>
</tbody>
</table>

Table continues on next page
<table>
<thead>
<tr>
<th>MODEINT (integer)</th>
<th>ARMode</th>
<th>Type of fault</th>
<th>1st shot</th>
<th>2nd-5th shot</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1ph + 1*2ph</td>
<td>1ph</td>
<td>1ph</td>
<td>3ph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2ph</td>
<td>2ph</td>
<td>.....</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3ph</td>
<td>.....</td>
<td>.....</td>
</tr>
<tr>
<td>5</td>
<td>1/2ph + 1*3ph</td>
<td>1ph</td>
<td>1ph</td>
<td>3ph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2ph</td>
<td>2ph</td>
<td>3ph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3ph</td>
<td>3ph</td>
<td>.....</td>
</tr>
<tr>
<td>6</td>
<td>1ph + 1*2/3ph</td>
<td>1ph</td>
<td>1ph</td>
<td>3ph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2ph</td>
<td>2ph</td>
<td>.....</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3ph</td>
<td>3ph</td>
<td>.....</td>
</tr>
</tbody>
</table>

A start of a new reclosing cycle is blocked during the set “reclaim time” after the selected number of reclosing shots have been made.

11.2.2.14 External selection of auto-reclose mode

The auto-reclose mode can be selected by use of the available logic function blocks. Below is an example where the choice of mode is done from a hardware function key in front of the IED with only 3 phase or 1/3 phase mode, but alternatively there can for example, be a physical selector switch on the front of the panel which is connected to a binary to integer function block (BTIGAPC).

The connection example for selection of the auto-reclose mode is shown in figure 86.

![Figure 86: Selection of the auto-reclose mode from a hardware functional key in front of the IED](IEC14000040-1-en.vsd)

11.2.2.15 Reclosing reclaim timer

The reclaim timer $t_{Reclaim}$ defines the time it takes from issue of the reclosing command, until the reclosing function resets. Should a new trip occur during this time, it is treated as a continuation of the first fault. The reclaim timer is started when the CB closing command is given.

11.2.2.16 Pulsing of the CB closing command and Counter

The CB closing command, CLOSECB is given as a pulse with a duration set by parameter $t_{Pulse}$. For circuit-breakers without an anti-pumping function, close pulse cutting can be used. It is selected by parameter $CutPulse=On$. In case of a new trip pulse (start), the closing command pulse is then cut (interrupted). The minimum closing pulse length is always 50 ms. At the issue of the Reclosing command, the appropriate Reclosing operation counter is incremented. There is a counter for each type of Reclosing and one for the total number of Reclosing commands.
11.2.17 Transient fault

After the Reclosing command the reclaim timer keeps running for the set time. If no tripping occurs within this time, $t_{\text{Reclaim}}$, the Auto-Reclosing will reset. The CB remains closed and the operating gear recharges. The input signals CBPOS and CBREADY will be set.

11.2.18 Permanent fault and reclosing unsuccessful signal

If a new trip occurs, and number of reclosing shots is set to 1, a new input signal START or TRSOTF appears, after the CB closing command, the output UNSUCCL (unsuccessful closing) is set high. The timer for the first shot can no longer be started. Depending on the set number of Reclosing shots further shots may be made or the Reclosing sequence is ended. After reclaim timer time-out the Auto-Reclosing function resets, but the CB remains open. The “CB closed” information through the input CBPOS is missing. Thus, the reclosing function is not ready for a new reclosing cycle.

Normally, the signal UNSUCCL appears when a new trip and start is received after the last reclosing shot has been made and the auto-reclosing function is blocked. The signal resets after reclaim time. The “unsuccessful” signal can also be made to depend on CB position input. The parameter $\text{UnsuccClByCBChek}$ should then be set to $\text{CBChek}$, and a timer $t_{\text{UnsuccCl}}$ should be set too. If the CB does not respond to the closing command and does not close, but remains open, the output UNSUCCL is set high after time $t_{\text{UnsuccCl}}$. The Unsuccessful output can for example, be used in Multi-Breaker arrangement to cancel the auto-reclosing function for the second breaker, if the first breaker closed onto a persistent fault. It can also be used to generate a Lock-out of manual closing until the operator has reset the Lock-out, see separate section.

11.2.19 Lock-out initiation

In many cases there is a requirement that a Lock-out is generated when the auto-reclosing attempt fails. This is done with logic connected to the in- and outputs of the Autoreclose function and connected to Binary IO as required. Many alternative ways of performing the logic exist depending on whether manual closing is interlocked in the IED, whether an external physical Lock-out relay exists and whether the reset is hardwired, or carried out by means of communication. There are also different alternatives regarding what shall generate Lock-out. Examples of questions are:

- Shall back-up time delayed trip give Lock-out (normally yes)
- Shall Lock-out be generated when closing onto a fault (mostly)
- Shall Lock-out be generated when the Autorecloser was OFF at the fault or for example, in Single phase AR mode and the fault was multi-phase (normally not as no closing attempt has been given)
- Shall Lock-out be generated if the Breaker did not have sufficient operating power for an auto-reclosing sequence (normally not as no closing attempt has been given)

In figures 87 and 88 the logic shows how a closing Lock-out logic can be designed with the Lock-out relay as an external relay alternatively with the Lock-out created internally with the manual closing going through the Synchro-check function. An example of Lock-out logic.
11.2.20 Evolving fault

An evolving fault starts as a single-phase fault which leads to single-phase tripping and then the fault spreads to another phase. The second fault is then cleared by three-phase tripping.

The Auto-Reclosing function will first receive a trip and start signal (START) without any three-phase signal (TR3P). The Auto-Reclosing function will start a single-phase reclosing, if programmed to do so. At the evolving fault clearance there will be a new signal START and three-phase trip information, TR3P. The single-phase reclosing sequence will then be stopped, and instead the timer, $t_{13Ph}$, for three-phase reclosing will be started from zero. The sequence will continue as a three-phase reclosing sequence, if it is a selected alternative reclosing mode.

The second fault which can be single phase is tripped three phase because trip module (TR) in the IED has an evolving fault timer which ensures that second fault is always tripped three phase. For other types of relays where the relays do not include this function the output PREP3PH (or the inverted PERMIT1PH) is used to prepare the other sub-system for three phase tripping. This signal will, for evolving fault situations be activated a short time after the first trip has reset and will thus ensure that new trips will be three phase.
11.2.2.21 Automatic continuation of the reclosing sequence

SMBRREC function can be programmed to proceed to the following reclosing shots (if multiple shots are selected) even if start signals are not received from the protection functions, but the breaker is still not closed. This is done by setting parameter AutoCont = On and tAutoContWait to the required delay for the function to proceed without a new start.

11.2.2.22 Thermal overload protection holding the auto-reclosing function back

If the input THOLHOLD (thermal overload protection holding reclosing back) is activated, it will keep the reclosing function on a hold until it is reset. There may thus be a considerable delay between start of Auto-Reclosing and reclosing command to the circuit-breaker. An external logic limiting the time and sending an inhibit to the INHIBIT input can be used. The input can also be used to set the Auto-Reclosing on hold for a longer or shorter period.

11.2.3 Setting guidelines

11.2.3.1 Configuration

Use the PCM600 configuration tool to configure signals.

Autorecloser function parameters are set via the local HMI or Parameter Setting Tool (PST). Parameter Setting Tool is a part of PCM600.

Recommendations for input signals

Please see figure 89 and default factory configuration for examples.

ON and OFF

These inputs can be connected to binary inputs or to a communication interface block for external control.

START

It should be connected to the trip output protection function, which starts the autorecloser for 1/2/3-phase operation (SMBRREC) function. It can also be connected to a binary input for start from an external contact. A logical OR-gate can be used to combine the number of start sources.

If StartByCBOpen is used, the CB Open condition shall also be connected to the input START.

STARTHS, Start High-speed auto-reclosing

It may be used when one wants to use two different dead times in different protection trip operations. This input starts the dead time t1 3PhHS. High-speed reclosing shot 1 started by this input is without a synchronization check.

INHIBIT

To this input shall be connected signals that interrupt a reclosing cycle or prevent a start from being accepted. Such signals can come from protection for a line connected shunt reactor, from transfer trip receive, from back-up protection functions, busbar protection trip or from breaker failure protection. When the CB open position is set to start SMBRREC, then manual opening must also be connected here. The inhibit is often a combination of signals from external IEDs via the IO and internal functions. An OR gate is then used for the combination.
**CBPOS and CBREADY**

These should be connected to binary inputs to pick-up information from the CB. The CBPOS input is interpreted as CB Closed, if parameter \textit{CBAuxContType} is set \textit{NormOpen}, which is the default setting. At three operating gears in the breaker (single pole operated breakers) the connection should be “All poles closed” (series connection of the NO contacts) or “At least one pole open” (parallel connection of NC contacts) if the \textit{CBAuxContType} is set to \textit{NormClosed}. The “CB Ready” is a signal meaning that the CB is ready for a reclosing operation, either Close-Open (CO), or Open-Close-Open (OCO). If the available signal is of type “CB not charged” or “not ready”, an inverter can be inserted in front of the CBREADY input.

**SYNC**

This is connected to the internal synchrocheck function when required. It can also be connected to a binary input for synchronization from an external device. If neither internal nor external synchronism or energizing check is required, it can be connected to a permanently high source, TRUE. The signal is required for three phase shots 1-5 to proceed (Note! Not the HS step).

**PLCLOST**

This is intended for line protection permissive signal channel lost (fail) for example, PLC=Power Line Carrier fail. It can be connected, when required to prolong the AutoReclosing time when communication is not working, that is, one line end might trip with a zone 2 delay. If this is used the autorecloser must also be started from Zone2 time delayed trip.

**TRSOFT**

This is the signal “Trip by Switch Onto Fault”. It is usually connected to the “switch onto fault” output of line protection if multi-shot Auto-Reclose attempts are used. The input will start the shots 2-5.

**THOLHOLD**

Signal “Thermal overload protection holding back Auto-Reclosing”. It can be connected to a thermal overload protection trip signal which resets only when the thermal content has fallen to an acceptable level, for example, 70%. As long as the signal is high, indicating that the line is hot, the Auto-Reclosing is held back. When the signal resets, a reclosing cycle will continue. Please observe that this have a considerable delay. Input can also be used for other purposes if for some reason the Auto-Reclose shot need to be halted.

**TR2P and TR3P**

Signals for two-phase and three-phase trip. They are usually connected to the corresponding output of the TRIP block. They control the choice of dead time and the reclosing cycle according to the selected program. Signal TR2P needs to be connected only if the trip has been selected to give 1/2/3 phase trip and an auto reclosing cycle with two phase reclosing is foreseen.

**BLKON**

Used to block the autorecloser for 3-phase operation (SMBRREC) function for example, when certain special service conditions arise. When used, blocking must be reset with BLOCKOFF.

**BLOCKOFF**

Used to Unblock SMBRREC function when it has gone to Block due to activating input BLKON or by an unsuccessful Auto-Reclose attempt if the setting\textit{BlockByUnsucCl} is set to \textit{On}.

**RESET**

Used to Reset SMBRREC to start condition. Possible Thermal overload Hold will be reset. Positions, setting On-Off. will be started and checked with set times.
Recommendations for output signals
Please see figure 89 and default factory configuration for examples.

SETON
Indicates that Autorecloser for 1/2/3-phase operation (SMBRREC) function is switched on and operative.

BLOCKED
Indicates that SMRREC function is temporarily or permanently blocked.

ACTIVE
Indicates that SMBRREC is active, from start until end of Reclaim time.

INPROGR
Indicates that a sequence is in progress, from start until reclosing command.

UNSUCCCL
Indicates unsuccessful reclosing.

CLOSECB
Connect to a binary output for circuit-breaker closing command.

READY
Indicates that SMBRREC function is ready for a new and complete reclosing sequence. It can be connected to the zone extension if a line protection should extended zone reach before automatic reclosing.

1PT1 and 2PT1
Indicates that single-phase or two-phase automatic reclosing is in progress. It is used to temporarily block an earth-fault and/or pole disagreement function during the single-phase or two-phase open interval.

3PT1, 3PT2, 3PT3, 3PT4 and 3PT5
Indicates that three-phase automatic reclosing shots 1-5 are in progress. The signals can be used as an indication of progress or for own logic.

PREP3P
Prepare three-phase trip is usually connected to the trip block to force a coming trip to be a three-phase one. If the function cannot make a single-phase or two-phase reclosing, the tripping should be three-phase.

PERMIT1P
Permit single-phase trip is the inverse of PREP3P. It can be connected to a binary output relay for connection to external protection or trip relays. In case of a total loss of auxiliary power, the output relay drops and does not allow single-phase trip.

Other outputs
The other outputs can be connected for indication, disturbance recording, as required.
### 11.2.3.2 Auto-recloser parameter settings

#### Operation

The operation of the Autorecloser for 1/2/3-phase operation (SMBRREC) function can be switched On and Off. The setting ExternalCtrl makes it possible to switch it On or Off using an external switch via IO or communication ports.

#### NoOfShots, Number of reclosing shots

In power transmission 1 shot is mostly used. In most cases one reclosing shot is sufficient as the majority of arcing faults will cease after the first reclosing shot. In power systems with many other types of faults caused by other phenomena, for example wind, a greater number of reclose attempts (shots) can be motivated.

#### First shot and reclosing program

There are six different possibilities in the selection of reclosing programs. The type of reclosing used for different kinds of faults depends on the power system configuration and the users practices and preferences. When the circuit-breakers only have three-phase operation, then three-phase reclosing has to be chosen. This is usually the case in subtransmission and distribution lines. Three-phase tripping and reclosing for all types of faults is also widely accepted in completely meshed power systems. In transmission systems with few parallel circuits, single-phase reclosing for single-phase faults is an attractive alternative for maintaining service and system stability.
Auto-reclosing open times, dead times

Single-phase auto-reclosing time: A typical setting is $t_1 \, 1Ph = 800 ms$. Due to the influence of energized phases the arc extinction may not be instantaneous. In long lines with high voltage the use of shunt reactors in the form of a star with a neutral reactor improves the arc extinction.

Three-phase shot 1 delay: For three-phase High-Speed Auto-Reclosing (HSAR) a typical open time is 400ms. Different local phenomena, such as moisture, salt, pollution, can influence the required dead time. Some users apply Delayed Auto-Reclosing (DAR) with delays of 10s or more. The delay of reclosing shot 2 and possible later shots are usually set at 30s or more. A check that the CB duty cycle can manage the selected setting must be done. The setting can in some cases be restricted by national regulations. For multiple shots the setting of shots 2-5 must be longer than the circuit breaker duty cycle time.

$Extended \, t_1$ and $t_{Extended \, t_1}$, Extended auto-reclosing open time for shot 1.

The communication link in a permissive (not strict) line protection scheme, for instance a power line carrier (PLC) link, may not always be available. If lost, it can result in delayed tripping at one end of a line. There is a possibility to extend the auto-reclosing open time in such a case by use of an input to PLCLOST, and the setting parameters. Typical setting in such a case: $Extended \, t_1 = On$ and $t_{Extended \, t_1} = 0.8 \, s$.

$t_{Sync}$, Maximum wait time for synchronization check

The time window should be coordinated with the operate time and other settings of the synchronization check function. Attention should also be paid to the possibility of a power swing when reclosing after a line fault. Too short a time may prevent a potentially successful reclosing.

$t_{Trip}$, Long trip pulse

Usually the trip command and start auto-reclosing signal reset quickly as the fault is cleared. A prolonged trip command may depend on a CB failing to clear the fault. A trip signal present when the CB is reclosed will result in a new trip. Depending on the setting $Extended \, t_1 = Off$ or On a trip/start pulse longer than the set time $t_{Trip}$ will either block the reclosing or extend the auto-reclosing open time. A trip pulse longer than the set time $t_{Trip}$ will inhibit the reclosing. At a setting somewhat longer than the auto-reclosing open time, this facility will not influence the reclosing. A typical setting of $t_{Trip}$ could be close to the auto-reclosing open time.

$t_{Inhibit}$, Inhibit resetting delay

A typical setting is $t_{Inhibit} = 5.0 \, s$ to ensure reliable interruption and temporary blocking of the function. Function will be blocked during this time after the $t_{Inhibit}$ has been activated.

$t_{Reclaim}$, Reclaim time

The Reclaim time sets the time for resetting the function to its original state, after which a line fault and tripping will be treated as an independent new case with a new reclosing cycle. One may consider a nominal CB duty cycle of for instance, O-0.3sec CO- 3 min. – CO. However the 3 minute (180 s) recovery time is usually not critical as fault levels are mostly lower than rated value and the risk of a new fault within a short time is negligible. A typical time may be $t_{Reclaim} = 60$ or $180 \, s$ dependent of the fault level and breaker duty cycle.

$StartByCBOpen$

The normal setting is $Off$. It is used when the function is started by protection trip signals. If set $On$ the start of the autorecloser is controlled by an CB auxiliary contact.
**FollowCB**

The usual setting is *Follow CB = Off*. The setting *On* can be used for delayed reclosing with long delay, to cover the case when a CB is being manually closed during the "auto-reclosing open time" before the auto-reclosing function has issued its CB closing command.

**tCBClosedMin**

A typical setting is 5.0 s. If the CB has not been closed for at least this minimum time, a reclosing start will not be accepted.

**CBAuxContType, CB auxiliary contact type**

It shall be set to correspond to the CB auxiliary contact used. A *NormOpen* contact is recommended in order to generate a positive signal when the CB is in the closed position.

**CBReadyType, Type of CB ready signal connected**

The selection depends on the type of performance available from the CB operating gear. At setting *OCO* (CB ready for an Open – Close – Open cycle), the condition is checked only at the start of the reclosing cycle. The signal will disappear after tripping, but the CB will still be able to perform the C-O sequence. For the selection *CO* (CB ready for a Close – Open cycle) the condition is also checked after the set auto-reclosing dead time. This selection has a value first of all at multi-shot reclosing to ensure that the CB is ready for a C-O sequence at shot 2 and further shots. During single-shot reclosing, the *OCO* selection can be used. A breaker shall according to its duty cycle always have storing energy for a CO operation after the first trip. (IEC 56 duty cycle is O-0.3sec CO-3minCO).

**tPulse, Breaker closing command pulse duration**

The pulse should be long enough to ensure reliable operation of the CB. A typical setting may be \( t_{\text{Pulse}} = 200 \text{ ms} \). A longer pulse setting may facilitate dynamic indication at testing, for example, in “Debug” mode of Application Configuration tool (ACT). In CBs without anti-pumping relays, the setting *CutPulse = On* can be used to avoid repeated closing operation when reclosing onto a fault. A new start will then cut the ongoing pulse.

**BlockByUnsucCl**

Setting of whether an unsuccessful auto-reclose attempt shall set the Auto-Reclose in block. If used the inputs BLOCKOFF must be configured to unblock the function after an unsuccessful Reclosing attempt. Normal setting is *Off*.

**UnsucClByCBCheck, Unsuccessful closing by CB check**

The normal setting is *NoCBCheck*. The “auto-reclosing unsuccessful” event is then decided by a new trip within the reclaim time after the last reclosing shot. If one wants to get the UNSUCC (Unsuccessful closing) signal in the case the CB does not respond to the closing command, CLOSECB, one can set *UnsucClByCBCheck = CB Check* and set \( t_{\text{UnsucCl}} = 1.0 \text{ s} \). (Note: If tUnsucCl=2 are used for the first shot, the CB will not be able to perform a second closing attempt).

**Priority and time \( t_{\text{WaitForMaster}} \)**

In single CB applications, one sets *Priority = None*. At sequential reclosing the function of the first CB, e.g. near the busbar, is set *Priority = High* and for the second CB *Priority = Low*. The maximum waiting time, \( t_{\text{WaitForMaster}} \) of the second CB is set longer than the “auto-reclosing open time” and a margin for synchrocheck at the first CB. Typical setting is \( t_{\text{WaitForMaster}} = 2 \text{ sec} \).
**AutoCont and tAutoContWait**, Automatic continuation to the next shot if the CB is not closed within the set time

The normal setting is AutoCont = Off. The tAutoContWait is the length of time SMBRREC waits to see if the breaker is closed when AutoCont is set to On. Normally, the setting can be tAutoContWait = 2 sec.

### 11.3 Apparatus control APC

#### 11.3.1 Application

The apparatus control is a function 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 90 gives an overview from what places the apparatus control function receive commands. Commands to an apparatus can be initiated from the Control Centre (CC), the station HMI or the local HMI on the IED front.

![Diagram](IEC08000227.vsd)

**Figure 90: 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 reservation function to prevent simultaneous operation
• 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
• Circuit switch SXSWI
• Bay control QCBAY
• Position evaluation POS_EVAL
• Bay reserve QCRSV
• Reservation input RESIN
• Local remote LOCREM
• Local remote control LOCREMCTRL

The signal flow between the function blocks is shown in Figure 91. To realize the reservation function, the function blocks Reservation input (RESIN) and Bay reserve (QCRSV) also are included in the apparatus control function. The application description for all these functions can be found below. The function SCILO in the Figure below is the logical node for interlocking.

Control operation can be performed from the local IED HMI. If the administrator has defined users with the IED Users tool in PCM600, then the local/remote switch is under authority control. If not, the default (factory) user is the SuperUser that can perform control operations from the local IED HMI without LogOn. The default position of the local/remote switch is on remote.
**Figure 91: Signal flow between apparatus control function blocks**

**Accepted originator categories for PSTO**

If the requested command is accepted by the authority, 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 23

**Table 23: 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 24.

Table 24: 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>

11.3.1.1 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
11.3.1.2 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 is not dependent on the type of switching device SXCBR or SXSWI. The switch controller represents the content of the SCSWI logical node (according to IEC 61850) with mandatory functionality.

11.3.1.3 **Switches (SXCBR/SXSWI)**

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 function are done with SXCBR representing a circuit breaker and with SXSWI representing a circuit switch that is, a disconnector or an earthing switch.

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 nodes Circuit breaker (SXCBR) and Circuit switch (SXSWI) with mandatory functionality.

11.3.1.4 **Reservation function (QCRSV and RESIN)**

The purpose of the reservation function is primarily to transfer interlocking information between IEDs in a safe way and to prevent double operation in a bay, switchyard part, or complete substation.

For interlocking evaluation in a substation, the position information from switching devices, such as circuit breakers, disconnectors and earthing switches can be required from the same bay or from several other bays. When information is needed from other bays, it is exchanged over the station bus between the distributed IEDs. The problem that arises, even at a high speed of communication, is a space of time during which the information about the position of the switching devices are uncertain. The interlocking function uses this information for evaluation, which means that also the interlocking conditions are uncertain.

To ensure that the interlocking information is correct at the time of operation, a unique reservation method is available in the IEDs. With this reservation method, the bay that wants the reservation sends a reservation request to other bays and then waits for a reservation granted signal from the other bays. Actual position indications from these bays are then
transferred over the station bus for evaluation in the IED. After the evaluation the operation can be executed with high security.

This functionality is realized over the station bus by means of the function blocks QCRSV and RESIN. The application principle is shown in Figure 93.

The function block QCRSV handles the reservation. It sends out either the reservation request to other bays or the acknowledgement if the bay has received a request from another bay.

The other function block RESIN receives the reservation information from other bays. The number of instances is the same as the number of involved bays (up to 60 instances are available). The received signals are either the request for reservation from another bay or the acknowledgment from each bay respectively, which have received a request from this bay. Also the information of valid transmission over the station bus must be received.

Figure 93: Application principles for reservation over the station bus

The reservation can also be realized with external wiring according to the application example in Figure 94. This solution is realized with external auxiliary relays and extra binary inputs and outputs in each IED, but without use of function blocks QCRSV and RESIN.

Figure 94: Application principles for reservation with external wiring
The solution in Figure 94 can also be realized over the station bus according to the application example in Figure 95. The solutions in Figure 94 and Figure 95 do not have the same high security compared to the solution in Figure 93, but instead have a higher availability, since no acknowledgment is required.

![Figure 95: Application principle for an alternative reservation solution](image)

### 11.3.2 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 Circuit switch (SXSWI) is the process interface to the disconnector or the earthing switch 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 Reservation (QCRSV) deals with the reservation function.
- 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 (SCILO) 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 SCILO.
- 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 96 below.
11.3.3 Setting guidelines

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

11.3.3.1 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.

11.3.3.2 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.
11.3.3.3 Switch (SXCBR/SXSWI)

$tStartMove$ is the supervision time for the apparatus to start moving after a command execution. When the time has expired, the switch function 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 switch function is reset, and a cause-code is given. The indication of the mid-position at SC SWI 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 SC SWI 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) and 500 ms for a disconnector (SXSWI).

$tClosePulse$ 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) and 500 ms for a disconnector (SXSWI).

11.3.3.4 Bay Reserve (QCRSV)

The timer $tCancelRes$ defines the supervision time for canceling the reservation, when this cannot be done by requesting bay due to for example communication failure.

When the parameter $ParamRequestx$ ($x=1-8$) is set to Only own bay res. individually for each apparatus ($x$) in the bay, only the own bay is reserved, that is, the output for reservation request of other bays (RES_BAYS) will not be activated at selection of apparatus $x$.

11.3.3.5 Reservation input (RESIN)

With the FutureUse parameter set to Bay future use the function can handle bays not yet installed in the SA system.

11.4 Logic rotating switch for function selection and LHMI presentation SLGAPC

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 rotating switch for function selection and LHMI presentation</td>
<td>SLGAPC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

11.4.2 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 $t_{Pulse}$.

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

### 11.4.3 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.

### 11.5 Selector mini switch VSGAPC

#### 11.5.1 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>Selector mini switch</td>
<td>VSGAPC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 11.5.2 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.

An example where VSGAPC is configured to switch Autorecloser on–off from a button symbol on the local HMI is shown in figure 97. The I and O buttons on the local HMI are normally used for on–off operations of the circuit breaker.

![Image of selector mini switch](IEC07000112-3-en.vsd)

**Figure 97: 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.

### 11.5.3 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.

### 11.6 Generic communication function for Double Point indication DPGAPC

#### 11.6.1 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>Generic communication function for Double Point indication</td>
<td>DPGAPC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 11.6.2 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 25 for the description of the input-output relationship in terms of the value and the quality attributes.

<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>

### 11.6.3 Setting guidelines

The function does not have any parameters available in the local HMI or PCM600.

### 11.7 Single point generic control 8 signals SPC8GAPC

#### 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>Single point generic control 8 signals</td>
<td>SPC8GAPC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 11.7.2 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 SPGGIO 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.

11.7.3 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):

Latchedx: decides if the command signal for output x is Latched (steady) or Pulsed.

tPulsex: if Latchedx is set to Pulsed, then tPulsex will set the length of the pulse (in seconds).

11.8 AutomationBits, command function for DNP3.0 AUTOBITS

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>AutomationBits, command function for DNP3</td>
<td>AUTOBITS</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

11.8.2 Application

Automation bits, 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.

11.8.3 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.

11.9 Single command, 16 signals SINGLECMD
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>Single command, 16 signals</td>
<td>SINGLECMD</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

11.9.2 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 98 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 98 shows a close operation. An open breaker operation is performed in a similar way but without the synchro-check condition.

![Diagram](en04000206.vsd)

*Figure 98: Application example showing a logic diagram for control of a circuit breaker via configuration logic circuits*

Figure 99 and figure 100 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.
11.9.3 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 12  Scheme communication

12.1  Scheme communication logic for distance or overcurrent protection ZCPSCH

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>Scheme communication logic for distance or overcurrent protection</td>
<td>ZCPSCH</td>
<td>-</td>
<td>85</td>
</tr>
</tbody>
</table>

12.1.2  Application

To achieve fast fault clearing for a fault on the part of the line not covered by the instantaneous zone 1, the stepped distance protection function can be supported with logic, that uses communication channels.

One communication channel in each direction, which can transmit an on/off signal is required. The performance and security of this function is directly related to the transmission channel speed, and security against false or lost signals. For this reason special channels are used for this purpose. When power line carrier is used for communication, these special channels are strongly recommended due to the communication disturbance caused by the primary fault.

Communication speed, or minimum time delay, is always of utmost importance because the purpose for using communication is to improve the tripping speed of the scheme.

To avoid false signals that could cause false tripping, it is necessary to pay attention to the security of the communication channel. At the same time it is important pay attention to the communication channel dependability to ensure that proper signals are communicated during power system faults, the time during which the protection schemes must perform their tasks flawlessly.

The logic supports the following communications schemes: blocking schemes (blocking and delta blocking), permissive schemes (overreaching and underreaching), unblocking scheme and direct intertrip.

A permissive scheme is inherently faster and has better security against false tripping than a blocking scheme. On the other hand, permissive scheme depends on a received CR signal for a fast trip, so its dependability is lower than that of a blocking scheme.

12.1.2.1  Blocking schemes

In blocking scheme a reverse looking zone is used to send a block signal to remote end to block an overreaching zone.

Since the scheme is sending the blocking signal during conditions where the protected line is healthy, it is common to use the line itself as communication media (PLC). The scheme can be used on all line lengths.
The blocking scheme is very dependable because it will operate for faults anywhere on the protected line if the communication channel is out of service. On the other hand, it is less secure than permissive schemes because it will trip for external faults within the reach of the tripping function if the communication channel is out of service.

Inadequate speed or dependability can cause spurious tripping for external faults. Inadequate security can cause delayed tripping for internal faults.

To secure that the send signal will arrive before the zone used in the communication scheme will trip, the trip is released first after the time delay $t_{Coord}$ has elapsed. The setting of $t_{Coord}$ must be set longer than the maximal transmission time of the channel. A security margin of at least 10 ms should be considered.

The timer $t_{SendMin}$ for prolonging the send signal is proposed to set to zero.

$$Z_{revA} \rightarrow CS_A$$

$$TRIP_B = OR_B + t_{Coord} + CR$$

**Figure 101: Principle of blocking scheme**

- OR: Overreaching
- CR: Communication signal received
- CS: Communication signal send
- $Z_{revA}$: Reverse zone

### 12.1.2.2 Delta blocking scheme

In the delta blocking scheme a fault inception detection element using delta based quantities of voltage and current will send a block signal to the remote end to block an overreaching zone.

The delta based start is very fast and if the transmission channel is fast then there is no need for delaying the operation of remote distance element. If the fault is in forward direction, the sending is inhibited by a forward directed distance (or directional current or directional earth fault) element.

Since the scheme is sending the blocking signal during conditions where the protected line is healthy, it is common to use the line itself as communication media (PLC). The scheme can be used on all line lengths.

The blocking scheme is very dependable because it will operate for faults anywhere on the protected line if the communication channel is out of service. Conversely, it is less secure than permissive schemes because it will trip for external faults within the reach of the tripping function if the communication channel is out of service.
Inadequate speed or dependability can cause spurious tripping for external faults. Inadequate security can cause delayed tripping for internal faults.

Since the blocking signal is initiated by the delta based detection which is very fast the time delay \( t_{Coord} \) can be set to zero seconds, except in cases where the transmission channel is slow.

The timer \( t_{SendMin} \) for prolonging the send signal is proposed to set to zero.

\[
\text{deltaA} \rightarrow \text{CS} \quad \text{TRIP}_B = \text{OR}_B + t_{Coord} + \overline{\text{CR}}
\]

**Figure 102: Principle of delta blocking scheme**

- OR: Overreaching
- CR: Communication signal received
- CS: Communication signal send
- deltaA: Delta based fault inception detection on A side that gets inhibited for forward faults

### 12.1.2.3 Permissive schemes

In permissive scheme permission to trip is sent from local end to remote end(s), that is protection at local end have detected a fault on the protected object. The received signal(s) is combined with an overreaching zone and gives an instantaneous trip if the received signal is present during the time the chosen zone is detected a fault in forward direction.

Either end may send a permissive (or command) signal to trip to the other end(s), and the teleprotection equipment need to be able to receive while transmitting.

A general requirement on permissive schemes is that it shall be fast and secure.

Depending on if the sending signal(s) is issued by underreaching or overreaching zone, it is divided into Permissive underreach or Permissive overreach scheme.

#### Permissive underreaching scheme

Permissive underreaching scheme is not suitable to use on short line length due to difficulties for distance protection measurement in general to distinguish between internal and external faults in those applications.

The underreaching zones at local and remote end(s) must overlap in reach to prevent a gap between the protection zones where faults would not be detected. If the underreaching zone do not meet required sensitivity due to for instance fault infeed from remote end blocking or permissive overreaching scheme should be considered.

The received signal (CR) must be received when the overreaching zone is still activated to achieve an instantaneous trip. In some cases, due to the fault current distribution, the overreaching zone can operate only after the fault has been cleared at the terminal nearest to
the fault. There is a certain risk that in case of a trip from an independent tripping zone, the zone issuing the send signal (CS) resets before the overreaching zone has operated at the remote terminal. To assure a sufficient duration of the received signal (CR), the send signal (CS), can be prolonged by a \textit{tSendMin} reset timer. The recommended setting of \textit{tSendMin} is 100 ms.

Since the received communication signal is combined with the output from an overreaching zone, there is less concern about false signal causing an incorrect trip. Therefore set the timer \textit{tCoord} to zero.

Failure of the communication channel does not affect the selectivity, but delays tripping at one end(s) for certain fault locations.

\textbf{Figure 103: Principle of Permissive underreaching scheme}

\begin{itemize}
  \item UR: Underreaching
  \item OR: Overreaching
  \item CR: Communication signal received
  \item CS: Communication signal send
\end{itemize}

\textbf{Permissive overreaching scheme}

In permissive overreaching scheme there is an overreaching zone that issues the send signal. At remote end the received signal together with activating of an overreaching zone gives instantaneous trip of the protected object. The overreaching zone used in the teleprotection scheme must be activated at the same time as the received signal is present. The scheme can be used for all line lengths.

In permissive overreaching schemes, the communication channel plays an essential role to obtain fast tripping at both ends. Failure of the communication channel may affect the selectivity and delay tripping at one end at least, for faults anywhere along the protected circuit.

Teleprotection operating in permissive overreaching scheme must beside the general requirement of fast and secure operation also consider requirement on dependability. Inadequate security can cause unwanted tripping for external faults. Inadequate speed or dependability can cause delayed tripping for internal faults or even unwanted operations.

This scheme may use virtually any communication media that is not adversely affected by electrical interference from fault generated noise or by electrical phenomena, such as lightning, that cause faults. Communication media that uses metallic path are particularly subjected to this type of interference, therefore, they must be properly shielded or otherwise designed to provide an adequate communication signal during power system faults.
At the permissive overreaching scheme, the send signal (CS) might be issued in parallel both from an overreaching zone and an underreaching, independent tripping zone. The CS signal from the overreaching zone must not be prolonged while the CS signal from zone 1 can be prolonged.

To secure correct operations of current reversal logic in case of parallel lines, when applied, the send signal CS shall not be prolonged. So set the \( t_{SendMin} \) to zero in this case.

There is no need to delay the trip at receipt of the signal, so set the timer \( t_{Coord} \) to zero.

![Figure 104: Principle of Permissive overreaching scheme](IEC09000014-1-en.vsd)

**Unblocking scheme**

Metallic communication paths adversely affected by fault generated noise may not be suitable for conventional permissive schemes that rely on signal transmitted during a protected line fault. With power line carrier, for example, the communication signal may be attenuated by the fault, especially when the fault is close to the line end, thereby disabling the communication channel.

To overcome the lower dependability in permissive schemes, an unblocking function can be used. Use this function at older, less reliable, power-line carrier (PLC) communication, where the signal has to be sent through the primary fault. The unblocking function uses a guard signal CRG, which must always be present, even when no CR signal is received. The absence of the CRG signal during the security time is used as a CR signal. This also enables a permissive scheme to operate when the line fault blocks the signal transmission. Set the \( t_{Security} \) to 35 ms.

**12.1.2.4 Intertrip scheme**

In some power system applications, there is a need to trip the remote end breaker immediately from local protections. This applies, for instance, when transformers or reactors are connected to the system without circuit-breakers or for remote tripping following operation of breaker failure protection.

In intertrip scheme, the send signal is initiated by an underreaching zone or from an external protection (transformer or reactor protection). At remote end, the received signals initiate a trip without any further protection criteria. To limit the risk for unwanted trip due to spurious
sending of signals, the timer $t_{Coord}$ should be set to 10-30 ms dependant on type of communication channel.

The general requirement for teleprotection equipment operating in intertripping applications is that it should be very secure and very dependable, since both inadequate security and dependability may cause unwanted operation. In some applications the equipment shall be able to receive while transmitting, and commands may be transmitted over longer time period than for other teleprotection systems.

12.1.3 Setting guidelines

The parameters for the scheme communication logic function are set via the local HMI or PCM600.

Configure the zones used for the CS send and for scheme communication tripping by using the ACT configuration tool.

The recommended settings of $t_{Coord}$ timer are based on maximal recommended transmission time for analogue channels according to IEC 60834-1. It is recommended to coordinate the proposed settings with actual performance for the teleprotection equipment to get optimized settings.

12.1.3.1 Blocking scheme

Set Operation = On
Set SchemeType = Blocking
Set $t_{Coord}$ = 25 ms (10 ms + maximal transmission time)
Set $t_{SendMin}$ = 0 s
Set Unblock = Off
  (Set to NoRestart if Unblocking scheme with no alarm for loss of guard is to be used.
  Set to Restart if Unblocking scheme with alarm for loss of guard is to be used)
Set $t_{Security}$ = 0.035 s

12.1.3.2 Delta blocking scheme

Set Operation = On
Set SchemeType = DeltaBlocking
Set $t_{Coord}$ = 0 s
Set $t_{SendMin}$ = 0 s
Set Unblock = Off
  (Set to NoRestart if Unblocking scheme with no alarm for loss of guard is to be used.
  Set to Restart if Unblocking scheme with alarm for loss of guard is to be used)
Set $t_{Security}$ = 0.035 s
Set DeltaI = 10 %IB
Set DeltaU = 5 %UB
Set Delta3I0 = 10 %IB
Set Delta3U0 = 5 %UB
12.1.3.3 Permissive underreaching scheme

Set Operation = On
Set SchemeType = Permissive UR
Set tCoord = 0 ms
Set tSendMin = 0.1 s
Set Unblock = Off
Set tSecurity = 0.035 s

12.1.3.4 Permissive overreaching scheme

Set Operation = On
Set Scheme type = Permissive OR
Set tCoord = 0 ms
Set tSendMin = 0.1 s (0 s in parallel line applications)
Set Unblock = Off
Set tSecurity = 0.035 s

12.1.3.5 Unblocking scheme

Set Unblock = Restart
(Loss of guard signal will give both trip and alarm
Choose NoRestart if only trip is required)
Set tSecurity = 0.035 s

12.1.3.6 Intertrip scheme

Set Operation = On
Set SchemeType = Intertrip
Set tCoord = 50 ms (10 ms + maximal transmission time)
Set tSendMin = 0.1 s (0 s in parallel line applications)
Set Unblock = Off
Set tSecurity = 0.015 s

12.2 Current reversal and Weak-end infeed logic for distance protection 3-phase ZCRWPSCH

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>Current reversal and weak-end infeed logic for distance protection 3-phase</td>
<td>ZCRWPSCH</td>
<td>-</td>
<td>85</td>
</tr>
</tbody>
</table>
12.2.2 Application

12.2.2.1 Current reversal logic

If parallel lines are connected to common buses at both terminals, overreaching permissive communication schemes can trip unselectable due to current reversal. The unwanted tripping affects the healthy line when a fault is cleared on the parallel line. This lack of security results in a total loss of interconnection between the two buses.

To avoid this kind of disturbances, a fault current reversal logic (transient blocking logic) can be used.

The unwanted operations that might occur can be explained by looking into Figure 105 and Figure 106. Initially the protection A2 at A side will detect a fault in forward direction and send a communication signal to the protection B2 at remote end, which is measuring a fault in reverse direction.

![Figure 105: Current distribution for a fault close to B side when all breakers are closed](IEC9900043-2.vsd)

![Figure 106: Current distribution for a fault close to B side when breaker B1 has opened](IEC9900044-2.vsd)

12.2.2.2 Weak-end infeed logic

Permissive communication schemes can basically operate only when the protection in the remote IED can detect the fault. The detection requires a sufficient minimum fault current, normally >20% of I_r. The fault current can be too low due to an open breaker or low short-circuit power of the source. To overcome these conditions, weak-end infeed (WEI) echo logic is used. The fault current can also be initially too low due to the fault current distribution. Here, the fault current increases when the breaker opens at the strong terminal, and a sequential
tripping is achieved. This requires a detection of the fault by an independent tripping zone 1. To avoid sequential tripping as described, and when zone 1 is not available, weak-end infeed tripping logic is used. The weak end infeed function only works together with permissive overreach communication schemes as the carrier send signal must cover the hole line length.

The WEI function sends back (echoes) the received signal under the condition that no fault has been detected on the weak-end by different fault detection elements (distance protection in forward and reverse direction).

The WEI function can be extended to trip also the breaker in the weak side. The trip is achieved when one or more phase voltages are low during an echo function.

In case of single-pole tripping, the phase voltages are used as phase selectors together with the received signal CRLn.

Together with the blocking teleprotection scheme some limitations apply:

- Only the trip part of the function can be used together with the blocking scheme. It is not possible to use the echo function to send the echo signal to the remote line IED. The echo signal would block the operation of the distance protection at the remote line end and in this way prevents the correct operation of a complete protection scheme.
- A separate direct intertrip channel must be arranged from remote end when a trip or accelerated trip is given there. The intertrip receive signal is connect to input CRL.
- The WEI function shall be set to \textit{WEI=Echo&Trip}. The WEI function block will then give phase selection and trip the local breaker.

Avoid using WEI function at both line ends. It shall only be activated at the weak-end.

### 12.2.3 Setting guidelines

The parameters for the current reversal logic and the weak-end infeed logic (WEI) function are set via the local HMI or PCM600.

Common base IED values for primary current \((i\text{Base})\), primary voltage \((U\text{Base})\) and primary power \((S\text{Base})\) are set in a Global base values for settings function \texttt{GBASVAL}.

\texttt{GlobalBaseSel}: It is used to select a \texttt{GBASVAL} function for reference of base values.

#### 12.2.3.1 Current reversal logic

Set \texttt{CurrRev} to \texttt{On} to activate the function.

Set \texttt{tDelayRev} timer at the maximum reset time for the communication equipment that gives the carrier receive (CRL) signal plus 30 ms. A minimum setting of 40 ms is recommended, typical 60 ms.

A long \texttt{tDelayRev} setting increases security against unwanted tripping, but delay the fault clearing in case of a fault developing from one line that evolves to the other one. The probability of this type of fault is small. Therefore set \texttt{tDelayRev} with a good margin.

Set the pick-up delay \texttt{tPickUpRev} to \(<80\%\) of the breaker operate time, but with a minimum of 20 ms.

#### 12.2.3.2 Weak-end infeed logic

Set \texttt{WEI} to \texttt{Echo}, to activate the weak-end infeed function with only echo function.

Set \texttt{WEI} to \texttt{Echo&Trip} to obtain echo with trip.
Set \( t_{\text{PickUpWEI}} \) to 10 ms, a short delay is recommended to avoid that spurious carrier received signals will activate WEI and cause unwanted carrier send (ECHO) signals.

Set the voltage criterion \( U_{\text{PP}}< \) and \( U_{\text{PN}}< \) for the weak-end trip to 70\% of the system base voltage \( U_{\text{Base}} \). The setting should be below the minimum operate voltage of the system but above the voltage that occurs for fault on the protected line. The phase-to-phase elements must be verified to not operate for phase to earth faults.

When single phase tripping is required a detailed study of the voltages at phase-to-phase respectively phase-to-earth faults, at different fault locations, is normally required.

### 12.3 Local acceleration logic ZCLCPSCH

#### 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>Local acceleration logic</td>
<td>ZCLCPSCH</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 12.3.2 Application

The local acceleration logic (ZCLCPSCH) is used in those applications where conventional teleprotection scheme is not available (no communication channel), but the user still require fast clearance for faults on the whole line.

This logic enables fast fault clearing during certain conditions, but naturally, it can not fully replace a teleprotection scheme.

The logic can be controlled either by the autorecloser (zone extension) or by the loss-of-load current (loss-of-load acceleration).

The loss-of-load acceleration gives selected overreach zone permission to operate instantaneously after check of the different current criteria. It can not operate for three-phase faults.

#### 12.3.3 Setting guidelines

The parameters for the local acceleration logic functions are set via the local HMI or PCM600.

Set \( \text{ZoneExtension} \) to \( \text{On} \) when the first trip from selected overreaching zone shall be instantaneous and the definitive trip after autoreclosure a normal time-delayed trip.

Set \( \text{LossOfLoad} \) to \( \text{On} \) when the acceleration shall be controlled by loss-of-load in healthy phase(s).

\( \text{LoadCurr} \) must be set below the current that will flow on the healthy phase when one or two of the other phases are faulty and the breaker has opened at remote end (three-phase). Calculate the setting according to equation 144.
\[ LoadCurr = \frac{0.5 \cdot I_{load \min}}{I_{base}} \]

(Equation 144)

where:

\( I_{load \min} \) is the minimum load current on the line during normal operation conditions.

The timer \( t_{LoadOn} \) is used to increase the security of the loss-of-load function for example to avoid unwanted release due to transient inrush current when energizing the line power transformer. The loss-of-load function will be released after the timer \( t_{LoadOn} \) has elapsed at the same time as the load current in all three phases are above the setting \( LoadCurr \). In normal acceleration applications there is no need for delaying the release, so set the \( t_{LoadOn} \) to zero.

The drop-out timer \( t_{LoadOff} \) is used to determine the window for the current release conditions for Loss-of-load. The timer is by default set to 300ms, which is judged to be enough to secure the current release.

The setting of the minimum current detector, \( MinCurr \), should be set higher than the unsymmetrical current that might flow on the non faulty line, when the breaker at remote end has opened (three-phase). At the same time it should be set below the minimum load current transfer during normal operations that the line can be subjected to. By default, \( MinCurr \) is set to 5% of \( I_{base} \).

The pick-up timer \( t_{LowCurr} \) determine the window needed for pick-up of the minimum current value used to release the function. The timer is by default set to 200 ms, which is judged to be enough to avoid unwanted release of the function (avoid unwanted trip).
Section 13 Logic

13.1 Tripping logic SMPPTRC

13.1.1 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>
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<tbody>
<tr>
<td>Tripping logic</td>
<td>SMPPTRC</td>
<td>I-&gt;O</td>
<td>94</td>
</tr>
</tbody>
</table>

13.1.2 Application

All trip signals from the different protection functions shall be routed through the trip logic. In its simplest alternative the logic will only link the TRIP signal and make sure that it 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). The logic also issues a three-phase tripping command when phase selection within the operating protection functions is not possible, or when external conditions request three-phase tripping.
- Two-phase tripping for two-phase faults.

The three-phase trip for all faults offers a simple solution and is often sufficient in well meshed transmission systems and in sub-transmission systems. Since most faults, especially at the highest voltage levels, are single phase-to-earth faults, single-phase tripping can be of great value. If only the faulty phase is tripped, power can still be transferred on the line during the dead time that arises before reclosing. Single-phase tripping during single-phase faults must be combined with single pole reclosing.

One SMPPTRC function block should be used for each breaker, if the line is connected to the substation via more than one breaker. Assume that single-phase tripping and autoreclosing is used on the line. Both breakers are then normally set up for 1/3-phase tripping and 1/3-phase autoreclosing. As an alternative, 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 can block the closing.
The two instances of the SMPPTRC function are identical except for the name of the function block (SMPPTRC1 and SMPPTRC2). References will therefore only be made to SMPPTRC1 in the following description, but they also apply to SMPPTRC2.

13.1.2.1 Three-phase tripping

A simple application with three-phase tripping from the logic block utilizes part of the function block. Connect the inputs from the protection function blocks to the input TRIN. If necessary (normally the case) use a logic OR block to combine the different function outputs to this input. Connect the output TRIP to the digital Output/s 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 = 3Ph and set the required length of the trip pulse to for example, tTripMin = 150ms.

For special applications such as Lock-out refer to the separate section below. The typical connection is shown below in figure 107. Signals that are not used are dimmed.

![Diagram of SMPPTRC function block](en05000544.vsd)

**Figure 107:** Tripping logic SMPPTRC is used for a simple three-phase tripping application

13.1.2.2 Single- and/or three-phase tripping

The single-/three-phase tripping will give single-phase tripping for single-phase faults and three-phase tripping for multi-phase fault. The operating mode is always used together with a single-phase autoreclosing scheme.

The single-phase tripping can include different options and the use of the different inputs in the function block.

The inputs 1PTRZ and 1PTREF are used for single-phase tripping for distance protection and directional earth fault protection as required.

The inputs are combined with the phase selection logic and the start signals from the 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 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 is normally connected to the respective output on the Synchrocheck, energizing check, and synchronizing function SESRSYN but can also be connected to other signals, for example an external logic signal. If two breakers are involved, one TR block instance and one SESRSYN instance is used for each breaker. This will ensure correct operation and behavior of each breaker.

The output Trip 3 Phase TR3P must be connected to the respective input in SESRSYN to switch SESRSYN to three-phase reclosing. If this signal is not activated SESRSYN will use single-phase reclosing dead time.

Note also that if a second line protection is utilizing the same SESRSYN the three-phase trip signal must be generated, for example by using the three-trip relays contacts in series and connecting them in parallel to the TR3P output from the trip block.

The trip logic also has inputs TRINL1, TRINL2 and TRINL3 where phase-selected trip signals can be connected. Examples can be individual phase inter-trips from remote end or internal/external phase selected trip signals, which are routed through the IED to achieve, for example SESRSYN, Breaker failure, and so on. Other back-up functions are connected to the input TRIN as described above. A typical connection for a single-phase tripping scheme is shown in figure 108.

Figure 108: The trip logic function SMPPTRC used for single-phase tripping application

### 13.1.2.3 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 multi-phase faults. The operating mode is always used together with an autoreclosing scheme with setting Program = 1/2/3Ph or Program = 1/3Ph attempt.
The functionality is very similar to the single-phase scheme described above. However SESRSYN must in addition to the connections for single phase above be informed that the trip is two phase by connecting the trip logic output TR2P to the respective input in SESRSYN.

13.1.2.4 Lock-out

This 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 (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 Lock-out but not initiate 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.

13.1.2.5 Blocking of the function block

The function block can be blocked in two different ways. Its use is dependent on the application. Blocking can be initiated internally by logic, or by the operator using a communication channel. Total blockage of the trip function is done by activating the input BLOCK and can be used to block the output of the trip logic in the event of internal failures. Blockage of lock-out output by activating input BLKLKOUT is used for operator control of the lock-out function.

13.1.3 Setting guidelines

The parameters for Tripping logic SMPPTRC are set via the local HMI or PCM600.

The following trip parameters can be set to regulate tripping.

Operation: Sets the mode of operation. Off switches the tripping off. The normal selection is On.

Program: Sets the required tripping scheme. Normally 3Ph or 1/2Ph are used.

TripLockout: Sets the scheme for lock-out. Off only activates the lock-out output. On activates the lock-out output and latches the output TRIP. The normal selection is Off.

AutoLock: Sets the scheme for lock-out. Off only activates lock-out through the input SETLKOUT. On additionally allows activation through the trip function itself. The normal selection is Off.

tTripMin: Sets the required minimum duration of the trip pulse. It should be set to ensure that the breaker is tripped correctly. Normal setting is 0.150s.

tWaitForPHS: Sets a duration after any of the inputs 1PTRZ or 1PTREF has been activated during which a phase selection must occur to get a single phase trip. If no phase selection has been achieved a three-phase trip will be issued after the time has elapsed.

13.2 Trip matrix logic TMAGAPC
13.2.1 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>

13.2.2 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.

13.2.3 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.*

13.3 Logic for group alarm ALMCALH

13.3.1 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>

13.3.2 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.
13.3.3 Setting guidelines

*Operation: On or Off*

13.4 Logic for group alarm WRNCALH

13.4.1 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>

13.4.1.1 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.

13.4.1.2 Setting guidelines

*Operation: On or Off*

13.5 Logic for group indication INDCALH

13.5.1 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>Logic for group indication</td>
<td>INDCALH</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

13.5.1.1 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.

13.5.1.2 Setting guidelines

*Operation: On or Off*

13.6 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.

**13.6.1 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. Additional logic blocks that, beside the normal logical function, have the capability to propagate timestamp and quality are also available. Those blocks have a designation including the letters QT, like ANDQT, ORQT etc.

**13.6.2 Setting guidelines**

There are no settings for AND gates, OR gates, inverters or XOR gates as well as, for ANDQT gates, ORQT gates or XORQT 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.

**13.6.2.1 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](IEC09000695_2_en.vsd)

*Figure 109: 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.

### 13.7 Fixed signal function block FXDSIGN

#### 13.7.1 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>

#### 13.7.2 Application

The Fixed signals function FXDSIGN generates 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 111: 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 112: REFPDIF function inputs for normal transformer application

13.8 Boolean 16 to Integer conversion B16I

13.8.1 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>

13.8.2 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: 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.

### 13.9 Boolean to integer conversion with logical node representation, 16 bit BTIGAPC

#### 13.9.1 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 16 to integer conversion with logic node representation</td>
<td>BTIGAPC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 13.9.2 Application

Boolean 16 to integer conversion with logic node representation function BTIGAPC is used to transform a set of 16 binary (logical) signals into an integer. BTIGAPC can receive an integer from a station computer – for example, over IEC 61850–8–1. These functions are very useful
when you want to generate logical commands (for selector switches or voltage controllers) by inputting an integer number. BTIGAPC has a logical node mapping in IEC 61850.

The Boolean 16 to integer conversion function (BTIGAPC) 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>
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</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 BTIGAPC function block.

13.10 Integer to Boolean 16 conversion IB16

13.10.1 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>
13.10.2 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>
<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 IB16 function block.

13.11 Integer to Boolean 16 conversion with logic node representation ITBGAPC
13.11.1 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>

13.11.2 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 26.

If the BLOCK input is activated, it freezes the logical outputs at the last value.

Table 26: 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.
13.12 Elapsed time integrator with limit transgression and overflow supervision TEIGAPC

13.12.1 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>Elapsed time integrator</td>
<td>TEIGAPC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

13.12.2 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.

13.12.3 Setting guidelines

The settings \( t_{\text{Alarm}} \) and \( t_{\text{Warning}} \) 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

\[
99 \, 999.99 \text{ seconds} \leq t_{\text{Alarm}} \leq 999 \, 999.9 \text{ seconds} \\
99 \, 999.99 \text{ seconds} \leq t_{\text{Warning}} \leq 999 \, 999.9 \text{ seconds}
\]

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.

13.13 Comparator for integer inputs - INTCOMP

13.13.1 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;=&gt;</td>
<td></td>
</tr>
</tbody>
</table>
13.13.2 **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.

13.13.3 **Setting guidelines**

For proper operation of comparison the set value should be set within the range of ±2 ×10⁹.

Setting procedure on the IED:

*EnaAbs*: This setting is used to select the comparison type between signed and absolute values.

- **Absolute**: The function will do absolute comparison between input and reference value
- **Signed**: The function will do signed comparison between input and reference value

*RefSource*: This setting is used to select the reference source between input and setting for comparison.

- **REF**: The function will take reference value from input REF
- **SetValue**: 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*.

13.13.4 **Setting example**

For absolute comparison between inputs:

Set the *EnaAbs* = 1

Set the *RefSource* = 1

Similarly for signed comparison between inputs

Set the *EnaAbs* = 0

Set the *RefSource* = 1

For absolute comparison between input and setting

Set the *EnaAbs* = 1

Set the *RefSource* = 0

*SetValue* shall be set between -2000000000 to 2000000000

Similarly for signed comparison between input and setting

Set the *EnaAbs* = 0

Set the *RefSource* = 0

*SetValue* shall be set between -2000000000 to 2000000000.
13.14 Comparator for real inputs - REALCOMP

13.14.1 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>Real&lt;&gt;</td>
<td></td>
</tr>
</tbody>
</table>

13.14.2 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.

13.14.3 Setting guidelines

Setting procedure on the IED:

*EnaAbs*: This setting is used to select the comparison type between signed and absolute values.

- *Absolute*: The function will do absolute comparison between input and reference value.
- *Signed*: The function will do signed comparison between input and reference value.

*RefSource*: This setting is used to select the reference source between input and setting for comparison.

- *REF*: The function will take reference value from input REF
- *SetValue*: 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*. If this setting value is less than 0.2% of the set unit then the output INLOW will never pickups.

*RefPrefix*: This setting is used to set the unit of the reference value for comparison when setting *RefSource* is selected as *SetValue*. 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 is high in last execution.

*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 is high in last execution.

13.14.4 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,
\[ EnaAbs = \text{Absolute} \]
\[ RefSource = \text{SetValue} \]
\[ SetValue = 100 \]
\[ RefPrefix = \text{Kilo} \]
\[ EqualBandHigh = 5.0 \% \text{ of reference value} \]
\[ EqualBandLow = 5.0 \% \text{ of reference value} \]

**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,

\[ EnaAbs = \text{Absolute} \]
\[ RefSource = \text{REF} \]
\[ EqualBandHigh = 5.0 \% \text{ of reference value} \]
\[ EqualBandLow = 5.0 \% \text{ of reference value} \].
Section 14 Monitoring

14.1 Measurement

14.1.1 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>Measurements</td>
<td>CVMMXN</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>P. Q. S. I. U. T</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>

14.1.2 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 of 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 respectively 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).

14.1.3 Zero clamping

The measuring functions, CVMMXN, CMMXU, VMMXU and VNMMXU have no interconnections regarding any setting or parameter.

Zero clamps are also entirely handled by the ZeroDb for each and every signal separately for each of the functions. For example, the zero clamping of U12 is handled by UL12ZeroDb in VMMXU, zero clamping of I1 is handled by IL1ZeroDb in CMMXU etc.
Example how CVMMXN is operating:

The following outputs can be observed on the local HMI under Measurements/Monitoring/Servicevalues(P_Q)/CVMMXN(P_Q)

- **S**  Apparent three-phase power
- **P**  Active three-phase power
- **Q**  Reactive three-phase power
- **PF** Power factor
- **ILAG** I lagging U
- **ILEAD** I leading U
- **U**  System mean voltage, calculated according to selected mode
- **I**  System mean current, calculated according to selected mode
- **F**  Frequency

The settings for this function is found under Measurements/Monitoring/Servicevalues(P_Q)/CVMMXN(P_Q)

It can be seen that:

- When system voltage falls below $U_{GenZeroDB}$, the shown value for S, P, Q, PF, ILAG, ILEAD, U and F on the local HMI is forced to zero
- When system current falls below $I_{GenZeroDB}$, the shown value for S, P, Q, PF, ILAG, ILEAD, U and F on the local HMI is forced to zero
- When the value of a single signal falls below the set dead band for that specific signal, the value shown on the local HMI is forced to zero. For example, if apparent three-phase power falls below $S_{ZeroDb}$ the value for S on the local HMI is forced to zero.

### 14.1.4 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-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.

**Xmax**: Maximum value for analog signal X.

**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) or integral deadband (Int deadband). The reporting interval is controlled by the parameter XDbRepInt.

**XDbRepInt**: Reporting deadband setting. Cyclic reporting is the setting value and is reporting interval in seconds. Amplitude deadband is the setting value in % of measuring range. Integral deadband setting is the integral area, that is, measured value in % of measuring range multiplied by the time between two measured values.

**XHiHiLim**: High-high limit. Set in applicable measuring unit.

**XHiLim**: High limit.

**XLowLim**: Low limit.

**XLowLowLim**: Low-low limit.
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, see section "Introduction".

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 113 (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.

Figure 113: Calibration curves

14.1.4.1 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 110kV OHL

Single line diagram for this application is given in figure 114:

![Single line diagram for 110kV OHL application](IEC09000039-2-en.vsd)

**Figure 114: Single line diagram for 110kV OHL application**

In order to monitor, supervise and calibrate the active and reactive power as indicated in figure 114 it is necessary to do the following:

1. Set correctly CT and VT data and phase angle reference channel `PhaseAngleRef` (see section "Setting of the phase reference channel") 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 27.
   - level supervision of active power as shown in table 28.
   - calibration parameters as shown in table 29.

**Table 27: 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>
<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>800</td>
<td>Set rated primary CT current used for OHL</td>
</tr>
</tbody>
</table>
Table 28: 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>PMin</td>
<td>Minimum value</td>
<td>-100</td>
<td>Minimum expected load</td>
</tr>
<tr>
<td>PMax</td>
<td>Minimum value</td>
<td>100</td>
<td>Maximum expected load</td>
</tr>
<tr>
<td>PZeroDb</td>
<td>Zero point clamping in 0.001% of range</td>
<td>3000</td>
<td>Set zero point clamping to 45 MW that is, 3% of 200 MW</td>
</tr>
<tr>
<td>PRepTyp</td>
<td>Reporting type</td>
<td>db</td>
<td>Select amplitude deadband supervision</td>
</tr>
<tr>
<td>PDbRepInt</td>
<td>Cycl: Report interval (s), Db: In % of range, Int Db: In %s</td>
<td>2</td>
<td>Set ±Δdb=30 MW that is, 2% (larger changes than 30 MW will be reported)</td>
</tr>
<tr>
<td>PHPHilim</td>
<td>High High limit (physical value)</td>
<td>60</td>
<td>High alarm limit that is, extreme overload alarm</td>
</tr>
<tr>
<td>PHilim</td>
<td>High limit (physical value)</td>
<td>50</td>
<td>High warning limit that is, overload warning</td>
</tr>
<tr>
<td>PLowLim</td>
<td>Low limit (physical value)</td>
<td>-50</td>
<td>Low warning limit. Not active</td>
</tr>
<tr>
<td>PLowLowLim</td>
<td>Low Low limit (physical value)</td>
<td>-60</td>
<td>Low alarm limit. Not active</td>
</tr>
<tr>
<td>PLimHyst</td>
<td>Hysteresis value in % of range</td>
<td>2</td>
<td>Set ±Δ Hysteresis MW that is, 2%</td>
</tr>
</tbody>
</table>

Table 29: 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>
<tr>
<td>IAngComp5</td>
<td>Angle calibration for current at 5% of Ir</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>IAngComp30</td>
<td>Angle pre-calibration for current at 30% of Ir</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>IAngComp100</td>
<td>Angle pre-calibration for current at 100% of Ir</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 115.
Figure 115: Single line diagram for transformer application

In order to measure the active and reactive power as indicated in figure 115, it is necessary to do the following:

1. Set correctly all CT and VT and phase angle reference channel PhaseAngleRef (see section “Setting of the phase reference channel”) 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 30:
### Table 30: General settings parameters for the Measurement function

<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 alment 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>
</tbody>
</table>

### 14.2 Gas medium supervision SSIMG

#### 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>Gas medium supervision</td>
<td>SSIMG</td>
<td>-</td>
<td>63</td>
</tr>
</tbody>
</table>

#### 14.2.2 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.

#### 14.2.3 Setting guidelines

The parameters for the gas medium supervision SSIMG are set via the local HMI or PCM600.

- **Operation**: Off/On
- **PresAlmLimit**: Alarm setting pressure limit for gas medium supervision
- **PresLOLimit**: Pressure lockout setting limit for gas medium supervision
- **TempAlarmLimit**: Temperature alarm level setting of the gas medium
• TempLOLimit: Temperature lockout level of the gas medium
• tPresAlarm: Time delay for pressure alarm of the gas medium
• tPresLockOut: Time delay for level lockout indication of the gas medium
• tTempAlarm: Time delay for temperature alarm of the gas medium
• tTempLockOut: Time delay for temperature lockout of the gas medium
• tResetPresAlm: Reset time delay for level alarm of the gas medium
• tResetPresLO: Reset time delay for level lockout of the gas medium
• tResetTempAlm: Reset time delay for temperature lockout of the gas medium
• tResetTempLO: Reset time delay for temperature alarm of the gas medium

14.3 Liquid medium supervision SSIML

14.3.1 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>Liquid medium supervision</td>
<td>SSIML</td>
<td>-</td>
<td>71</td>
</tr>
</tbody>
</table>

14.3.2 Application

Liquid medium supervision (SSIML) is used for monitoring the circuit breaker condition. Proper arc extinction by the compressed oil in the circuit breaker is very important. When the level becomes too low, compared to the required value, the circuit breaker operation is blocked to minimize the risk of internal failures. Binary information based on the oil level in the circuit breaker is used as input signals to the function. In addition to that, the function generates alarms based on received information.

14.3.3 Setting guidelines

The parameters for the Liquid medium supervision SSIML are set via the local HMI or PCM600.

• Operation: Off/On
• LevelAlmLimit: Alarm setting level limit for liquid medium supervision
• LevelLOLimit: Level lockout setting limit for liquid medium supervision
• TempAlarmLimit: Temperature alarm level setting of the liquid medium
• TempLOLimit: Temperature lockout level of the liquid medium
• tLevelAlarm: Time delay for level alarm of the liquid medium
• tLevelLockOut: Time delay for level lockout indication of the liquid medium
• tTempAlarm: Time delay for temperature alarm of the liquid medium
• tTempLockOut: Time delay for temperature lockout of the liquid medium
• tResetLevelAlm: Reset time delay for level alarm of the liquid medium
• tResetLevelLO: Reset time delay for level lockout of the liquid medium
• tResetTempAlm: Reset time delay for temperature lockout of the liquid medium
• tResetTempLO: Reset time delay for temperature alarm of the liquid medium

14.4 Breaker monitoring SSCBR

14.4.1 Identification
### 14.4.2 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 116.
Figure 116: An example for estimating the remaining life of a circuit breaker

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.

### 14.4.3 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.

#### 14.4.3.1 Setting procedure on the IED

The parameters for breaker monitoring (SSCBR) can be set using 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.

### 14.5 Event function EVENT

#### 14.5.1 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>

#### 14.5.2 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 and double indication values are also transferred through the EVENT function.

14.5.3 Setting guidelines

The parameters for the Event (EVENT) function are set via the local HMI or PCM600.

**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

**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.

14.6 Disturbance report DRPRDRE

14.6.1 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>
</tr>
<tr>
<td>Disturbance report</td>
<td>A1RADR - A4RADR</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Disturbance report</td>
<td>B1RBDR - B8RBDR</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
14.6.2 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
- 128 binary signals.

Disturbance report function is a common name for several functions that is, Indications (IND), Event recorder (ER), Event list (EL), Trip value recorder (TVR), Disturbance recorder (DR) and Fault locator (FL).

Disturbance report function is characterized by great flexibility as far as configuration, starting conditions, recording times, and large 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.

14.6.3 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 128 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 is 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 117 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 (BxBRBD). Trip value recorder (TVR) uses analog information from
the analog input function blocks (AxRADR), which is used by Fault locator (FL) after estimation by Trip Value Recorder (TVR). Disturbance report function acquires information from both AxRADR and BxRBDR.

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

**Figure 117: 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.
**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.

### 14.6.3.1 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 (*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 (*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 (*TimeLimit*) is the maximum recording time after trig. The parameter limits the recording time if some triggering condition (fault-time) is very long or permanently set (does not influence the Trip value recorder (TVR) function).

Post retrigger (*PostRetrig*) can be set to *On* or *Off*. Makes it possible to choose performance of Disturbance report function if a new trig signal appears in the post-fault window.
PostRetrig = Off

The function is insensitive for new trig signals during post fault time.

PostRetrig = On

The function completes current report and starts a new complete report that is, the latter will include:

• new pre-fault- and fault-time (which will overlap previous report)
• events and indications might be saved in the previous report too, due to overlap
• new fault locator and trip value calculations if installed, in operation and started

Operation in test mode
If the IED is in test mode and OpModeTest = Off. Disturbance report function does not save any recordings and no LED information is displayed.

If the IED is in test mode and OpModeTest = On. Disturbance report function works in normal mode and the status is indicated in the saved recording.

14.6.3.2 Binary input signals

Up to 128 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 128 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.

14.6.3.3 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 \((\text{On})\) or not \((\text{Off})\).

**OverTrigLeM, UnderTrigLeM**: Over or under trig level, Trig high/low level relative nominal value for analog input M in percent of nominal value.

### 14.6.3.4 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 \((\text{Show})\), a status change of that particular input, will be fetched and shown in the disturbance summary on local HMI. If not set \((\text{Hide})\), 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 \((\text{On})\) or not \((\text{Off})\).

If *OperationM* = \(\text{Off}\), 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* = \(\text{On}\), waveform (samples) will also be recorded and reported in graph.

**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.

### 14.6.3.5 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 \((\text{PostFaultrecT} \text{ and } \text{TimeLimit})\).

- 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 \((\text{PostRetrig})\)?

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.

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.

14.7 Logical signal status report BINSTATREP

14.7.1 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>

14.7.2 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.

![Figure 118: BINSTATREP logical diagram](IEC09000732-1-en.vsd)

14.7.3 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.
14.8 Fault locator LMBRFLO

14.8.1 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>Fault locator</td>
<td>LMBRFLO</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

14.8.2 Application

The main objective of line protection and monitoring IEDs is fast, selective and reliable operation for faults on a protected line section. Besides this, information on distance to fault is very important for those involved in operation and maintenance. Reliable information on the fault location greatly decreases the downtime of the protected lines and increases the total availability of a power system.

The fault locator is started with the input CALCDIST to which trip signals indicating in-line faults are connected, typically distance protection zone 1 and accelerating zone or the line differential protection. The disturbance report must also be started for the same faults since the function uses pre- and post-fault information from the trip value recorder function (TVR).

Beside this information the function must be informed about faulted phases for correct loop selection (phase selective outputs from differential protection, distance protection, directional OC protection, and so on). The following loops are used for different types of faults:

- for 3 phase faults: loop L1 - L2.
- for 2 phase faults: the loop between the faulted phases.
- for 2 phase-to-earth faults: the loop between the faulted phases.
- for phase-to-earth faults: the phase-to-earth loop.

LMBRFLO function indicates the distance to fault as a percentage of the line length, in kilometers or miles as selected on the local HMI. LineLengthUnit setting is used to select the unit of length either, in kilometer or miles for the distance to fault. The distance to the fault, which is calculated with a high accuracy, is stored together with the recorded disturbances. This information can be read on the local HMI, uploaded to PCM600 and is available on the station bus according to IEC 61850–8–1.

The distance to fault can be recalculated on the local HMI by using the measuring algorithm for different fault loops or for changed system parameters.

14.8.3 Setting guidelines

The parameters for the Fault locator function are set via the local HMI or PCM600.

The Fault locator algorithm uses phase voltages, phase currents and residual current in observed bay (protected line) and residual current from a parallel bay (line, which is mutual coupled to protected line).

The Fault locator has close connection to the Disturbance report function. All external analog inputs (channel 1-30), connected to the Disturbance report function, are available to the Fault locator and the function uses information calculated by the Trip value recorder. After allocation of analog inputs to the Disturbance report function, the user has to point out which analog inputs to be used by the Fault locator. According to the default settings the first four
analog inputs are currents and next three are voltages in the observed bay (no parallel line expected since chosen input is set to zero). Use the Parameter Setting tool within PCM600 for changing analog configuration.

The measured phase voltages can be fine tuned with the parameters $UL1Gain$, $UL2Gain$ and $UL3Gain$ to further increase the accuracy of the fault locator.

The list of parameters explains the meaning of the abbreviations. Figure 119 also presents these system parameters graphically. Note, that all impedance values relate to their primary values and to the total length of the protected line.

\[
Z_0m = Z_{0m} + jX_{0m} \\
R_{1A} + jX_{1A} \\
R_{1L} + jX_{1L} \\
R_{2L} + jX_{2L} \\
R_{0L} + jX_{0L} \\
R_{1B} + jX_{1B}
\]

Figure 119: Simplified network configuration with network data, required for settings of the fault location-measuring function

For a single-circuit line (no parallel line), the figures for mutual zero-sequence impedance ($X_{OM}$, $R_{OM}$) and analog input are set at zero.

Power system specific parameter settings are not general settings but specific setting included in the setting groups, that is, this makes it possible to change conditions for the Fault locator with short notice by changing setting group.

The source impedance is not constant in the network. However, this has a minor influence on the accuracy of the distance-to-fault calculation, because only the phase angle of the distribution factor has an influence on the accuracy. The phase angle of the distribution factor is normally very low and practically constant, because the positive sequence line impedance, which has an angle close to 90°, dominates it. Always set the source impedance resistance to values other than zero. If the actual values are not known, the values that correspond to the source impedance characteristic angle of 85° give satisfactory results.

14.8.3.1 Connection of analog currents

Connection diagram for analog currents included IN from parallel line shown in figure 120.
14.9 Limit counter L4UFCNT

14.9.1 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>Limit counter</td>
<td>L4UFCNT</td>
<td></td>
<td>-</td>
</tr>
</tbody>
</table>

14.9.2 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.

14.9.3 Setting guidelines

The parameters for Limit counter L4UFCNT are set via the local HMI or PCM600.

14.10 Running hour-meter TEILGAPC

14.10.1 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>Running hour-meter</td>
<td>TEILGAPC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

14.10.2 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.

14.10.3 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 15  Metering

15.1  Pulse-counter logic PCFCNT

15.1.1  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>Pulse-counter logic</td>
<td>PCFCNT</td>
<td></td>
<td>-</td>
</tr>
</tbody>
</table>

15.1.2  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.

15.1.3  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.

15.2 Function for energy calculation and demand handling ETPMMTR

15.2.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 608617 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>

15.2.2 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 121.

![Figure 121: Connection of energy calculation and demand handling function ETPMMTR to the measurements function (CVMMXN)](IEC13000184-1-en.vsd)

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.

15.2.3 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 (IBase), (UBase) and (SBase).

- **Operation**: Off/On

- **EnaAcc**: Off/On is used to switch the accumulation of energy on and off.

- **tEnergy**: Time interval when energy is measured.

- **tEnergyOnPls**: 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.

- **tEnergyOffPls**: gives the OFF time between pulses. Typical value can be 100 ms.

- **EAFAccPlsQty** and **EARAccPlsQty**: 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.

- **ERFAccPlsQty** and **ERVAccPlsQty**: 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.
16.1 Communication protocols

Each IED is provided with a communication interface, 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
- LON communication protocol
- SPA or IEC 60870-5-103 communication protocol
- DNP3.0 communication protocol

Several protocols can be combined in the same IED.

16.2 IEC 61850-8-1 communication protocol

16.2.1 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 122 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 122: SA system with IEC 61850–8–1

Figure 123 shows the GOOSE peer-to-peer communication.

Figure 123: Example of a broadcasted GOOSE message
16.2.2 Horizontal communication via GOOSE for interlocking GOOSEINTLKRCV

Table 31: GOOSEINTLKRCV Non group settings (basic)

<table>
<thead>
<tr>
<th>Name</th>
<th>Values (Range)</th>
<th>Unit</th>
<th>Step</th>
<th>Default</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td>Off</td>
<td>-</td>
<td>-</td>
<td>Off</td>
<td>Operation Off/On</td>
</tr>
<tr>
<td></td>
<td>On</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

16.2.3 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.

**GOOSE** has to be set to the Ethernet link where GOOSE traffic shall be send and received.

16.2.4 Generic communication function for Single Point indication SPGAPC, SP16GAPC

16.2.4.1 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. It has one visible input, that should be connected in ACT tool.

16.2.4.2 Setting guidelines

There are no settings available for the user for SPGAPC.

16.2.5 Generic communication function for Measured Value MVGAPC

16.2.5.1 Application

Generic communication function for Measured Value 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.

16.2.5.2 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.

### 16.2.6 IEC 61850-8-1 redundant station bus communication - PRP

#### 16.2.6.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>LHMI and ACT identification</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual ethernet port link status</td>
<td>PRPSTATUS</td>
<td>PRPSTATUS</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>IEC 62439-3 parallel redundancy protocol</td>
<td>PRP</td>
<td>PRP</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 16.2.6.2 Application

Dual ethernet port link status (PRPSTATUS) together with IEC 62439-3 parallel redundancy protocol (PRP) are 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. Together PRPSTATUS and PRP provide redundant communication over station bus running IEC 61850-8-1 protocol. The redundant communication use both port AB and CD on OEM module.

![Figure 124: Redundant station bus](IEC09000758-4-en.vsd)
16.2.6.3 Setting guidelines

Redundant communication (PRP) is configured in the local HMI under Main menu/Configuration/Communication/Ethernet configuration/PRP.

The settings are found in the Parameter Setting tool in PCM600 under IED Configuration/Communication/Ethernet configuration/PRP. By default the settings are read only in the Parameter Settings tool, but can be unlocked by right clicking the parameter and selecting Lock/Unlock Parameter.

Operation: The redundant communication will be activated when this parameter is set to On. After confirmation the IED will restart and the setting alternatives Rear OEM - Port AB and CD will not be further displayed in the local HMI. The ETHLANAB and ETHLANCD in the Parameter Setting Tool are irrelevant when the redundant communication is activated, only PRP IPAdress and IPMask are valid.

<table>
<thead>
<tr>
<th>Group / Parameter Name</th>
<th>IED Value [SGI/Comm]</th>
<th>PC Value [SGI/Comm]</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
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</thead>
<tbody>
<tr>
<td>Ethernet configuration</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>✓ FRONT-1</td>
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<td>✓ LANAB-1</td>
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<td>✓ Mode</td>
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<tr>
<td>✓ IPMask</td>
<td>255.255.255.0</td>
<td>255.255.255.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✓ GATEWAY-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✓ GWAdress</td>
<td>10.1.150.1</td>
<td>10.1.150.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✓ PRP-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✓ Operation</td>
<td>On</td>
<td>On</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✓ PRPMode</td>
<td>PRP-1</td>
<td>PRP-1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✓ IPAdress</td>
<td>136.227.103.131</td>
<td>136.227.103.131</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✓ IPMask</td>
<td>255.255.254.0</td>
<td>255.255.254.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 125: PST screen: PRP Operation is set to On, which affect Rear OEM - Port AB and CD which are both set to PRP
16.3 LON communication protocol

16.3.1 Application

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.

The fibre optic LON bus is implemented using either glass core or plastic core fibre optic cables.

Table 32: Specification of the fibre optic connectors

<table>
<thead>
<tr>
<th></th>
<th>Glass fibre</th>
<th>Plastic fibre</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>

Figure 126: Example of LON communication structure for a station automation system

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.

The HV Control 670 software module and 670 series Object Type files are used with both 650 and 670 series IEDs.

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.

16.3.2 MULTICMDRCV and MULTICMDSND

16.3.2.1 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>

16.3.2.2 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.
16.3.2.3 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.

16.4 SPA communication protocol

16.4.1 Application

SPA communication protocol as an alternative to IEC 60870-5-103. The same communication port as for IEC 60870-5-103 is used.

When communicating with a PC connected to the utility substation LAN, via WAN and the utility office LAN, as shown in figure 127, and using the rear Ethernet port on the optical Ethernet module (OEM), the only hardware required for a station monitoring system is:

- Optical fibres from the IED to the utility substation LAN.
- PC connected to the utility office LAN.

![Diagram of SPA communication structure](image)

*Figure 127: SPA communication structure for a remote monitoring system via a substation LAN, WAN and utility LAN*

The SPA communication is mainly used for the Station Monitoring System. It can include different IEDs with remote communication possibilities. Connection to a computer (PC) can be made directly (if the PC is located in the substation) or by 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.

16.4.2 Setting guidelines

The setting parameters for the SPA communication are set via the local HMI.

SPA, IEC 60870-5-103 and DNP3 uses the same rear communication port. Set the parameter Operation, under Main menu / Configuration / Communication / SLM configuration / Rear optical SPA-IEC-DNP port / Protocol selection to the selected protocol.

When the communication protocols have been selected, the IED is automatically restarted.

The most important settings in the IED for SPA communication are the slave number and baud rate (communication speed). These settings are absolutely essential for all communication contact to the IED.

These settings can only be done on the local HMI for rear channel communication and for front channel communication.

The slave number can be set to any value from 1 to 899, as long as the slave number is unique within the used SPA loop.

The baud rate, which is the communication speed, can be set to between 300 and 38400 baud. Refer to technical data to determine the rated communication speed for the selected communication interfaces. The baud rate should be the same for the whole station, although different baud rates in a loop are possible. If different baud rates in the same fiber optical loop or RS485 network are used, consider this when making the communication setup in the communication master, the PC.

For local fiber optic communication, 19200 or 38400 baud is the normal setting. If telephone communication is used, the communication speed depends on the quality of the connection and on the type of modem used. But remember that the IED does not adapt its speed to the actual communication conditions, because the speed is set on the local HMI.
16.5 IEC 60870-5-103 communication protocol

16.5.1 Application

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.

**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.

**Design**

General

The protocol implementation consists of the following functions:

- Event handling
- Report of analog service values (measurands)
- Fault location
- Command handling

---

*Figure 128: 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.

**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.

**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

Commands
The commands defined in the IEC 60870-5-103 protocol are represented in a dedicated function blocks. These blocks have output signals for all available commands according to the protocol.

• 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
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 B6RBDR. 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.

Settings
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 only 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
     - RS485PROT:1 (off, DNP, IEC103)
   - SLM optical serial port
     - PROTOCOL:1 (off, DNP, IEC103, SPA)

![Figure 129: Settings for IEC 60870-5-103 communication](image)

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.

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 33.

**Table 33**: 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>
</tbody>
</table>

Table continues on next page
<table>
<thead>
<tr>
<th>DRA#-Input</th>
<th>ACC</th>
<th>IEC 60870-5-103 meaning</th>
</tr>
</thead>
<tbody>
<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>
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<td>12</td>
<td>67</td>
<td>Private range</td>
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<td>91</td>
<td>Private range</td>
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<td>92</td>
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<td>93</td>
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<tr>
<td>39</td>
<td>94</td>
<td>Private range</td>
</tr>
<tr>
<td>40</td>
<td>95</td>
<td>Private range</td>
</tr>
</tbody>
</table>

**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 fibre 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.

16.6 DNP3 Communication protocol

16.6.1 Application

For more information on the application and setting guidelines for the DNP3 communication protocol refer to the DNP3 Communication protocol manual.
Section 17  Security

17.1 Authority status ATHSTAT

17.1.1 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.

17.2 Self supervision with internal event list INTERRSIG

17.2.1 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.

17.3 Change lock CHNGLCK

17.3.1 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.

17.4 Denial of service DOS

17.4.1 Application

The denial of service functions (DOSFRNT, DOSLANAB and DOSLANCD) are 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.

DOSFRNT, DOSLANAB and DOSLANCD 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 outputs:

- LINKUP indicates the Ethernet link status
- WARNING indicates that communication (frame rate) is higher than normal
- ALARM indicates that the IED limits communication

### 17.4.2 Setting guidelines

The function does not have any parameters available in the local HMI or PCM600.
Section 18  Basic IED functions

18.1  IED identifiers TERMINALID

18.1.1  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.

18.2  Product information PRODINF

18.2.1  Application

The Product identifiers function contains constant data (i.e. not possible to change) that uniquely identifies the IED:

- ProductVer
- ProductDef
- FirmwareVer
- SerialNo
- OrderingNo
- ProductionDate
- IEDProdType

The settings are visible on the local HMI, under Main menu/Diagnostics/IED status/Product identifiers and under Main menu/Diagnostics/IED Status/IED identifiers. This information is very helpful when interacting with ABB product support (e.g. during repair and maintenance).

18.2.2  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**

    |   | is the Major version of the manufactured product this means, new platform of the product |
    |---|---|
    | 1 | is the Minor version of the manufactured product this means, new functions or new hardware added to the product |
    | 2 | is the Major revision of the manufactured product this means, functions or hardware is either changed or enhanced in the product |

  • **IEDMainFunType**
    • Main function type code according to IEC 60870-5-103. Example: 128 (meaning line protection).

  • **SerialNo**
  • **OrderingNo**
  • **ProductionDate**

### 18.3 Measured value expander block RANGE_XP

#### 18.3.1 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>

#### 18.3.2 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.

#### 18.3.3 Setting guidelines

There are no settable parameters for the measured value expander block function.
18.4 Parameter setting groups

18.4.1 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.

18.4.2 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.

18.5 Rated system frequency PRIMVAL

18.5.1 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>

18.5.2 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.
18.5.3  Setting guidelines

Set the system rated frequency. Refer to section "Signal matrix for analog inputs SMAI" for description on frequency tracking.

18.6  Summation block 3 phase 3PHSUM

18.6.1  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.

18.6.2  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 UBase (base voltage setting (for each instance x)).

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

18.7  Global base values GBASVAL

18.7.1  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>
18.7.2 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.

18.7.3 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 \( SBase = \sqrt{3} \cdot UBase \cdot IBase \).

18.8 Signal matrix for binary inputs SMBI

18.8.1 Application

The Signal matrix for binary inputs function SMBI is used within the Application Configuration tool in direct relation with the Signal Matrix tool. SMBI represents the way binary inputs are brought in for one IED configuration.

18.8.2 Setting guidelines

There are no setting parameters for the Signal matrix for binary inputs SMBI available to the user in Parameter Setting tool. However, the user shall give a name to SMBI instance and the SMBI inputs, directly in the Application Configuration tool. These names will define SMBI 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.

18.9 Signal matrix for binary outputs SMBO

18.9.1 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.
18.9.2 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.

18.10 Signal matrix for mA inputs SMMI

18.10.1 Application

The Signal matrix for mA inputs function SMMI is used within the Application Configuration tool in direct relation with the Signal Matrix tool. SMMI represents the way milliamp (mA) inputs are brought in for one IED configuration.

18.10.2 Setting guidelines

There are no setting parameters for the Signal matrix for mA inputs SMMI available to the user in the Parameter Setting tool. However, the user must give a name to SMMI instance and SMMI inputs, directly in the Application Configuration tool.

18.11 Signal matrix for analog inputs SMAI

18.11.1 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).

18.11.2 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 130 to make SMAI calculate a positive sequence voltage.
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.

18.11.3 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 \( \text{Negate3Ph} \), only the neutral signal \( \text{NegateN} \) or both \( \text{Negate3Ph+N} \). negation means rotation with 180° of the vectors.

**GlobalBaseSel:** Selects the global base value group used by the function to define \((I\text{Base})\), \((U\text{Base})\) and \((S\text{Base})\).

**MinValFreqMeas:** The minimum value of the voltage for which the frequency is calculated, expressed as percent of UBase (for each instance n).

Settings \( \text{DFTRefExtOut} \) and \( \text{DFTReference} \) shall be set to default value \( \text{InternalDFTRef} \) if no VT inputs are available.

Even if the user sets the \( \text{AnalogInputType} \) of a SMAI block to “Current”, the \( \text{MinValFreqMeas} \) is still visible. However, using the current channel values as base for frequency measurement is **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.

**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 \( \text{DFTReference} \) has the same set value for all of the preprocessing blocks involved.
Figure 131: 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 shows 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 application the usual setting of the parameter DFTReference of SMAI is InternalDFTRef.

Example 1
Figure 132: 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 131 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 132) 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:

- SMAI13 – SMAI12:24: DFTReference = ExternalDFTRef to use DFTSPFC input of SMAI13 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 131 for numbering):

SMAI1:1 – SMAI12:12: \(DFTReference = \text{ExternalDFTRef}\) 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 133)

SMAI2:14 – SMAI12:24: \(DFTReference = DFTRefGrp4\) to use SMAI4:16 as reference.

For task time group 3 this gives the following settings:

SMAI1:25 – SMAI12:36: \(DFTReference = \text{ExternalDFTRef}\) to use DFTSPFC input as reference (SMAI4:16)

### 18.12 Test mode functionality TESTMODE

#### 18.12.1 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 so on.
18.12.1.1 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/IEC61850-8-1:1 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 LDO 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.

18.12.2 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.

18.13 Time synchronization TIMESYNCHGEN

18.13.1 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. If a global common source (i.e. GPS) is used in different substations for the time synchronization, also comparisons and analysis between recordings made at different locations can be easily performed and a more accurate view of the actual sequence of events can be obtained.

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
- GPS
- IEC103
- SNTP
- IRIG-B
- SPA
- LON
- PPS
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.

It is possible to set a backup time-source for GPS signal, for instance SNTP. In this case, when the GPS signal quality is bad, the IED will automatically choose SNTP as the time-source. At a given point in time, only one time-source will be used.

18.13.2 Setting guidelines

All the parameters related to time are divided into two categories: System time and Synchronization.

18.13.2.1 System time

The time is set with years, month, day, hour, minute, second and millisecond.

18.13.2.2 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:
  - Off
  - SPA
  - LON
  - DNP
  - IEC 60870-5-103

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.
19.1 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.

19.1.1 Current transformer classification

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.

There are several different ways to specify CTs. Conventional magnetic core CTs are usually specified and manufactured according to some international or national standards, which specify different protection classes as well. There are many different standards and a lot of classes but fundamentally there are three different types of CTs:

- High remanence type CT
- Low remanence type CT
- Non remanence type CT

**The high remanence type** has no limit for the remanent flux. This CT has a magnetic core without any airgaps and a remanent flux might remain almost infinite time. In this type of transformers the remanence can be up to around 80% of the saturation flux. Typical examples of high remanence type CT are class P, PX, TPX according to IEC, class P, X according to BS (old British Standard) and non gapped class C, K according to ANSI/IEEE.

**The low remanence type** has a specified limit for the remanent flux. This CT is made with a small air gap to reduce the remanence to a level that does not exceed 10% of the saturation flux. The small air gap has only very limited influences on the other properties of the CT. Class PXR, TPY according to IEC are low remanence type CTs.

**The non remanence type CT** has practically negligible level of remanent flux. This type of CT has relatively big air gaps in order to reduce the remanence to practically zero level. In the same time, these air gaps reduce the influence of the DC-component from the primary fault current. The air gaps will also decrease the measuring accuracy in the non-saturated region of operation. Class TPZ according to IEC is a non remanence type CT.

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.

19.1.2 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.

19.1.3 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.

19.1.4 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.

19.1.5 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.

19.1.6 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.

19.1.6.1 Distance protection

The current transformers must have a rated equivalent limiting secondary e.m.f. $E_{al}$ that is larger than the maximum of the required rated equivalent limiting secondary e.m.f. $E_{alreq}$ below:

$$E_{al} \geq E_{alreq} = \frac{I_{k\text{max}}I_{sr}}{I_{pr}} \cdot a \left( R_{ct} + R_{L} + \frac{S_{R}}{I_{r}^2} \right)$$

(Equation 145)

$$E_{al} \geq E_{alreq} = \frac{I_{k\text{zone1}}I_{sr}}{I_{pr}} \cdot k \left( R_{ct} + R_{L} + \frac{S_{R}}{I_{r}^2} \right)$$

(Equation 146)
where:

- $I_{k_{\text{max}}}$: Maximum primary fundamental frequency current for close-in forward and reverse faults (A)
- $I_{k_{\text{zone1}}}$: Maximum primary fundamental frequency current for faults at the end of zone 1 reach (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 wire and additional load (Ω). In solidly earthed systems, the loop resistance containing the phase and neutral wires should be used for phase-to-earth faults and the resistance of the phase wire should be used for three-phase faults. In isolated or high impedance earthed systems, the resistance of the single secondary wire can always be used.
- $S_R$: 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

- $a$: This factor depends on the design of the protection function and can be a function of the primary DC time constant of the close-in fault current.
- $k$: This factor depends on the design of the protection function and can be a function of the primary DC time constant of the fault current for a fault at the set reach of zone 1.

The $a$- and $k$-factors have the following values for the different types of distance function:

**High speed distance**: (ZMFPDIS and ZMFCPDIS)
- Quadrilateral characteristic:
  - $a = 1$ for primary time constant $T_p \leq 400$ ms
  - $k = 3$ for primary time constant $T_p \leq 200$ ms
- Mho characteristic:
  - $a = 2$ for primary time constant $T_p \leq 400$ ms (For $a = 1$ the delay in operation due to saturation is still under 1.5 cycles)
  - $k = 3$ for primary time constant $T_p \leq 200$ ms

**Quadrilateral distance**: (ZMQPDIS, ZMQAPDIS and ZMCPDIS, ZMCAPDIS and ZMMPDIS, ZMMAPDIS)
- $a = 1$ for primary time constant $T_p \leq 100$ ms
- $a = 3$ for primary time constant $T_p > 100$ and $\leq 400$ ms
- $k = 4$ for primary time constant $T_p \leq 50$ ms
- $k = 5$ for primary time constant $T_p > 50$ and $\leq 150$ ms

**Mho distance**: (ZMHFPDIS)
- $a = 1$ for primary time constant $T_p \leq 100$ ms
- $a = 3$ for primary time constant $T_p > 100$ and $\leq 400$ ms
- $k = 4$ for primary time constant $T_p \leq 40$ ms
- $k = 5$ for primary time constant $T_p > 40$ and $\leq 150$ ms

### 19.1.6.2 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 rated equivalent limiting secondary e.m.f. $E_{alreq}$ below:
\[ E_{al} \geq E_{alreq} = 5 \cdot I_{op} \cdot \frac{I_{sr}}{I_{pr}} \left( R_{ct} + R_L + \frac{S_R}{I_r^2} \right) \]

(Equation 147)

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 (W)
- \( R_L \): 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). \( S_R = 0.020 \text{ VA/channel for } I_r = 1 \text{ A and } S_R = 0.150 \text{ VA/channel for } I_r = 5 \text{ A} \)

19.1.7 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.

19.1.7.1 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. \( E_{al} \). The value of the \( E_{al} \) 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. \( E_{al} \) that fulfills the following:

\[ E_{2\text{max}} > \max E_{alreq} \]

(Equation 148)

19.1.7.2 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, \( E_{kneeBS} \) 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 \( E_{knee} \) is approximately 80 % of the \( E_{al} \). Therefore, the CTs according to class PX, PXR, X and TPS must have a rated knee point e.m.f. \( E_{knee} \) that fulfills the following:
19.1.7.3 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:

\[
E_{\text{alANSI}} = 20 \cdot I_{\text{sr}} \cdot R_{\text{ct}} + U_{\text{ANSI}} = 20 \cdot I_{\text{sr}} \cdot R_{\text{ct}} + 20 \cdot I_{\text{sr}} \cdot Z_{\text{bANSI}}
\]

(Equation 150)

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 fulfils the following:

\[
E_{\text{alANSI}} > \text{maximum of } E_{\text{alreq}}
\]

(Equation 151)

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:

\[
V_{\text{kneeANSI}} > 0.75 \cdot (\text{maximum of } E_{\text{alreq}})
\]

(Equation 152)

19.2 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.

19.3 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.

19.4 Sample specification of communication requirements for the protection and control terminals in digital telecommunication networks

The communication requirements are based on echo timing.

Bit Error Rate (BER) according to ITU-T G.821, G.826 and G.828

- $< 10^{-6}$ according to the standard for data and voice transfer

Bit Error Rate (BER) for high availability of the differential protection

- $< 10^{-8}$-$10^{-9}$ during normal operation
- $< 10^{-6}$ during disturbed operation

During disturbed conditions, the trip security function in can cope with high bit error rates up to $10^{-5}$ or even up to $10^{-4}$. The trip security can be configured to be independent of COMFAIL from the differential protection communication supervision, or blocked when COMFAIL is issued after receive error $>100$ms. (Default).

Synchronization in SDH systems with G.703 E1 or IEEE C37.94

The G.703 E1, 2 Mbit shall be set according to ITU-T G.803, G.810-13

- One master clock for the actual network
- The actual port Synchronized to the SDH system clock at 2048 kbit
- Synchronization; bit synchronized, synchronized mapping
- Maximum clock deviation $< \pm 50$ ppm nominal, $< \pm 100$ ppm operational
- Jitter and Wander according to ITU-T G.823 and G.825
- Buffer memory $< 250 \mu s$, $< 100 \mu s$ asymmetric difference
- Format.G 704 frame, structured etc. Format.
- No CRC-check

Synchronization in PDH systems connected to SDH systems
Independent synchronization, asynchronous mapping

The actual SDH port must be set to allow transmission of the master clock from the PDH-system via the SDH-system in transparent mode.

- Maximum clock deviation <±50 ppm nominal, <±100 ppm operational
- Jitter and Wander according to ITU-T G.823 and G.825
- Buffer memory <100 μs
- Format: Transparent
- Maximum channel delay
- Loop time <40 ms continuous (2 x 20 ms)

**IED with echo synchronization of differential clock (without GPS clock)**

- Both channels must have the same route with maximum asymmetry of 0,2-0,5 ms, depending on set sensitivity of the differential protection.
- A fixed asymmetry can be compensated (setting of asymmetric delay in built in HMI or the parameter setting tool PST).

**IED with GPS clock**

- Independent of asymmetry.
# Section 20  Glossary

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<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>AC</td>
<td>Alternating current</td>
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<td>ACC</td>
<td>Actual channel</td>
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<tr>
<td>ACT</td>
<td>Application configuration tool within PCM600</td>
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<tr>
<td>A/D converter</td>
<td>Analog-to-digital converter</td>
</tr>
<tr>
<td>ADBS</td>
<td>Amplitude deadband supervision</td>
</tr>
<tr>
<td>ADM</td>
<td>Analog digital conversion module, with time synchronization</td>
</tr>
<tr>
<td>AI</td>
<td>Analog input</td>
</tr>
<tr>
<td>ANSI</td>
<td>American National Standards Institute</td>
</tr>
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<td>AR</td>
<td>Autoreclosing</td>
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<tr>
<td>ASCT</td>
<td>Auxiliary summation current transformer</td>
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<tr>
<td>ASD</td>
<td>Adaptive signal detection</td>
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<tr>
<td>ASDU</td>
<td>Application service data unit</td>
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<td>AWG</td>
<td>American Wire Gauge standard</td>
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<tr>
<td>BBP</td>
<td>Busbar protection</td>
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<tr>
<td>BFOC/2,5</td>
<td>Bayonet fiber optic connector</td>
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<tr>
<td>BFP</td>
<td>Breaker failure protection</td>
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<tr>
<td>BI</td>
<td>Binary input</td>
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<tr>
<td>BIM</td>
<td>Binary input module</td>
</tr>
<tr>
<td>BOM</td>
<td>Binary output module</td>
</tr>
<tr>
<td>BOS</td>
<td>Binary outputs status</td>
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<tr>
<td>BR</td>
<td>External bistable relay</td>
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<tr>
<td>BS</td>
<td>British Standards</td>
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<tr>
<td>BSR</td>
<td>Binary signal transfer function, receiver blocks</td>
</tr>
<tr>
<td>BST</td>
<td>Binary signal transfer function, transmit blocks</td>
</tr>
<tr>
<td>C37.94</td>
<td>IEEE/ANSI protocol used when sending binary signals between IEDs</td>
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<tr>
<td>CAN</td>
<td>Controller Area Network. ISO standard (ISO 11898) for serial communication</td>
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<tr>
<td>CB</td>
<td>Circuit breaker</td>
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<tr>
<td>CBM</td>
<td>Combined backplane module</td>
</tr>
<tr>
<td>CCM</td>
<td>CAN carrier module</td>
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<tr>
<td>CCVT</td>
<td>Capacitive Coupled Voltage Transformer</td>
</tr>
<tr>
<td>Class C</td>
<td>Protection Current Transformer class as per IEEE/ ANSI</td>
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<tr>
<td>CMPPS</td>
<td>Combined megapulses per second</td>
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<td>CMT</td>
<td>Communication Management tool in PCM600</td>
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<td>Term</td>
<td>Definition</td>
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<td>-----------------------------</td>
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<tr>
<td>CO cycle</td>
<td>Close-open cycle</td>
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<tr>
<td>Codirectional</td>
<td>Way of transmitting G.703 over a balanced line. Involves two twisted pairs 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 recorder according to IEEE/ANSI C37.111, 1999 / IEC 60255-24</td>
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<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>
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<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>
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<tr>
<td>CS</td>
<td>Carrier send</td>
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<tr>
<td>CT</td>
<td>Current transformer</td>
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<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>
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<tr>
<td>DARPA</td>
<td>Defense Advanced Research Projects Agency (The US developer of the TCP/IP protocol etc.)</td>
</tr>
<tr>
<td>DBDL</td>
<td>Dead bus dead line</td>
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<tr>
<td>DBLL</td>
<td>Dead bus live line</td>
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<tr>
<td>DC</td>
<td>Direct current</td>
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<tr>
<td>DFC</td>
<td>Data flow control</td>
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<tr>
<td>DFT</td>
<td>Discrete Fourier transform</td>
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<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>
</tr>
<tr>
<td>DSP</td>
<td>Digital signal processor</td>
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<tr>
<td>DTT</td>
<td>Direct transfer trip scheme</td>
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<tr>
<td>EHV network</td>
<td>Extra high voltage network</td>
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<tr>
<td>EIA</td>
<td>Electronic Industries Association</td>
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<tr>
<td>EMC</td>
<td>Electromagnetic compatibility</td>
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<tr>
<td>EMF</td>
<td>Electromotive force</td>
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<tr>
<td>EMI</td>
<td>Electromagnetic interference</td>
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<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>EnFP</td>
<td>End fault protection</td>
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<td>EPA</td>
<td>Enhanced performance architecture</td>
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<tr>
<td>ESD</td>
<td>Electrostatic discharge</td>
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<tr>
<td>F-SMA</td>
<td>Type of optical fiber connector</td>
</tr>
<tr>
<td>FAN</td>
<td>Fault number</td>
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<tr>
<td>FCB</td>
<td>Flow control bit; Frame count bit</td>
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<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>FTP</td>
<td>File Transfer Protocol</td>
</tr>
<tr>
<td>FUN</td>
<td>Function type</td>
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<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>
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<tr>
<td>GCM</td>
<td>Communication interface module with carrier of GPS receiver module</td>
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<td>GDE</td>
<td>Graphical display editor within PCM600</td>
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<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>HMI</td>
<td>Human-machine interface</td>
</tr>
<tr>
<td>HSAR</td>
<td>High speed autoreclosing</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>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>IEEE 802.12</td>
<td>A network technology standard that provides 100 Mbits/s on twisted-pair or optical fiber cable</td>
</tr>
<tr>
<td>IEEE P1386.1</td>
<td>PCI Mezzanine Card (PMC) standard for local bus modules. References the CMC (IEEE P1386, also known as Common Mezzanine Card)</td>
</tr>
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</table>
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

**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 differential 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

**OEM**  
Optical Ethernet module
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
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
PSM  Power supply module
PST  Parameter setting tool within PCM600
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
SCADA  Supervision, control and data acquisition
SCT  System configuration tool according to standard IEC 61850
SDU  Service data unit
SLM  Serial communication module.
SMA connector  Subminiature version A, A threaded connector with constant impedance.
SMT  Signal matrix tool within PCM600
SMS  Station monitoring system
SNTP
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.

SOF
Status of fault

SPA
Strömberg Protection Acquisition (SPA), a serial master/slave protocol for point-to-point and ring communication.

SRY
Switch for CB ready condition

ST
Switch or push button to trip

Starpoint
Neutral point of transformer or generator

SVC
Static VAr compensation

TC
Trip coil

TCS
Trip circuit supervision

TCP
Transmission control protocol. The most common transport layer protocol used on Ethernet and the Internet.

TCP/IP
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.

TEF
Time delayed earth-fault protection function

TLS
Transport Layer Security

TM
Transmit (disturbance data)

TNC connector
Threaded Neill-Concelman, a threaded constant impedance version of a BNC connector

TP
Trip (recorded fault)

TPZ, TPY, TPX, TPS
Current transformer class according to IEC

TRM
Transformer Module. This module transforms currents and voltages taken from the process into levels suitable for further signal processing.

TYP
Type identification

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.

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>UV</td>
<td>Undervoltage</td>
</tr>
<tr>
<td>WEI</td>
<td>Weak end infeed logic</td>
</tr>
<tr>
<td>VT</td>
<td>Voltage transformer</td>
</tr>
<tr>
<td>$3I_0$</td>
<td>Three times zero-sequence current. Often referred to as the residual or the earth-fault current</td>
</tr>
<tr>
<td>$3U_0$</td>
<td>Three times the zero sequence voltage. Often referred to as the residual voltage or the neutral point voltage</td>
</tr>
</tbody>
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