Relion® 670 series

Phasor measurement unit RES670 2.0 IEC
Application manual
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This product includes cryptographic software written/developed by: Eric Young (eay@cryptsoft.com) and Tim Hudson (tjh@cryptsoft.com).

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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 and DNP3.

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 substation 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 application and functionality 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 Dokumentenänderungsverzeichnis

### 1.3.3 Related documents

<table>
<thead>
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<th>670 series manuals</th>
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<tr>
<td>Operation manual</td>
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1.4 Document symbols and conventions

1.4.1 Symbols

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

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

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

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 and .

• HMI menu paths are presented in bold.
  For example, select Main menu/Settings.

• LHMI messages are shown in Courier font.
  For example, to save the changes in non-volatile memory, select Yes and press .

• Parameter names are shown in italics.
  For example, the function can be enabled and disabled with the Operation setting.

• Each function block symbol shows the available input/output signal.
  • the character ^ in front of an input/output signal name indicates that the signal name may be customized using the PCM600 software.
  • the character * after an input signal name indicates that the signal must be connected to another function block in the application configuration to achieve a valid application configuration.

• Logic diagrams describe the signal logic inside the function block and are bordered by dashed lines.
  • Signals in frames with a shaded area on their right hand side represent setting parameter signals that are only settable via the PST or LHMI.
  • If an internal signal path cannot be drawn with a continuous line, the suffix -int is added to the signal name to indicate where the signal starts and continues.
  • Signal paths that extend beyond the logic diagram and continue in another diagram have the suffix ”-cont.”

Illustrations are used as an example and might show other products than the one the manual describes. The example that is illustrated is still valid.
### IEC 61850 edition 1 / edition 2 mapping

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Section 2  Application

2.1  General IED application

RES670 is a Phasor Measurement Unit (PMU) that provides power system AC voltages and currents as phasors for all voltage levels in power system networks. Phasors are provided as real and imaginary or as magnitude and phase angle. The reference for the phase angle is the NavStar Global Positioning System – GPS that also supplies highly accurate time and date. The measured data in each PMU is time-synchronized via Global Positioning System (GPS) receivers – with an accuracy of one microsecond – and transmitted to Phasor Data Concentrators (every 100 milliseconds for example). The accurate time tagging of measurements taken at different geographical locations makes it possible to derive the synchronized phasor quantities (synchrophasors). Based on synchrophasors, a number of power system applications are available.

The PMUs are installed at substation level, and can be connected directly to current and voltage transformers within the substations. Each RES670 can have its own antenna and GPS system for time synchronization purposes or it can receive the IRIG-B signal from an external GPS-based clock. It is also possible to have both direct GPS and IRIG-B connection to provide time synchronization redundancy for the PMU. RES670 streams out its synchrophasor data according to IEEE C37.118 and/or IEEE 1344 standards for synchrophasor data streaming and with user-selectable reporting rates. RES670 supports reporting rates of 10, 25, 50, 100, and 200 frames per second for 50Hz system (or 10, 12, 15, 30, 60, 120, and 240 frames per second for 60Hz system). Each RES670 can communicate its synchrophasor data to up to eight independent clients over TCP and/or six independent UDP channels (unicast/multicast), simultaneously. More information is available in RES670 Application Manual under Wide Area Measurement System section.

In addition to the synchrophasor communication standard (IEEE 1344, IEEE C37.118), RES670 is also compliant to IEC 61850-8-1 standard for integration to substation automation systems and exchange of GOOSE messages, when necessary. RES670 is able to communicate over IEC 62439-3 PRP for redundant station bus communication for both IEEE C37.118 and IEC 61850-8-1, simultaneously.

Figure 2 shows an example of a system architecture for a Wide Area Monitoring System (WAMS). PMUs are the building blocks for a WAMS. The architecture of a WAMS consists of the following main components:

- **PMU** Phasor Measurement Unit, including all accessories for time synchronization
- **TCP/IP** and/or **UDP/IP** communication network infra-structure
- **PDC** Phasor Data Concentrator, including wide area applications
A Wide Area Monitoring System collects, stores, transmits and provides ways to analyze critical data from key points across the power networks and over large geographical areas. The architecture of the WAMS can provide a scalable solution, from small installations for data collection and basic visualization (PDC) to larger systems with intelligent monitoring using wide area applications. The Wide Area Monitoring applications are designed to detect abnormal system conditions and evaluate large area disturbances in order to preserve system integrity and maintain acceptable power system performance.

The WAMS is configured in a way to acquire synchrophasor data from several PMUs. Based on the data collected in the PDCs, WAMS is able to present the state of the grid to the power system operator, and to provide monitoring of the power system based on real-time measurements and the results of on-line applications. In addition, the data available from PDCs enables off-line analysis of the power system for post-disturbance assessments. It is possible to communicate the PMU measurements and the results of the advanced applications to SCADA/EMS systems as a way to improve the supervision of the system, providing the operator with a clear indication how likely the system is to collapse, thus giving the possibility to react in time.
2.2 Wide area measurement functions

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2.3 Back-up protection functions

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1) 67 requires voltage
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# Control and monitoring functions

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## 2.5 Communication

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### Table 2: Basic IED functions

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<td>IRIG-B</td>
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1) Only included for 9-2LE products

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2.6 Basic IED functions
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Section 3 Configuration

3.1 Introduction

There are two different software alternatives with which the IED can be ordered. The intention is that these configurations shall suit most applications with minor or no changes. The few changes required on binary input and outputs can be done from the signal matrix tool in the PCM600 engineering platform.

Only the main PMU reporting function (first instance) is switched On at delivery. The other PMU reporting function (second instance) and all the protection functions are switched Off at delivery. Back-up functions that are not generally used are also set to Off.

The configurations are:
- A20 – Phasor Measurement Unit, 3 bays, single busbar, 12AI (9I+3U)
- B20 – Phasor Measurement Unit, 6 bays, double busbar, 24AI (9I+3U, 9I+3U)

All IEDs can be reconfigured with the help of the Application Configuration Tool (ACT) in the PCM600 engineering platform. The IED can be adapted to special applications and special logic can be developed.

On request, ABB is available to support the re-configuration work, either directly or to do the design checking.

Optional functions and optional IO ordered, will not be configured at delivery. It means that the user shall configure and add them to the standard configuration. It should be noted that the standard only includes one binary input and one binary output module and only the important outputs such as protection function alarms are connected to the outputs. The required total IO must be calculated and specified at ordering.

Hardware modules are configured with the hardware configuration tool in the PCM600 engineering platform.
3.2 Description of configuration RES670

3.2.1 Introduction

3.2.1.1 Description of configuration A20

The configuration of the IED is shown in figure 3.

RES670 A20 configuration is applicable for a typical single busbar single breaker arrangement monitoring up to three bays. RES670 A20 is delivered in 1/2, 3/4 and full (1/1)19” rack casing. For this application 12 analog inputs are used, thus only one transformer module (TRM) with 12 analog inputs (9I+3U) is available in A20 standard configuration. As shown in figure 3, RES670 A20 configuration as a PMU is measuring one 3-phase voltage of the busbar and three 3-phase currents of bays 1 to 3. There are two instances of PMU reporting functionality available in A20 configuration, meaning two independent IEEE C37.118/1344 data streams. In the standard A20 configuration, each instance of PMU, in addition to frequency-deviation and rate-of-change-of-frequency data, is reporting 16 synchrophasors over IEEE C37.118/1344; that is four 3-phase synchrophasors and 12 single phase synchrophasors in each data stream corresponding to the AC voltage and current measurements.

In addition, each data stream includes 8 analog and 8 binary reporting channels over IEEE C37.118/1344 in the standard configuration. The number of analog and binary reporting channels can be extended to maximum 24 channels per PMU instance (on each data stream) on request. This can be done when ordering the RES670 A20 configuration. In the standard A20 configuration, the analog reporting channels are used for reporting P and Q measurements from each bay over IEEE C37.118/1344.

In addition to the binary reporting channels, there are 4 trigger bits (FREQTRIG, DFDTTRIG, OCTRIG and UVTRIG) available per PMU instance, which are used to report the existing protection function triggers over IEEE C37.118/1344.

The main functionality of the RES670 is synchrophasor reporting or PMU functionality. In addition, this configuration also includes general back-up protection functions which are mainly intended for alarm purposes. Available protection functions in standard A20 configuration are Overvoltage, Undervoltage, Overfrequency, Underfrequency and Rate-of-change frequency.

Measuring functions for S, P, Q, I, U, PF, f are available for local presentation on the local HMI and remote presentation via IEEE C37.118/1344 and/or via IEC61850. The calibration parameters on the measurement function allows calibration at site to very high accuracy.

As shown in figure 3, there are optional functions such as Earth fault protection (EF4 PTOC), Overcurrent protection (OC4 PTOC), Under/Over power protection (GUPPDUP, GOPPDOP), etc. which can be added per request. RES670 A20 function
library also includes additional functions, which are available but not configured. Note that RES670 A20 must be reconfigured if any additional functions are used.

**3.2.1.2 Description of configuration B20**

The configuration of the IED is shown in Figure 4.

Figure 3: Configuration diagram for configuration A20
RES670 B20 configuration is applicable for a typical double busbar single breaker arrangement monitoring up to six bays. RES670 B20 is delivered in ¼, and full (1/1)19” rack casing. For this application 24 analog inputs are used, thus two transformer modules (TRM) with 12 analog inputs (9I+3U) per TRM are available in B20 standard configuration. As shown in figure 4, RES670 B20 configuration as a PMU is measuring two 3-phase voltages of the busbars and six 3-phase currents of bays 1 to 6. There are two instances of PMU reporting functionality available in B20 configuration, meaning two independent IEEE C37.118/1344 data streams. Each instance of PMU is reporting frequency-deviation and rate-of-change-of-frequency data. In the standard B20 configuration, in addition to frequency data, first instance of PMU (first data stream) is reporting 32 synchrophasors over IEEE C37.118/1344; that is eight 3-phase synchrophasors and 24 single phase synchrophasors corresponding to the AC voltage and current measurements. Second instance of PMU (second data stream) is reporting 16 synchrophasors over IEEE C37.118/1344; that is four 3-phase synchrophasors and 12 single phase synchrophasors corresponding to the AC voltage and current measurements. The number of synchrophasor reporting channels on second instance of PMU can be extended to 32 channels per request. This can be done when ordering the RES670 B20 configuration.

In addition, each data stream includes 16 analog and 16 binary reporting channels over IEEE C37.118/1344 in the standard configuration. The number of analog and binary reporting channels can be extended to maximum 24 channels per PMU instance (on each data stream) on request. This can be done when ordering the RES670 B20 configuration. In the standard B20 configuration the analog reporting channels are used for reporting P and Q measurements from each bay over IEEE C37.118/1344. In addition to the binary reporting channels there are 4 trigger bits (FREQTRIG, DFDTTRIG, OCTRIG, and UVTRIG) available per PMU instance which are used to report the existing protection function triggers over IEEE C37.118/1344.

The main functionality of the RES670 is synchrophasor reporting or PMU functionality. In addition, this configuration also includes general back-up protection functions which are mainly intended for alarm purposes. Available protection functions in standard B20 configuration are Over Voltage, Under Voltage, Over Frequency, Under Frequency and Rate of Change of Frequency.

Measuring functions for S, P, Q, I, U, PF, f are available for local presentation on the local HMI and remote presentation via IEEE C37.118/1344 and/or via IEC61850. The calibration parameters on the measurement function allows calibration at site to very high accuracy.

As shown in figure 4, there are optional functions such as Earth fault protection (EF4 PTOC), Overcurrent protection (OC4 PTOC), Under/Over power protection (GUPPDUP, GOPPDOP), etc. which can be added per request. RES670 B20 function library also includes additional functions which are available but not configured. Note that RES670 B20 must be reconfigured if any additional functions are used.
**Figure 4:** Configuration diagram for configuration B20
4.1 Introduction

Analog input channels must be configured and set properly 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 properly. 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 \textit{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 IED has the ability to receive analog values from primary equipment, that are sampled by Merging units (MU) connected to a process bus, via the IEC 61850-9-2 LE protocol.

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

4.2 Setting guidelines

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

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 \textit{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 5.

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 5.

![Diagram of Protected Object, Line, Transformer, etc](en05000456.vsd)

**Figure 5:** 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 6: Example how to set CTStarPoint parameters in the IED

The figure 6 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 7: 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.
Transformer and Line protection

Transformer

Line

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

IED

Transformer and Line protection

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

Forward
Reverse

Definition of direction for directional line functions

Figure 8: 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 9. The same currents are fed to two separate groups of inputs and the line and transformer protection functions are configured to the different inputs. The CT direction for the current channels to the line protection is set with the line as reference object and the directional functions of the line protection shall be set to Forward to protect the line.
Transformer and Line protection

Transformer

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 transformer functions:
Set parameter CTStarPoint with Transformer as reference object. Correct setting is "ToObject".

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

IED

Definition of direction for directional line functions
Reverse
Forward

Figure 9: Example how to set CTStarPoint parameters in the IED
Figure 10: Example how to set CTStarPoint parameters in the IED

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

The first solution will be to use busbar as a reference object. In that case for all CT inputs marked with 1 in figure 10, set CTStarPoint = ToObject, and for all CT inputs marked with 2 in figure 10, set CTStarPoint = FromObject.

The second solution will be to use all connected bays as reference objects. In that case for all CT inputs marked with 1 in figure 10, set CTStarPoint = FromObject, and for all CT inputs marked with 2 in figure 10, set CTStarPoint = ToObject.

Regardless which one of the above two options is selected busbar differential protection will behave correctly.
The main CT ratios must also be set. This is done by setting the two parameters $CT_{sec}$ and $CT_{prim}$ for each current channel. For a 1000/1 A CT the following setting shall be used:

- $CT_{prim} = 1000$ (value in A)
- $CT_{sec} = 1$ (value in A).

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

Figure 11 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.*

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 12 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 12: 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 12.

   • 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, negative and zero sequence quantities are available.

A11, A12, A13, A14 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 the figure below:
In the example in figure 13 case everything is done in a similar way as in the above described example (figure 12). The only difference is the setting of the parameter CTStarPoint of the used current inputs on the TRM (item 2 in the figure):

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

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 the figure below.
Figure 14: 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.

- CTprim=800A
- CTsec=1A
- CTStarPoint=FromObject
- ConnectionType=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).

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.

Table continues on next page
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 15 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 15: 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.

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

- \( CTStarPoint = ToObject \)
- \( ConnectionType = Ph-Ph \)

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 4). Depending on the type of functions which need this current information, more than one preprocessing block might be connected in parallel to these three CT inputs.

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

- 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 \( DFTRef \)erence shall be set accordingly.

Another alternative is to have the delta connected CT set as shown in figure 16:
Figure 16: \textit{Delta DAC connected three-phase CT set}

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

\[ CT_{\text{prim}} = 800 \text{A} \]

\[ CT_{\text{sec}} = 1 \text{A} \]

- \textit{CTStarPoint}=ToObject
- \textit{ConnectionType}=Ph-Ph

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

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

Figure 17 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 17: 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 17:
   \[ CT_{prim} = 1000 \text{ A} \]
   \[ CT_{sec} = 1\text{ A} \]
   \[ CTStarPoint = \text{ToObject} \]

   For connection (b) shown in figure 17:
   \[ CT_{prim} = 1000 \text{ A} \]
   \[ CT_{sec} = 1\text{ A} \]
   \[ CTStarPoint = \text{FromObject} \]

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 \textit{DFTReference} shall be set accordingly.
4.2.3 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.

4.2.3.1 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)

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

Figure 18 defines the marking of voltage transformer terminals commonly used around the world.

![Commonly used markings of VT terminals](en060000591.vsd)

**Figure 18:** 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.

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

Figure 19 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 19: 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:

\[ VT_{pri} = 66 \text{ kV} \]
\[ VT_{sec} = 110 \text{ V} \]

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

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

(Equation 2)

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

4) shows that in this example the fourth (that is, residual) input channel of the preprocessing block is not connected in SMT tool. Thus the preprocessing block will automatically calculate \(3U_0\) inside by vectorial sum from the three phase to earth voltages connected to the first three input channels of the same preprocessing block. Alternatively, the fourth input channel can be connected to open delta VT input, as shown in figure 21.

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

- \(U_{\text{Base}}=66\ \text{kV}\) (that is, rated Ph-Ph voltage)

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

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

Figure 20 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 20:** 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:

- $V_{T\text{prim}} = 13.8\, \text{kV}$
- $V_{T\text{sec}} = 120\, \text{V}$

Please note that inside the IED only ratio of these two parameters is used.

Table continues on next page
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:

- ConnectionType=Ph-Ph
- 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 DFTReference shall be set accordingly.

4.2.3.5 Example on how to connect an open delta VT to the IED for high impedance earthed or unearthed networks

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

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

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

(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 21 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 21: 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:

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

(Equation 4)

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

(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.

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

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

Figure 22 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 $3U_0$ 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:

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

(Equation 7)

The primary rated voltage of such VT is always equal to $U_{Ph-E}$. 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 22 gives an overview of the actions which are needed to make this measurement available to the built-in protection and control functions within the IED.

Figure 22: 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.  

+3Uo 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:

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

(Equation 8)

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

(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.

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

(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.

4.2.3.7 Example on how to connect a neutral point VT to the IED

Figure 23 gives an example on how to connect a neutral point VT to the IED. This type of VT connection presents secondary voltage proportional to U₀ to the IED.
In case of a solid earth fault in high impedance earthed or unearthed systems the primary value of $U_0$ voltage will be equal to:

$$U_0 = \frac{U_{m} - m}{\sqrt{3}} = U_{m} - \varepsilon$$

(Equation 11)

Figure 23 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 as well.

**Figure 23**: Neutral point connected VT
Section 4
Analog inputs

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:

   \[ VT_{prim} = \frac{6.6}{\sqrt{3}} = 3.81kV \]  
   \[ \text{(Equation 12)} \]

   \[ VT_{sec} = 100V \]  
   \[ \text{(Equation 13)} \]

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

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.
Figure 24: Local human-machine interface

The LHMI of the IED contains the following elements:
The LHMI is used for setting, monitoring and controlling.

5.1 Display

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

The display view is divided into four basic areas.

Figure 25: Display layout

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

![Function button panel](IEC13000281-1-en.vsd)

**Figure 26:** Function button panel

The alarm LED panel shows on request the alarm text labels for the alarm LEDs. Three alarm LED pages are available.

![Alarm LED panel](IEC13000240-1-en.vsd)

**Figure 27:** Alarm LED panel

The function button and alarm 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 the panels have dynamic width that depends on the label string length that the panel contains.
5.2 LEDs

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

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

5.3 Keypad

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

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

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

5.4.1 Protection and alarm indication

Protection indicators

The protection indicator LEDs are Ready, Start and Trip.

![Information icon]

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 BxBRDR binary input function block using the PCM600 and configure the setting to Off, Start or Trip for that particular signal.

<table>
<thead>
<tr>
<th>Table 3: Ready LED (green)</th>
<th>LED state</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off</td>
<td></td>
<td>Auxiliary supply voltage is disconnected.</td>
</tr>
<tr>
<td>On</td>
<td></td>
<td>Normal operation.</td>
</tr>
<tr>
<td>Flashing</td>
<td></td>
<td>Internal fault has occurred.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4: Start LED (yellow)</th>
<th>LED state</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off</td>
<td></td>
<td>Normal operation.</td>
</tr>
<tr>
<td>On</td>
<td></td>
<td>A protection function has started and an indication message is displayed. The start indication is latching and must be reset via communication, LHMI or binary input on the LEDGEN component. To open the reset menu on the LHMI, press Clear.</td>
</tr>
<tr>
<td>Flashing</td>
<td></td>
<td>The IED is in test mode and protection functions are blocked, or the IEC61850 protocol is blocking one or more functions. The indication disappears when the IED is no longer in test mode and blocking is removed. The blocking of functions through the IEC61850 protocol can be reset in Main menu/Test/Reset IEC61850 Mod. The yellow LED changes to either On or Off state depending on the state of operation.</td>
</tr>
</tbody>
</table>
### Table 5: Trip LED (red)

<table>
<thead>
<tr>
<th>LED state</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off</td>
<td>Normal operation.</td>
</tr>
<tr>
<td>On</td>
<td>A protection function has tripped. An indication message is displayed if the auto-indication feature is enabled in the local HMI. The trip indication is latching and must be reset via communication, LHMI or binary input on the LEDGEN component. To open the reset menu on the LHMI, press .</td>
</tr>
<tr>
<td>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 6: 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.

![Figure 29: RJ-45 communication port and green indicator LED](image)

1. RJ-45 connector
2. Green indicator LED
Section 6  Wide area measurement system

6.1  C37.118 Phasor Measurement Data Streaming Protocol Configuration PMUCONF

6.1.1  Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60817 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration parameters for IEEE 1344 and C37.118 protocol</td>
<td>PMUCONF</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

6.1.2  Application

RES670 supports the following IEEE synchrophasor standards:

- IEEE 1344-1995 (Both measurements and data communication)
- IEEE Std C37.118-2005 (Both measurements and data communication)
- IEEE Std C37.118.1–2011 and C37.118.1a-2014 (Measurements)
- IEEE Std C37.118.2-2011 (Data communication)

PMUCONF contains the PMU configuration parameters for both IEEE C37.118 and IEEE 1344 protocols. This means all the required settings and parameters in order to establish and define a number of TCP and/or UDP connections with one or more PDC clients (synchrophasor client). This includes port numbers, TCP/UDP IP addresses, and specific settings for IEEE C37.118 as well as IEEE 1344 protocols.

6.1.3  Operation principle

The Figure 30 demonstrates the communication configuration diagram. As can be seen, the IED can support communication with maximum 8 TCP clients and 6 UDP client groups, simultaneously. Every client can communicate with only one instance of the two available PMUREPORT function block instances at a time. It means that one client cannot communicate with both PMUREPORT:1 and PMUREPORT:2 at the same time. However, multiple clients can communicate with the same instance of PMUREPORT function block at the same time. For TCP clients, each client can decide to communicate with an existing instance of PMUREPORT by knowing the corresponding PMU ID for that PMUREPORT instance. Whereas, for UDP clients, the PMUREPORT instance for each UDP channel is defined by the user in the PMU and the client has to know the PMU ID corresponding to that instance in order to be
able to communicate. More information is available in the sections Short guidance for the use of TCP and Short guidance for the use of UDP.

**Figure 30:** The communication configuration (PMUCONF) structure in the IED

### 6.1.3.1 Short guidance for use of TCP

Port 7001 is used by the SPA on TCP/IP (field service tool). If the port is used for any other protocol, for example C37.118, the SPA on TCP/IP stops working.

RES670 supports 8 concurrent TCP connections using IEEE1344 and/or C37.118 protocol. The following parameters are used to define the TCP connection between RES670 and the TCP clients:

1. **1344TCPPort** – TCP port for control of IEEE 1344 data for TCP clients
2. **C37.118TCPPort** – TCP port for control of IEEE C37.118 data for TCP clients
3. **PortSelTCPClient** – Select network port for TCP clients

As can be seen, there are two separate parameters in RES670 for selecting port numbers for TCP connections; one for IEEE1344 protocol (1344TCPPort) and another one for C37.118 protocol (C37.118 TCPPort). Client can communicate with RES670 over IEEE1344 protocol using the selected TCP port defined in 1344TCPPort, and can communicate with RES670 over IEEE C37.118 protocol using the selected TCP port number in C37.118TCPPort.
All the frames (the header frame, configuration frame, command frame and data frame) are communicated over the same TCP port. The client can request (by sending a command frame) a configuration and/or header via the TCP channel and the requested configuration and/or header will be sent back to the client (as Configuration frame/Header frame) over the same TCP channel.

Once the TCP client connects to RES670, the client has to necessarily send a command frame to start a communication. As shown in Figure 30, RES670 can support 2 PMUREPORT instances and the client has to specify the PMU ID Code in order to know which PMUREPORT data needs to be sent out to that client. In this figure, X and Y are referring to the user-defined PMU ID Codes for PMUREPORT instances 1 or 2, respectively. It is up to the TCP client to decide which PMUREPORT function block shall communicate with that client. Upon successful reception of the first command by RES670, the PMU ID will be extracted out of the command; if there is a PMUREPORT instance configured in the RES670 with matching PMU ID, then the client connection over TCP with RES670 will be established and further communication will take place. Otherwise, the connection will be terminated and the TCPCtrn/CfgErrCnt is incremented in the PMU Diagnostics on RES670 Local HMI under Main menu/Diagnostics/Communication/PMU diagnostics/PMUSTATUS:1

There are three physical ports on the RES670: the Front port, LANAB optical port, and LANCD optical port. The parameter PortSelTCPclient decides on which physical port should the IEEE1344/C37.118 messages communicate over TCP. The parameter also has an option *Any* where the TCP IEEE1344/C37.118 communication will be available over all the ports and with the option ‘None’ the TCP IEEE1344/C37.118 communication is stopped.

It is possible to turn off/on the TCP data communication by sending a IEEE1344 or C37.118 command frame remotely from the client to the PMU containing RTDOFF/RTDON command.

At any given point of time maximum of 8 TCP clients can be connected to RES670 for IEEE1344/C37.118 protocol. If there is an attempt made by the 9th client, the connection to the new client will be terminated without influencing the connection of the other clients already connected. A list of active clients can be seen on RES670 Local HMI in the diagnostics menu under Main menu/Diagnostics/Communication/PMU diagnostics/PMUSTATUS:1

### 6.1.3.2 Short guidance for use of UDP

RES670 supports maximum of 6 concurrent UDP streams. They can be individually configured to send IEEE1344 or C37.118 data frames as unicast / multicast. Note that [x] at the end of each parameter is referring to the UDP stream number (UDP client group) and is a number between 1 and 6. Each of the 6 UDP groups in the RES670 has the following settings:
1.  *SendDataUDP[x]* – Enable / disable UDP data stream
2.  *ProtocolOnUDP[x]* – Send IEEE1344 or C37.118 on UDP
3.  *PMUReportUDP[x]* – Instance number of PMUREPORT function block that must send data on this UDP stream (UDP client group[x])
4.  *UDPDestAddress[x]* – UDP destination address for UDP client group[x] (unicast / multicast address range)
5.  *UDPDestPort[x]* – UDP destination port number for UDP client group[x]
6.  *TCPportUDPdataCtrl[x]* – TCP port to control of data sent over UDP client group[x], i.e. to receive commands and send configuration frames
7.  *MCastCtrlPortSel[x]* – Physical network port selection to route multicast data
8.  *SendCfgOnUDP[x]* – Send configuration frame 2 (CFG-2) on UDP for client group[x]

It is possible to turn off/on the UDP data communication either by setting the parameter *SendDataUDP[x]* to *Off/On* locally in the PMU or by sending a C37.118 or IEEE1344 command frame (*RTDOFF/RTDON*) remotely from the client to the PMU as defined in IEEE 1344/C37.118 standard.

However, such a remote control to stop the streams from the client is only possible when the parameter *SendDataUDP[x]* is set to *SetByProtocol*. The command *RTDOFF/RTDON* sent by the client is stored in the IED, i.e. if the RES670 is rebooted for some reason, the state of the stream will remain the same.

If the parameter *SendDataUDP[x]* is set *On* the *RTDOFF/RTDON* commands received from the clients are ignored in RES670.

It is recommended not to set the parameter *SendDataUDP[x]* to *SetByProtocol* in case of a multicast. This is because if one of the clients sends the *RTDOFF* command, all the clients will stop receiving the frames.

The UDP implementation in RES670 is a UDP_TCP. This means that by default, only the data frames are sent out on UDP stream and the header frame, configuration frame and command frame are sent over TCP. This makes the communication more reliable especially since commands are sent over TCP which performs request/acknowledgment exchange to ensure that no data (command in this case) is lost.

However, by setting the parameter *SendCfgOnUDP[x]* to *On*, the configuration frame 2 (CFG-2) of IEEE C37.118 data stream is cyclically sent on the corresponding UDP stream (UDP client group[x]) once per minute. This is useful in case of multicast UDP data stream when a lot of PMU clients are receiving the same UDP stream from the same UDP group (UDP client group[x]).

As shown in Figure 30, there are maximum 2 instances of PMUREPORT function blocks available in RES670. Each UDP client group[x] can only connect to one of the PMUREPORT instances at the same time. This is defined in the PMU by the parameter *PMUReportUDP[x]* which is used to define the instance number of PMUREPORT function block that must send data on this UDP stream (UDP client group[x]).
The data streams in RES670 can be sent as unicast or as multicast. The user-defined IP address set in the parameter \textit{UDPDestAddress}\[x\] for each UDP stream defines if it is a Unicast or Multicast. The address range 224.0.0.0 to 239.255.255.255 (Class D IP addresses) is treated as multicast. Any other IP address outside this range is treated as unicast and the UDP data will be only sent to that specific unicast IP address. In addition to \textit{UDPDestAddress}\[x\] parameter, \textit{UDPDestPort}\[x\] parameter is used to define the UDP destination port number for UDP client group\[x\].

In case of multicast IP, it will be the network switches and routers that take care of replicating the packet to reach multiple receivers. Multicast mechanism uses network infrastructure efficiently by requiring the RES670 to send a packet only once, even if it needs to be delivered to a large number of receivers.

When using the multicast IP address range (Class D IP addresses), the user can choose the physical network interface on the device to send out the multicast data by setting the parameter \textit{MCastCtrlPortSel}\[x\]. If \textit{MCastCtrlPortSel}\[x\] is set to \textit{Any/Follow Gateway} it means that the multicast UDP stream will follow the gateway and will be routed to the physical network interface which is on the same subnetwork as the gateway. Here \textit{Any} means that any physical network interface (Front port, LANAB, LANCD) can be used for sending the TCP command frames.

If there are more than one UDP client group defined as multicast, the user shall set different multicast IP addresses for each UDP group. If the user set similar multicast IP addresses for multiple UDP groups, the \textit{MCastCtrlPortSel}\[x\] setting of the first UDP group with similar multicast IP will be applied to all the UDP groups with similar multicast IP address.

The PMU clients receiving the UDP frames can also connect to RES670 to request (command frame) config frame 1, config frame 2, config frame 3, or header frame, and to disable/enable real time data. This can be done by connecting to the TCP port selected in \textit{TCPportUDPdataCtrl}\[x\] for each UDP group. This connection is done using TCP. The RES670 allows 4 concurrent client connections for every \textit{TCPportUDPdataCtrl}\[x\] port (for each UDP client group\[x\]).

If the client tries to connect on \textit{TCPportUDPdataCtrl}\[x\] port using a PMU-ID other than what is configured for that PMUREPORT instance \textit{(PMUReportUDP}\[x\]), then that client is immediately disconnected and the \textit{UDPCtrlCfgErrCnt} is incremented in PMU Diagnostics on LHMI at \textbf{Main menu/Diagnostics/Communication/PMU diagnostics/PMUSTATUS:1}

Even if the parameter \textit{SendDataUDP}\[x\] is set to \textit{Off} it is still possible for the clients to connect on the TCP port and request the configuration frames.
## 6.2 Protocol reporting via IEEE 1344 and C37.118

### PMUREPORT

#### 6.2.1 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>Protocol reporting via IEEE 1344 and C37.118</td>
<td>PMUREPORT</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 6.2.2 Application

The phasor measurement reporting block moves the phasor calculations into an IEEE C37.118 and/or IEEE 1344 synchrophasor frame format. The PMUREPORT block contains parameters for PMU performance class and reporting rate, the IDCODE and Global PMU ID, format of the data streamed through the protocol, the type of reported synchrophasors, as well as settings for reporting analog and digital signals.

The message generated by the PMUREPORT function block is set in accordance with the IEEE C37.118 and/or IEEE 1344 standards.

There are settings for Phasor type (positive sequence, negative sequence or zero sequence in case of 3-phase phasor and L1, L2 or L3 in case of single phase phasor), PMU’s Service class (Protection or Measurement), Phasor representation (polar or rectangular) and the data types for phasor data, analog data and frequency data.

Synchrophasor data can be reported to up to 8 clients over TCP and/or 6 UDP group clients for multicast or unicast transmission of phasor data from RES670. More information regarding synchrophasor communication structure and TCP/UDP configuration is available in section C37.118 Phasor Measurement Data Streaming Protocol Configuration.

Multiple PMU functionality can be configured in RES670, which can stream out same or different data at different reporting rates or different performance (service) classes. There are 2 instances of PMU functionality available in RES670. Each instance of PMU functionality includes a set of PMU reporting function blocks tagged by the same instance number (1 or 2). As shown in the following figures, each set of PMU reporting function blocks includes PMUREPORT, PHASORREPORT1-4, ANALOGREPORT1-3, and BINARYREPORT1-3 function blocks. In general, each instance of PMU functionality has 32 configurable phasor channels (PHASORREPORT1–4 blocks), 24 analog channels (ANALOGREPORT1-3 blocks), and 28 digital channels (24 digital-report channels in BINARYREPORT1-3 and 4 trigger-report channels in PMUREPORT function block). Special rules shall be taken into account in PCM600 for Application Configuration and Parameter Settings of multiple PMUREPORT blocks. These rules are explained in RES670 Application Manual in section PMU Report Function Blocks Connection Rules.
Figure 31 shows both instances of the PMUREPORT function block. As seen, each PMUREPORT instance has 4 predefined binary input signals corresponding to the Bits 03-00: Trigger Reason defined in STAT field of the Data frame in IEEE C37.118.2 standard. These are predefined inputs for Frequency Trigger, Rate of Change of Frequency trigger, Magnitude High and Magnitude Low triggers.

![Figure 31: Multiple instances of PMUREPORT function block](IEC140000118-1-en.vsd)

Figure 32 shows both instances of the PHASORREPORT function blocks. The instance number is visible in the bottom of each function block. For each instance, there are four separate PHASORREPORT blocks including 32 configurable phasor channels (8 phasor channels in each PHASORREPORT block). Each phasor channel can be configured as a 3-phase (symmetrical components positive/negative/zero) or single-phase phasor (L1/L2/L3).

![Figure 32: Multiple instances of PHASORREPORT blocks](IEC140000119-1-en.vsd)

Figure 33 shows both instances of ANALOGREPORT function blocks. The instance number is visible in the bottom of each function block. For each instance, there are three separate ANALOGREPORT blocks capable of reporting up to 24 Analog signals (8 Analog signals in each ANALOGREPORT block). These can include for example transfer of active and reactive power or reporting the milliampere input signals to the PDC clients as defined in IEEE C37.118 data frame format.

![Figure 33: Multiple instances of ANALOGREPORT function blocks](IEC140000120-1-en.vsd)
6.2.3 Operation principle

The Phasor Measurement Unit (PMU) features three main functional principles:
To measure the power system related AC quantities (voltage, current) and to calculate the phasor representation of these quantities.

- To synchronize the calculated phasors with the UTC by time-tagging, in order to make synchrophasors (time is reference).
- To publish all phasor-related data by means of TCP/IP or UDP/IP, following the standard IEEE C37.118 protocol.

The C37.118 standard imposes requirements on the devices and describes the communication message structure and data. The PMU complies with all the standard requirements with a specific attention to the Total Vector Error (TVE) requirement. The TVE is calculated using the following equation:

\[
TVE = \sqrt{\left(\frac{X_r(n) - X_r}{X_r}\right)^2 + \left(\frac{X_i(n) - X_i}{X_i}\right)^2}
\]

(Equation 14)

where,

\[X_r(n)\] and \[X_i(n)\] are the measured values
\[X_r\] and \[X_i\] are the theoretical values

In order to comply with TVE requirements, special calibration is done in the factory on the analog input channels of the PMU, resulting in increased accuracy of the measurements. The IEEE C37.118 standard also imposes a variety of steady state and dynamic requirements which are fulfilled in RES670 with the help of high accuracy measurements and advanced filtering techniques.

Figure 35 shows an overview of the PMU functionality and operation. In this figure, only one instance of PMUREPORT (PMUREPORT1) is shown. Note that connection of different signals to the PMUREPORT, in this figure, is only an example and the actual connections and reported signals on the IEEE C37.118/1344 can be defined by the user.
The TRM modules are individually AC-calibrated in the factory. The calibration data is stored in the prepared area of the TRM EEPROM. The pre-processor block is extended with calibration compensation and a new angle reference method based on timestamps. The A13P output of the preprocessor block is used to provide the required information for each respective PMUREPORT phasor channel. More information about preprocessor block is available in the section Signal matrix for analog inputs SMAI.

### 6.2.3.1 Frequency reporting

By using patented algorithm the IED can track the power system frequency in quite wide range from 9 Hz to 95 Hz. In order to do that, the three-phase voltage signal shall be connected to the IED. Then IED can adapt its filtering algorithm in order to properly measure phasors of all current and voltage signals connected to the IED. This feature is essential for proper operation of the PMUREPORT function or for protection during generator start-up and shut-down procedure.

This adaptive filtering is ensured by proper configuration and settings of all relevant pre-processing blocks, see Signal matrix for analog inputs in the Application manual. Note that in all preconfigured IEDs such configuration and settings are already made and the three-phase voltage are used as master for frequency tracking. With such
settings the IED will be able to properly estimate the magnitude and the phase angle of measured current and voltage phasors in this wide frequency range.

One of the important functions of a PMU is reporting a very accurate system frequency to the PDC client. In the IED, each of the PMUREPORT instances is able to report an accurate frequency. Each voltage-connected preprocessor block (SMAI block) delivers the frequency data, derived from the analog input AC voltage values, to the respective voltage phasor channel. Every phasor channel has a user-settable parameter (PhasorXUseFreqSrc) to be used as a source of frequency data for reporting to the PDC client. It is very important to set this parameter to On for the voltage-connected phasor channels. There is an automatic frequency source selection logic to ensure an uninterpreted reporting of the system frequency to the PDC client. In this frequency source selection logic, the following general rules are applied:

- Only the voltage phasor channels are used
- The phasor channel with a lower channel number is prioritized to the one with a higher channel number

As a result, the first voltage phasor is always the one delivering the system frequency to the PDC client and if, by any reason, this voltage gets disconnected then the next available voltage phasor is automatically used as the frequency source and so on. If the first voltage phasor comes back, since it has a higher priority compare to the currently selected phasor channel, after 500 ms it will be automatically selected again as the frequency source. There is also an output available on the component which shows if the reference frequency is good, error or reference channel unavailable.

It is possible to monitor the status of the frequency reference channel (frequency source) for the respective PMUREPORT instance on Local HMI under Test/Function status/Communication/Station Communication/PMU Report/PMUREPORT:1/Outputs, where the FREQREFCHSEL output shows the selected channel as the reference for frequency and FREQREFCHERR output states if the reference frequency is good, or if there is an error or if the reference channel is unavailable. For more information refer to the table PMUREPORT monitored data.

### Table 7: PMUREPORT Monitored data

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Values (Range)</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIMESTAT</td>
<td>BOOLEAN</td>
<td>1=Ready 0=Fail</td>
<td>-</td>
<td>Time synchronization status</td>
</tr>
<tr>
<td>FREQ</td>
<td>REAL</td>
<td>-</td>
<td>Hz</td>
<td>Frequency</td>
</tr>
<tr>
<td>FREQGRAD</td>
<td>REAL</td>
<td>-</td>
<td>-</td>
<td>Rate of change of frequency</td>
</tr>
<tr>
<td>FREQREFCHSEL</td>
<td>INTEGER</td>
<td>-</td>
<td>-</td>
<td>Frequency reference channel number selected</td>
</tr>
<tr>
<td>FREQREFCHERR</td>
<td>BOOLEAN</td>
<td>0=Freq ref not available 1=Freq ref error 2=Freq ref available</td>
<td>-</td>
<td>Frequency reference channel error</td>
</tr>
<tr>
<td>FREQTRIG</td>
<td>BOOLEAN</td>
<td>-</td>
<td>-</td>
<td>Frequency trigger</td>
</tr>
</tbody>
</table>

Table continues on next page
### 6.2.3.2 Reporting filters

The PMUREPORT function block implements the reporting filters designed to avoid aliasing as the reporting frequency is lower than the sample/calculation frequency. This means, the synchrophasor and frequency data which are included in the C37.118 synchrophasor streaming data are filtered in order to suppress aliasing effects, as the rate of the C37.118 data is slower than the data rate for internal processing. For this purpose, there is an anti-aliasing filter designed for each reporting rate. The correct anti-aliasing filter will be automatically selected based on the reporting rate and the performance class (P/M) settings. The filters are designed to attenuate all aliasing frequencies to at least -40 dB (a gain of 0.01) at M class.

The synchrophasor measurement is adaptive as it follows the fundamental frequency over a wide range despite the reporting rate.

For example, when the synchrophasor measurement follows the fundamental frequency beyond the fixed Nyquist limits in C37.118 standard, the anti-aliasing filter stopband moves with the measured fundamental frequency. This has to be considered in connection with C37.118, where the passband is defined relative to a fixed nominal frequency as shown in the equation 15.

\[ f_0 = \frac{F_s}{2} \]

(Equation 15)

where,

- \( f_0 \) is the nominal frequency
- \( F_s \) is the reporting rate

### 6.2.3.3 Scaling Factors for ANALOGREPORT channels

The internal calculation of analog values in the IED is based on 32 bit floating point. Therefore, if the user selects to report the analog data (AnalogDataType) as Integer, there will be a down-conversion of a 32 bit floating value to a new 16 bit integer value. In such a case, in order to optimize the resolution of the reported analog data, the user-defined analog scaling is implemented in the IED.

The analog scaling in the IED is automatically calculated by use of the user-defined parameters AnalogXRange for the respective analog channel X. The analog data value
on the input X will have a range between \(-\text{AnalogXRange}\) and \(+\text{AnalogXRange}\). The resulting scale factor will be applied to the reported analog data where applicable.

If the \text{AnalogDataType} is selected as \text{Float}, then these settings are ignored.

The analog scaling in the IED is calculated using the equation:

\[
\text{Scalefactor} = \frac{\text{AnalogXRange} \times 2}{65535.0}
\]

\[
\text{offset} = 0.0
\]

\[
65535.0 = 16 \text{ bit integer range}
\]

According to the IEEE C37.118.2 standard, the scale factors (conversion factor) for analog channels are defined in configuration frame 2 (CFG-2) and configuration frame 3 (CFG-3) frames as follows:

- \textbf{CFG-2 frame:} The field ANUNIT (4 bytes) specifies the conversion factor as a signed 24 bit word for user defined scaling. Since it is a 24 bit integer, in order to support the floating point scale factor, the scale factor itself is multiplied in 10, so that a minimum of 0.1 scale factor can be sent over the CFG-2 frame. The resulting scale factor is rounded to the nearest decimal value. The clients receiving the Analog scale factor over CFG-2 should divide the received scale factor by 10 and then apply it to the corresponding analog data value.

- \textbf{CFG-3 frame:} The field ANSCALE (8 bytes) specifies the conversion factor as \(X' = M \times X + B\) where; M is magnitude scaling in 32 bit floating point (first 4 bytes) and B is the offset in 32 bit floating point (last 4 bytes).

The server uses CFG-3 scale factor to scale the analog data values. As a result, the clients which use scale factors in CFG-3 in order to recalculate analog values, will get a better resolution than using the scale factors in CFG-2.

The following examples show how the scale factor is calculated.

\textbf{Example 1:}

\[
\text{AnalogXRange} = 3277.0
\]

The scale factor is calculated as follows:

\[
\text{scalefactor} = \frac{(3277.0 \times 2.0)}{65535.0} = 0.1 \text{ and offset} = 0.0
\]

The scale factor will be sent as 1 on configuration frame 2, and 0.1 on configuration frame 3. The range of analog values that can be transmitted in this case is \(-0.1\) to \(-3276.8\) and \(+0.1\) to \(+3276.7\).
Example 2:

\[ \text{AnalogXRange} = 4915.5 \]

The scale factor is calculated as follows:

\[ \text{scalefactor} = \frac{(4915.5 \times 2.0)}{65535.0} = 0.15 \text{ and offset} = 0.0 \]

The scale factor will be sent as 1 on configuration frame 2, and 0.15 on configuration frame 3. The range of analog values that can be transmitted in this case is \(-0.15\) to \(-4915.5\) and \(+0.15\) to \(+4915.5\).

Example 3:

\[ \text{AnalogXRange} = 10000000000 \]

The scale factor is calculated as follows:

\[ \text{scalefactor} = \frac{(10000000000 \times 2.0)}{65535.5} = 305180.43 \text{ and offset} = 0.0 \]

The scale factor will be sent as 3051804 on configuration frame 2, and 305180.43 on configuration frame 3. The range of analog values that can be transmitted in this case is \(-305181\) to \(-10000000000\) and \(+305181\) to \(+10000000000\).

### 6.2.3.4 PMU Report Function Blocks Connection Rules in PCM600 Application Configuration Tool (ACT)

There are 3 important general rules which have to be considered in PCM600 ACT for the connection of preprocessor blocks (SMAI) and 3PHSUM blocks to PHASORREPORT blocks:

**Rule 1:**

Only SMAI or 3PHSUM blocks shall be connected to PMU PHASORREPORT blocks and they shall have the same cycle time, 1ms.

Figure 36 shows an example of correct connection of SMAI and PHASORREPORT blocks in ACT where both function blocks are working on 1ms cycle time.
Figure 36: An example of correct connection of SMAI and PHASORREPORT blocks in ACT

Figure 37 shows an example of wrong connection of SMAI and PHASORREPORT blocks in ACT where the SMAI block is working on 3ms while PHASORREPORT block is working on 1ms cycle time.

Violation of rule 1 results in PMU applications not running at all. The reason is the inconsistent cycle time. For example, in Figure 37, the SMAI block is updating its output every 3ms while the PHASORREPORT block is expecting input every 1ms. The PHASORREPORT filtering window is designed to receive updated input every 1ms and therefore the application will fail.

Rule 2:

The same SMAI or 3PHSUM block can be connected to more than one PHASORREPORT block only if all the connected PHASORREPORT blocks have similar instance number or only if all the connected PHASORREPORT blocks have similar settings for SvcClass and ReportRate. Figure 38 shows the settings for PMUREPORT function block demonstrated by PCM600 Parameter Setting Tool (PST).
Figure 38: **PMUREPORT settings in PCM600 PST**

Figure 39 shows an example of correct connection of SMAI and PHASORREPORT blocks in ACT where two different SMAI blocks are connected to different PHASORREPORT blocks with different instance numbers. In this example, as the PHASORREPORT blocks have different instance numbers and different settings for SvcClass and ReportRate, a separate SMAI block is used for each PHASORREPORT block.
Figure 39: An example of correct connection of SMAI and PHASORREPORT blocks in ACT

Figure 40 shows an example of wrong connection of SMAI and PHASORREPORT blocks in ACT where the same SMAI block is connected to different PHASORREPORT blocks with different instance numbers. Such connection will be only correct if both connected PHASORREPORT blocks have similar settings for SvcClass and ReportRate. If settings for PMUREPORT instances differ for SvcClass or ReportRate, then PHASOR1 connection in PHASORREPORT1 instance 2 will not be compliant with IEEE C37.118 standard. The reason is that the filtering in SMAI/3PHSUM block is adapted according to the performance class (SvcClass) and reporting rate of the connected instance of PHASORREPORT function block. In this example, SMAI1 will adapt its filtering according to PHASORREPORT instance 1 (because of higher priority) and therefore PHASORREPORT instance 2 will receive data which does not match its performance class and report rate.
Figure 40: An example of wrong connection of SMAI and PHASORREPORT blocks in ACT

Rule 3:

This rule is only related to the connection of 3PHSUM block to the PHASORREPORT block. If 3PHSUM block is configured to use external DFT reference (from SMAI reference block), it shall only be connected to the same PHASORREPORT block instance as the one the SMAI reference block is connected to. In other words, both the SMAI reference block and 3PHSUM block (3PHSUM block with external DFT reference) shall be connected to the same instance of PHASORREPORT block (PHASOR1-32 of Instance number 1 or 2).

Figure 41 shows an example of correct connection of 3PHSUM and PHASORREPORT blocks in ACT where SMAI3 is configured as the reference block for DFT reference external out (DFTRefExtOut) and 3PHSUM uses external DFT reference (from SMAI3). Figures 42 and 43 show the corresponding setting parameters.
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Figure 41: An example of correct connection of 3PHSUM and PHASORREPORT blocks in ACT

Figure 42: SMAI1 setting parameters example—showing that SMAI3 is selected as the DFT reference (DFTRefGrp3)
IEC 140000131-1 en

Figure 43: 3PHSUM setting parameters example-showing that 3PHSUM is using the External DFT reference coming indirectly from SMAI3

Figure 44 shows an example of wrong connection of 3PHSUM and PHASORREPORT blocks in ACT where SMAI3 is configured as the reference block for DFT reference external out (DFTRefExtOut) and 3PHSUM uses external DFT reference (from SMAI3).

IEC 140000132-1 en

Figure 44: An example of wrong connection of 3PHSUM and PHASORREPORT blocks in ACT

If settings for PMUREPORT instances (PHASORREPORT1 instances 1 and 2 above) differ for SvcClass or ReportRate, then the synchrophasor reported by PHASOR2 connection from PHASORREPORT1 instance 2 will not be compliant with IEEE C37.118 standard. The reason is as in the rule 2, the filtering in SMAI/3PHSUM block is adapted according to the performance class (SvcClass) and reporting rate of the connected instance of PHASORREPORT function block. On the other hand, when
3PHSUM uses external DFT reference, it also adapts its filtering according to the SMAI reference block. Therefore, in order to avoid two different filtering applied to the 3PHSUM block, both SMAI reference block and 3PHSUM shall be connected to the same PHASORREPORT instance. In this example (Figure 44), SMAI3 adapts its filtering according to PHASORREPORT1 instance 2 (due to connection) and 3PHSUM is adapting its filtering according to PHASORREPORT1 instance 1. On the other hand, since 3PHSUM is set to receive external DFT reference from SMAI3, therefore If settings for PHASORREPORT1 instances 1 and 2 above differ for SvcClass or ReportRate, then 3PHSUM block will be affected by two different filtering at the same time which is not possible. For example in Figure 44, PHASOR2 from PHASORREPORT1 instance 1 may not be fully compliant with IEEE C37.118 standard.

**Note:** If the SMAI reference block is not connected to any PHASORREPORT block, then 3PHSUM block can be freely connected to any PHASORREPORT block regardless of its DFT reference setting.

**Note:** If more 3PHSUM blocks need to be used, all 3PHSUM blocks (using external DFT ref) have to be connected to the same instance of PHASORREPORT blocks (PHASOR1-32 of Instance number 1 or 2).

**Note:** If settings SvcClass and ReportRate are the same for different instances of PHASORREPORT blocks, then 3PHSUM block can be freely connected to any of them regardless of 3PHSUM block DFT reference setting or the reference SMAI block connection.

**Note:** Violation of rules 2 or 3 results in non-compliance with IEEE C37.118 standard for some of the synchrophasors. In case of rule 2 violation, the non-compliance only applies to synchrophasors from instance 2 and the synchrophasors from instance 1 will be still compliant. The non-compliance with the standard may be quite obvious as in case of rule 2 violation with different SvcClass settings. This produces big angle error. On the other hand, it may be difficult to detect the non-compliance with the standard if rule 2 is violated with different ReportRates, or if rule 3 is violated. In such cases, the synchrophasors may only fail to comply (with small error) in some particular test case(s).

For more information regarding 3PHSUM block application, please refer to RES670 Application Manual under section Basic IED functions.

**6.2.4 Setting guidelines**

Based on the functionality and appearance in PCM600, the PMU reporting functionality is categorized into 4 different categories (function block) as follows:

1. PMUREPORT
2. PHASORREPORT
3. ANALOGREPORT
4. BINARYREPORT
Each category has its corresponding parameter settings except for BINARYREPORT function block which does not have any specific parameters and settings.

1. **PMUREPORT** is the main function block which controls the operation of other PMU reporting function blocks. Each instance of PMUREPORT function block has the following parameters:

   - **Operation**: Enables/Disables the operation of the corresponding instance of PMU reporting functionality by choosing *On/Off* setting.

   - **SvcClass**: It refers to the 1-byte SVC_CLASS field of the configuration frame 3 (CFG-3) organization defined in IEEE C37.118.2 message format. Here the user can select the performance class (service class) used for synchrophasor data measurement according to IEEE C37.118.1 standard. The options are *P class* or *M class*.

     **Note**: There are 2 PMUREPORT instances available (PMUREPORT:1 and PMUREPORT:2) corresponding to 2 independent data streams. The user can set different or identical service class for each data stream. In case of different service classes, special rules shall be considered in PCM600 ACT for the connection of preprocessor blocks (SMAI) and 3PHSUM blocks to PHASORREPORT blocks. More details are available under section **PMU Report Function Blocks Connection Rules in PCM600 Application Configuration Tool (ACT)**.

   - **Global_PMU_ID**: It refers to the 16-byte G_PMU_ID field of the configuration frame 3 (CFG-3) organization defined in IEEE C37.118.2 message format. It is a 16-character (128 bits) user-assigned value which can be sent with the configuration 3 message. It allows uniquely identifying PMUs in a system that has more than 65535 PMUs. The coding for the 16 bytes is left to the user for assignment.

   - **PMUdataStreamIDCODE**: It refers to the 2-byte IDCODE field of the configuration frame and data frame organization defined in IEEE C37.118.2 message format. It is a user assigned ID number (1-65534) for each data stream sent out from the PMU. This is especially important when having multiple data streams (multiple PMU functionality).

     **Note**: The data stream IDCODE is a unique code for each and every data stream in one physical PMU device. In the IED, there are 2 PMUREPORT instances available (PMUREPORT:1 and PMUREPORT:2) corresponding to 2 independent data streams. The user must set different IDCODEs for each instance.

   - **PhasorFormat**: It refers to the Bit 0 of the FORMAT field of the configuration frames 1, 2 and 3 organization defined in IEEE C37.118.2 message format. Here the user can select the format of the calculated synchrophasors. The options are **Rectangular** or **Polar** format. Rectangular format represents the synchrophasor as real and imaginary values, real value first \((a + bj)\) while the Polar format represents the synchrophasor as magnitude and angle, magnitude first \((A e^{j\alpha})\).

   - **PhasorDataType**: It refers to the Bit 1 of the FORMAT field of the configuration frames 1, 2 and 3 organization defined in IEEE C37.118.2 message format. Here the user can select the data type of the calculated synchrophasors. The options are **Integer** or **Float** data. The synchrophasor data are sent via the PHASORS field of data frame organization of IEEE C37.118.2 message format.
C37.118.2 message format. Depends on the phasor data type, the size of PHASORS field can be 4 (Integer) or 8 (Float) bytes per IEEE C37.118.2 message.

**Integer** data type for the phasors corresponds to a 16-bit integer value. It represents a 16-bit signed integer, range –32 767 to +32 767, in rectangular format, and in polar format it represents a 16-bit unsigned integer range 0 to 65535 for the magnitude and a 16-bit signed integer, in radians \( \times 10^4 \), range –31 416 to +31 416 for the angle.

**Float** data type for the phasors corresponds to 32-bit values in IEEE floating-point format. In rectangular format, it represents real and imaginary, in engineering units (real value first) and in polar format it represents magnitude and angle, in engineering units (magnitude first) and angle in radians, range \(-\pi\) to \(+\pi\).

- **AnalogDataType**: It refers to the Bit 2 of the FORMAT field of the configuration frames 1, 2 and 3 organization defined in IEEE C37.118.2 message format. Here the user can select the type of the analog data which are reported along with the synchrophasor data over IEEE C37.118.2 message. The options are **Integer** or **Float** data corresponding to the 16-bit integer or 32-bit IEEE floating-point values, respectively. The analog data could be sampled data such as control signal or transducer values, or it can be active and reactive power measurement values from each feeder in the substation. Values and ranges are separately defined by user via the parameter settings related to the ANALOGREPORT function block. The analog data are sent via the ANALOG field of data frame organization of IEEE C37.118.2 message format. Depends on the analog data type, the size of ANALOG field can be 2 (Integer) or 4 (Float) bytes per IEEE C37.118.2 message. More information is available under the section [Scaling Factors for ANALOGREPORT channels](#).

- **FrequencyDataType**: It refers to the Bit 3 of the FORMAT field of the configuration frames 1, 2 and 3 organization defined in IEEE C37.118.2 message format. Here the user can select the type of the frequency-deviation and rate-of-change-of-frequency data (FREQ/DFREQ) which can be reported along with the synchrophasor data over IEEE C37.118.2 message. The options are **Integer** or **Float** data corresponding to the 16-bit integer or 32-bit IEEE floating-point value, respectively. The frequency-deviation and rate-of-change-of-frequency data are sent via the FREQ and DFREQ fields of data frame organization of IEEE C37.118.2 message format. Depends on the selected data type, the size of each field can be 2 (Integer) or 4 (Float) bytes per IEEE C37.118.2 message.

  The data sent via the FREQ field is frequency deviation from nominal frequency (50 Hz or 60 Hz), in mHz. It is ranged from \(-32.767\) to \(+32.767\) Hz. **Integer** data type for frequency-deviation data represents 16-bit signed integers, range \(-32 767\) to \(+32 767\) \(32\), and **Float** data type represents actual frequency value in IEEE floating-point format.

  The data sent via the DFREQ field is Rate Of Change Of Frequency (ROCOF), in Hertz per second times 100. It is ranged from \(-327.67\) to \(+327.67\) Hz per second. **Integer** data type for ROCOF data represents 16-bit signed integers, range \(-32 767\) to \(+32 767\) \(32\), and **Float** data type represents actual value in IEEE floating-point format.
• **SendFreqInfo**: Enables/Disables sending of the frequency-deviation and Rate Of Change Of Frequency (ROCOF) data by choosing *On/Off* setting.

• **ReportRate**: It refers to the 2-byte DATA_RATE field of the configuration frames 1, 2 and 3 organization defined in IEEE C37.118.2 message format. The DATA_RATE field is identifying the Rate of phasor data transmissions by a 2-byte integer word (−32767 to +32767). Here the user can select the synchrophasor data reporting rate from the PMU based on the number of frames per second.

In general, the IED has 5 different reporting rates (10, 25, 50, 100, 200 fr/s) on the 50 Hz system frequency, and has 8 different reporting rates (10, 12, 15, 20, 30, 60, 120, 240 fr/s) on the 60 Hz system frequency. The options are as follows:

- **10/10 fr/s (60/50Hz)**
- **12/10 fr/s (60/50Hz)**
- **15/10 fr/s (60/50Hz)**
- **20/25 fr/s (60/50Hz)**
- **30/25 fr/s (60/50Hz)**
- **60/50 fr/s (60/50Hz)**
- **120/100 fr/s (60/50Hz)**
- **240/200 fr/s (60/50Hz)**

The first number is identifying the reporting rate in a 60Hz system, and the second number is the reporting rate in a 50Hz system. For example, if the selected setting is **15/10 fr/s (60/50Hz)**, this means that the synchrophasor data reporting rate would be 15 frames per second if the system frequency is 60Hz. Likewise, if the system frequency is 50Hz, the selected rate is equal to 10 frames per second.

• **RptTimetag**: It refers to the method of time-tagging used in the IED which is related to the phasor estimation and filtering technique. The options are **FirstSample**, **MiddleSample** and **LastSample**. The time-stamp of the PMU output represents the phasor equivalent, frequency, and ROCOF of the power system signal at the time it is applied to the PMU input. All of these estimates must be compensated for PMU processing delays including analog input filtering, sampling, and estimation group delay. If the sample time tags are compensated for all input delays, the time tag of the sample in the middle of the estimation window can be used for the phasor estimation (output) time tag as long as the filtering coefficients are symmetrical across the filtering window.

**Note**: It is recommended to set this parameter on *MiddleSample*.

2. **PHASORREPORT** is the function block responsible for reporting the synchrophasors. Each instance of PMUREPORT function block has 32 phasor channels with the following setting parameters; where X is a number from 1 to 32:

• **PhasorXReport**: Enables/Disables the phasor channel X (reporting of PhasorX) by choosing *On/Off* setting.

• **PhasorX**: The group selector for PhasorX. Here, the user can select the type of reported synchrophasor from the phasor channel X as either a 3-phase symmetrical component or a single-phase phasor. The options are as follows:
• A
• B
• C
• NEGSEQ
• POSSEQ
• ZEROSEQ

• PhasorXUseFreqSrc: Enables/Disables the contribution of Phasor channel X in automatic frequency source selection by choosing On/Off setting. Each voltage-connected preprocessor block delivers the frequency data, derived from the analog input AC voltage values, to the respective voltage phasor channel. Every phasor channel has a user-settable parameter (PhasorXUseFreqSrc) to be used as a source of frequency data for reporting to the PDC client. It is very important to set this parameter to On for the voltage-connected phasor channels. There is an automatic frequency source selection logic to ensure an uninterrupted reporting of the system frequency to the PDC client. More information is available under the section Frequency reporting.

3. ANALOGREPORT is the function block responsible for reporting the analog values. Each instance of ANALOGREPORT function block has 24 analog channels with the following setting parameters; where X is a number from 1 to 24:

• AnalogXRange: This parameter defines a range between $-\text{AnalogXRange}$ and $+\text{AnalogXRange}$ for AnalogX value. The range will be used by the IED to apply a proper scale factor to the AnalogX values when Integer format is used. It refers to the 4-byte ANUNIT field of the configuration frames 1, 2 organization and the 8-byte ANSCALE field of the configuration frame 3 organization defined in IEEE C37.118.2 message format. The AnalogXRange value can be a number between $3277.0$ and $10000000000$. This setting is only important if the AnalogDataType setting is selected as Integer. More information is available under the section Scaling Factors for ANALOGREPORT channels.
• AnalogXUnitType: Unit type for analog signal X. It refers to the 4-byte ANUNIT field of the configuration frames 1, 2 organization defined in IEEE C37.118.2 message format. The options are Single point-on-wave, RMS of analog input and Peak of analog input.
Section 7  Impedance protection

7.1  Power swing detection ZMRPSB

7.1.1  Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60817 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power swing detection</td>
<td>ZMRPSB</td>
<td></td>
<td>68</td>
</tr>
</tbody>
</table>

7.1.2  Application

7.1.2.1  General

Various changes in power system may cause oscillations of rotating units. The most typical reasons for these oscillations are big changes in load or changes in power system configuration caused by different faults and their clearance. As the rotating masses strive to find a stable operate condition, they oscillate with damped oscillations until they reach the final stability.

The extent of the oscillations depends on the extent of the disturbances and on the natural stability of the system.

The oscillation rate depends also on the inertia of the system and on the total system impedance between different generating units. These oscillations cause changes in phase and amplitude of the voltage difference between the oscillating generating units in the power system, which reflects further on in oscillating power flow between two parts of the system - the power swings from one part to another - and vice versa.

Distance IEDs located in interconnected networks see these power swings as the swinging of the measured impedance in relay points. The measured impedance varies with time along a locus in an impedance plane, see figure 45. This locus can enter the operating characteristic of a distance protection and cause, if no preventive measures have been considered, its unwanted operation.
7.1.2.2 Basic characteristics

Power swing detection function (ZMRPSB) detects reliably power swings with periodic time of swinging as low as 200 ms (which means slip frequency as high as 10% of the rated frequency on the 50 Hz basis). It detects the swings under normal system operate conditions as well as during dead time of a single-pole automatic reclosing cycle.

ZMRPSB function is able to secure selective operation for internal faults during power. The operation of the distance protection function remains stable for external faults during the power swing condition, even with the swing (electrical) centre located on the protected power line.

The operating characteristic of the ZMRPSB function is easily adjustable to the selected impedance operating characteristics of the corresponding controlled distance protection zones as well as to the maximum possible load conditions of the protected power lines. See the corresponding description in “Technical reference manual” for the IEDs.

7.1.3 Setting guidelines

Setting guidelines are prepared in the form of a setting example for the protected power line as part of a two-machine system presented in figure 46.
Reduce the power system with protected power line into equivalent two-machine system with positive sequence source impedances $Z_{SA}$ behind the IED and $Z_{SB}$ behind the remote end bus B. Observe a fact that these impedances can not be directly calculated from the maximum three-phase short circuit currents for faults on the corresponding busbar. It is necessary to consider separate contributions of different connected circuits.

The required data is as follows:

- $U_r = 400kV$ Rated system voltage
- $U_{\min} = 380kV$ Minimum expected system voltage under critical system conditions
- $f_r = 50Hz$ Rated system frequency
- $U_p = \frac{400}{\sqrt{3}} kV$ Rated primary voltage of voltage protection transformers used
- $U_s = \frac{0.11}{\sqrt{3}} kV$ Rated secondary voltage of voltage instrument transformers used
- $I_p = 1200A$ Rated primary current of current protection transformers used
- $I_s = 1A$ Rated secondary current of current protection transformers used
- $Z_{L1} = (10.71 + j75.6) \Omega$ Line positive sequence impedance
\[ Z_{S1} = (1.15 + j43.5) \Omega \] Positive sequence source impedance behind A bus

\[ Z_{SB1} = (5.3 + j35.7) \Omega \] Positive sequence source impedance behind B bus

\[ S_{\text{max}} = 1000 \text{MVA} \] Maximum expected load in direction from A to B (with minimum system operating voltage \( U_{\text{min}} \))

\[ \cos( \varphi_{\text{max}} ) = 0.95 \] Power factor at maximum line loading

\[ \varphi_{\text{max}} = 25^\circ \] Maximum expected load angle

\[ f_{\text{sl}} = 2.5 \text{Hz} \] Maximum possible initial frequency of power oscillation

\[ f_{\text{sc}} = 7.0 \text{Hz} \] Maximum possible consecutive frequency of power oscillation

The impedance transformation factor, which transforms the primary impedances to the corresponding secondary values is calculated according to equation 16. Consider a fact that all settings are performed in primary values. The impedance transformation factor is presented for orientation and testing purposes only.

\[
KIMP = \frac{I_p}{I_s} \cdot \frac{U_s}{U_p} = \frac{1200}{1} \cdot \frac{0.11}{400} = 0.33
\]

(Equation 16)

The minimum load impedance at minimum expected system voltage is equal to equation 17.

\[
|Z_{L,\text{min}}| = \frac{U_{\text{min}}^2}{S_{\text{max}}} = \frac{380^2}{1000} = 144.4 \Omega
\]

(Equation 17)

The minimum load resistance \( R_{L,\text{min}} \) at maximum load and minimum system voltage is equal to equation 18.

\[
R_{L,\text{min}} = |Z_{L,\text{min}}| \cdot \cos( \varphi_{\text{max}} ) = 144.4 \cdot 0.95 = 137.2 \Omega
\]

(Equation 18)
The system impedance $Z_S$ is determined as a sum of all impedance in an equivalent two-machine system, see figure 46. Its value is calculated according to equation 19.

$$Z_S = Z_{S41} + Z_{L1} + Z_{S91} = (17.16 + j154.8) \Omega$$

(Equation 19)

The calculated value of the system impedance is of informative nature and helps determining the position of oscillation center, see figure 47, which is for general case calculated according to equation 20.

$$Z_{CO} = \frac{Z_S}{1 + \left| \frac{E_B}{E_A} \right|} - Z_{S41}$$

(Equation 20)

In particular cases, when

$$\left| \frac{E_A}{E_B} \right| = \left| \frac{E_A}{E_B} \right|$$

(Equation 21)

resides the center of oscillation on impedance point, see equation 22.

$$Z_{CO} = \frac{Z_S}{2} - Z_{S41} = (7.43 + j33.9) \Omega$$

(Equation 22)
Figure 47: Impedance diagrams with corresponding impedances under consideration

The outer boundary of oscillation detection characteristic in forward direction $RLdOutFw$ should be set with certain safety margin $K_L$ compared to the minimum expected load resistance $R_{Lmin}$. When the exact value of the minimum load resistance is not known, the following approximations may be considered for lines with rated voltage 400 kV:
• \( K_L = 0.9 \) for lines longer than 150 km
• \( K_L = 0.85 \) for lines between 80 and 150 km
• \( K_L = 0.8 \) for lines shorter than 80 km

Multiply the required resistance for the same safety factor \( K_L \) with the ratio between actual voltage and 400kV when the rated voltage of the line under consideration is higher than 400kV. The outer boundary \( R_{LdOutFw} \) obtains in this particular case its value according to equation 23.

\[
R_{LdOutFw} = K_L \cdot R_{L_{min}} = 0.9 \cdot 137.2 = 123.5 \Omega
\]

(Equation 23)

It is a general recommendation to set the inner boundary \( R_{LdInFw} \) of the oscillation detection characteristic to 80% or less of its outer boundary. Exceptions are always possible, but must be considered with special care especially when it comes to settings of timers \( tP1 \) and \( tP2 \) included in oscillation detection logic. This requires the maximum permitted setting values of factor \( k_{LdRFw} = 0.8 \). Equation 24 presents the corresponding maximum possible value of \( R_{LdInFw} \).

\[
R_{LdInFw} = k_{LdRFw} \cdot R_{LdOutFw} = 98.8 \Omega
\]

(Equation 24)

The load angles, which correspond to external \( \delta_{Out} \) and internal \( \delta_{In} \) boundary of proposed oscillation detection characteristic in forward direction, are calculated with sufficient accuracy according to equation 25 and 26 respectively.

\[
\delta_{Out} = 2 \cdot \arctan \left( \frac{|Z_L|}{2 \cdot R_{LdOutFw}} \right) = 2 \cdot \arctan \left( \frac{155.75}{2 \cdot 123.5} \right) = 64.5^\circ
\]

(Equation 25)

\[
\delta_{In} = 2 \cdot \arctan \left( \frac{|Z_L|}{2 \cdot R_{LdInFw_{max}}} \right) = 2 \cdot \arctan \left( \frac{155.75}{2 \cdot 98.8} \right) = 76.5^\circ
\]

(Equation 26)

The required setting \( tP1 \) of the initial oscillation detection timer depends on the load angle difference according to equation 27.

\[
tP1 = \frac{\delta_{In} - \delta_{Out}}{f_s \cdot 360^\circ} = \frac{76.5^\circ - 64.5^\circ}{2.5 \cdot 360^\circ} = 13.3 \text{ms}
\]

(Equation 27)

The general tendency should be to set the \( tP1 \) time to at least 30 ms, if possible. Since it is not possible to further increase the external load angle \( \delta_{Out} \), it is necessary to
reduce the inner boundary of the oscillation detection characteristic. The minimum required value is calculated according to the procedure listed in equation 28, 29, 30 and 31.

\[ tP_{1_{\text{min}}} = 30 \text{ms} \]

(Equation 28)

\[ \delta_{m_{\text{in}}} = 360^\circ \cdot f_{s1} \cdot tP_{1_{\text{min}}} + \delta_{Out} = 360^\circ \cdot 2.5 \cdot 0.030 + 64.5^\circ = 91.5^\circ \]

(Equation 29)

\[ RLDInFw_{max1} = \frac{|Z_s|}{2 \cdot \tan \left( \frac{\delta_{m_{\text{in}}}}{2} \right)} = \frac{155.75}{2 \cdot \tan \left( \frac{91.5^\circ}{2} \right)} = 75.8\Omega \]

(Equation 30)

\[ kLdRFw = \frac{RLDInFw_{max1}}{RLDOutFw} = \frac{75.8}{123.5} = 0.61 \]

(Equation 31)

Also check if this minimum setting satisfies the required speed for detection of consecutive oscillations. This requirement will be satisfied if the proposed setting of \( tP_2 \) time remains higher than 10 ms, see equation 32.

\[ tP_{2_{\text{max}}} = \frac{\delta_{m} - \delta_{Out}}{f_{sc} \cdot 360^\circ} = \frac{91.5^\circ - 64.5^\circ}{7 \cdot 360^\circ} = 10.7\text{ms} \]

(Equation 32)

The final proposed settings are as follows:

RLDOutFw = 123.5Ω

kLdRFw = 0.61

\( tP_1 = 30 \text{ ms} \)

\( tP_2 = 10 \text{ ms} \)

Consider RLdInFw = 75.0Ω.

Do not forget to adjust the setting of load encroachment resistance \( RLdFw \) in Phase selection with load encroachment (FDPSPDIS or FRPSPDIS) to the value equal to or less than the calculated value RLdInFw. It is at the same time necessary to adjust the load angle in
FDSPDIS or FRPSPDIS to follow the condition presented in equation 33.

Index PHS designates correspondence to FDSPDIS or FRPSPDIS function and index PSD the correspondence to ZMRPSB function.

\[ \text{ArgLd}_{PHS} \geq \arctan \left( \frac{\tan (\text{ArgLd}_{PSD})}{kLdRFw} \right) \]

(Equation 33)

Consider equation 34,

\[ \text{ArgLd}_{PSD} = \varphi_{\text{max}} = 25^\circ \]

(Equation 34)

then it is necessary to set the load argument in FDSPDIS or FRPSPDIS function to not less than equation 35.

\[ \text{ArgLd}_{PHS} \geq \arctan \left( \frac{\tan (\text{ArgLd}_{PSD})}{kLdRFw} \right) = \arctan \left( \frac{\tan (25^\circ)}{0.61} \right) = 37.5^\circ \]

(Equation 35)

It is recommended to set the corresponding resistive reach parameters in reverse direction (RLdOutRv and kLdRRv) to the same values as in forward direction, unless the system operating conditions, which dictate motoring and generating types of oscillations, requires different values. This decision must be made on basis of possible system contingency studies especially in cases, when the direction of transmitted power may change fast in short periods of time. It is recommended to use different setting groups for operating conditions, which are changing only between different periods of year (summer, winter).

System studies should determine the settings for the hold timer \( tH \). The purpose of this timer is, to secure continuous output signal from Power swing detection function (ZMRPSB) during the power swing, even after the transient impedance leaves ZMRPSB operating characteristic and is expected to return within a certain time due to continuous swinging. Consider the minimum possible speed of power swinging in a particular system.

The \( tR1 \) inhibit timer delays the influence of the detected residual current on the inhibit criteria for ZMRPSB. It prevents operation of the function for short transients in the residual current measured by the IED.

The \( tR2 \) inhibit timer disables the output START signal from ZMRPSB function, if the measured impedance remains within ZMRPSB operating area for a time longer than
the set $tR_2$ value. This time delay was usually set to approximately two seconds in older power-swing devices.

The setting of the $tEF$ timer must cover, with sufficient margin, the opening time of a circuit breaker and the dead-time of a single-phase autoreclosing together with the breaker closing time.

### 7.2 Out-of-step protection OOSPPAM

#### 7.2.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60817 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Out-of-step protection</td>
<td>OOSPPAM</td>
<td></td>
<td>78</td>
</tr>
</tbody>
</table>

#### 7.2.2 Application

Under balanced and stable conditions, a generator operates with a constant rotor (power) angle, delivering an active electrical power to the power system, which is equal to the mechanical input power on the generator axis, minus the small losses in the generator. In the case of a three-phase fault electrically close to the generator, no active power can be delivered. Almost all mechanical power from the turbine is under this condition used to accelerate the moving parts, that is, the rotor and the turbine. If the fault is not cleared quickly, the generator may not remain in synchronism after the fault has been cleared. If the generator loses synchronism (Out-of-step) with the rest of the system, pole slipping occurs. This is characterized by a wild flow of synchronizing power, which reverses in direction twice for every slip cycle.

The out-of-step phenomenon occurs when a phase opposition occurs periodically between different parts of a power system. This is often shown in a simplified way as two equivalent generators connected to each other via an equivalent transmission line and the phase difference between the equivalent generators is 180 electrical degrees.
The center of the electromechanical oscillation can be in the generator unit (or generator-transformer unit) or outside, somewhere in the power system. When the center of the electromechanical oscillation occurs within the generator it is essential to trip the generator immediately. If the center of the electromechanical oscillation is outside any of the generators in the power system, the power system should be split into two different parts; so each part may have the ability to restore stable operating conditions. This is sometimes called “islanding”. The objective of islanding is to prevent an out-of-step condition from spreading to the healthy parts of the power system. For this purpose, uncontrolled tripping of interconnections or generators must be prevented. It is evident that a reasonable strategy for out-of-step relaying as well as, appropriate choice of other protection relays, their locations and settings require detailed stability studies for each particular power system and/or subsystem. On the other hand, if severe swings occur, from which a fast recovery is improbable, an attempt should be made to isolate the affected area from the rest of the system by opening connections at predetermined points. The electrical system parts swinging to each other can be separated with the lines closest to the center of the power swing allowing the two systems to be stable as separated islands. The main problem involved with systemic islanding of the power system is the difficulty, in some cases, of predicting the optimum splitting points, because they depend on the fault location and the pattern of generation and load at the respective time. It is hardly possible to state general rules for out-of-step relaying, because they shall be defined according to the particular design and needs of each electrical network. The reason for the existence of two zones of operation is selectivity, required for successful islanding. If there are several out-of-step relays in the power system, then selectivity between separate relays is obtained by the relay reach (for example zone 1) rather then by time grading.

The out-of-step condition of a generator can be caused by different reasons. Sudden events in an electrical power system such as large changes in load, fault occurrence or slow fault clearance, can cause power oscillations, that are called power swings. In a non-recoverable situation, the power swings become so severe that the synchronism is lost: this condition is called pole slipping.
Undamped oscillations occur in power systems, where generator groups at different locations are not strongly electrically connected and can oscillate against each other. If the connection between the generators is too weak the magnitude of the oscillations may increase until the angular stability is lost. More often, a three-phase short circuit (unsymmetrical faults are much less dangerous in this respect) may occur in the external power grid, electrically close to the generator. If the fault clearing time is too long, the generator accelerates so much, that the synchronism cannot be maintained even if the power system is restored to the pre-fault configuration, see Figure 49.

![Figure 49: Stable and unstable case. For the fault clearing time t\text{cl} = 200 ms, the generator remains in synchronism, for t\text{cl} = 260 ms, the generator loses step.](IEC10000108-2-en.vsd)

A generator out-of-step condition, with successive pole slips, can result in damages to the generator, shaft and turbine.

- Stator windings are under high stress due to electrodynamic forces.
- The current levels during an out-of-step condition can be higher than those during a three-phase fault and, therefore, there is significant torque impact on the generator-turbine shaft.
- In asynchronous operation there is induction of currents in parts of the generator normally not carrying current, thus resulting in increased heating. The consequence can be damages on insulation and iron core of both rotor and stator.

Measurement of the magnitude, direction and rate-of-change of load impedance relative to a generator’s terminals provides a convenient and generally reliable means of detecting whether pole-slipping is taking place. The out-of-step protection should protect a generator or motor (or two weakly connected power systems) against pole-
slipping with severe consequences for the machines and stability of the power system. In particular it should:

1. Remain stable for normal steady state load.
2. Distinguish between stable and unstable rotor swings.
3. Locate electrical centre of a swing.
4. Detect the first and the subsequent pole-slips.
5. Prevent stress on the circuit breaker.
7. Provide information for post-disturbance analysis.

### 7.2.3 Setting guidelines

The setting example for generator protection application shows how to calculate the most important settings $\text{ForwardR}$, $\text{ForwardX}$, $\text{ReverseR}$, and $\text{ReverseX}$.

<table>
<thead>
<tr>
<th>Turbine (hydro)</th>
<th>Generator 200 MVA</th>
<th>Transformer 300 MVA</th>
<th>Double power line 230 kV, 300 km</th>
<th>Equivalent power system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data required</td>
<td>Generator</td>
<td>Step-up transformer</td>
<td>Single power line</td>
<td>Power system</td>
</tr>
<tr>
<td></td>
<td>UBase = Ugen = 13.8 kV</td>
<td>U1 = 13.8 kV</td>
<td>Uline = 230 kV</td>
<td>Unorm = 230 kV</td>
</tr>
<tr>
<td></td>
<td>iBase = Igen = 8367 A</td>
<td>U2 = 230 kV</td>
<td></td>
<td>SC level = 5000 MVA</td>
</tr>
<tr>
<td></td>
<td>Xd' = 0.2960 pu</td>
<td>usc = 10%</td>
<td></td>
<td>SC current = 12 551 A</td>
</tr>
<tr>
<td></td>
<td>Rs = 0.0029 pu</td>
<td>I1 = 12 551 A</td>
<td></td>
<td>$\phi = 84.289^\circ$</td>
</tr>
<tr>
<td></td>
<td>Xe = 10.5801 Ω</td>
<td></td>
<td>Ze = 10.5801 Ω</td>
<td></td>
</tr>
<tr>
<td>1-st step in calculation</td>
<td>ZBase = 0.9522 Ω (generator)</td>
<td>ZBase (13.8 kV) = 0.6348 Ω</td>
<td>Xline = 300 · 0.4289 = 128.7 Ω</td>
<td>Xe = Ze · sin ($\phi$) = 10.52 Ω</td>
</tr>
<tr>
<td></td>
<td>Rs = 0.0029 · 0.952 = 0.003 Ω</td>
<td>Rt = 0.0054 · 0.635 = 0.003 Ω</td>
<td>Rline = 300 · 0.0659 = 19.8 Ω</td>
<td>Re = Ze · cos ($\phi$) = 1.05 Ω</td>
</tr>
<tr>
<td></td>
<td>Rs = 0.0029 · 0.952 = 0.003 Ω</td>
<td>Xi = 0.100 · 0.6348 = 0.064 Ω</td>
<td>X and R above on 230 kV basis</td>
<td>(X and R referred to 230 kV basis)</td>
</tr>
<tr>
<td></td>
<td>Xi = 0.100 · 0.6348 = 0.064 Ω</td>
<td>Rl = 0.0054 · 0.635 = 0.003 Ω</td>
<td>Xl = 0.100 · 0.6348 = 0.064 Ω</td>
<td>X and R referred to 13.8 kV</td>
</tr>
<tr>
<td>2-nd step in calculation</td>
<td>Xl = 0.100 · 0.6348 = 0.064 Ω</td>
<td>Rl = 0.0054 · 0.635 = 0.003 Ω</td>
<td>Xe = 128.7 · (13.8/230)^2 = 0.064 Ω</td>
<td>Xe = 10.52 · (13.8/230)^2 = 0.038 Ω</td>
</tr>
<tr>
<td></td>
<td>Xi = 0.100 · 0.6348 = 0.064 Ω</td>
<td>Rl = 0.0054 · 0.635 = 0.003 Ω</td>
<td>Rline = 19.8 · (13.8/230)^2 = 0.071 Ω</td>
<td>Re = 1.05 · (13.8/230)^2 = 0.004 Ω</td>
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<td></td>
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<td></td>
<td></td>
<td>(X and R referred to 13.8 kV)</td>
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<td>3-rd step in calculation</td>
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<tr>
<td>Final resulted settings</td>
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</table>

Settings $\text{ForwardR}$, $\text{ForwardX}$, $\text{ReverseR}$, and $\text{ReverseX}$. 
A precondition in order to be able to use the Out-of-step protection and construct a suitable lens characteristic is that the power system in which the Out-of-step protection is installed, is modeled as a two-machine equivalent system, or as a single machine – infinite bus equivalent power system. Then the impedances from the position of the Out-of-step protection in the direction of the normal load flow can be taken as forward.

The settings $\text{ForwardX}$, $\text{ForwardR}$, $\text{ReverseX}$ and $\text{ReverseR}$ must, if possible, take into account, the post-disturbance configuration of the simplified power system. This is not always easy, in particular with islanding. But for the two machine model as in Table 8, the most probable scenario is that only one line is in service after the fault on one power line has been cleared by line protections. The settings $\text{ForwardX}$, $\text{ForwardR}$ must therefore take into account the reactance and resistance of only one power line.

All the reactances and resistances ($\text{ForwardX}$, $\text{ForwardR}$, $\text{ReverseX}$ and $\text{ReverseR}$) must be referred to the voltage level where the Out-of-step relay is installed; for the example case shown in Table 8, this is the generator nominal voltage $U_{\text{Base}} = 13.8$ kV. This affects all the forward reactances and resistances in Table 8.

All reactances and resistances must be finally expressed in percent of $Z_{\text{Base}}$, where $Z_{\text{Base}}$ is for the example shown in Table 8 the base impedance of the generator, $Z_{\text{Base}} = 0.9522 \, \Omega$. Observe that the power transformer’s base impedance is different, $Z_{\text{Base}} = 0.6348 \, \Omega$. Observe that this latter power transformer $Z_{\text{Base}} = 0.6348 \, \Omega$ must be used when the power transformer reactance and resistance are transformed.

For the synchronous machines as the generator in Table 8, the transient reactance $X_d'$ shall be used. This due to the relatively slow electromechanical oscillations under out-of-step conditions.

Sometimes the equivalent resistance of the generator is difficult to get. A good estimate is 1 percent of transient reactance $X_d'$. No great error is done if this resistance is set to zero (0).

Inclination of the Z-line, connecting points SE and RE, against the real (R) axis can be calculated as $\arctan\left(\frac{\text{ReverseX} + \text{ForwardX}}{\text{ReverseR} + \text{ForwardR}}\right)$, and is for the case in Table 8 equal to 84.55 degrees, which is a typical value.

Other settings:

- $\text{ReachZ1}$: Determines the reach of the zone 1 in the forward direction. Determines the position of the X-line which delimits zone 1 from zone 2. Set in % of $\text{ForwardX}$. In the case shown in Table 8, where the reactance of the step-up power transformer is 11.32 % of the total $\text{ForwardX}$, the setting $\text{ReachZ1}$ should be set to $\text{ReachZ1} = 12$ %. This means that the generator – step-up transformer unit would be in the zone 1. In other words, if the centre of oscillation would be found to be within the zone 1, only a very limited number of pole-slips would be allowed, usually only one.

- $\text{StartAngle}$: Angle between the two equivalent rotors induced voltages (that is, the angle between the two internal induced voltages $E1$ and $E2$ in an equivalent simplified two-machine system) to get the start signal, in degrees. The width of the lens characteristic is determined by the value of this setting. Whenever the
complex impedance $Z(R, X)$ enters the lens, this is a sign of instability. The angle recommended is 110 or 120 degrees, because it is at this rotor angle where problems with dynamic stability usually begin. Power angle 120 degrees is sometimes called “the angle of no return” because if this angle is reached under generator swings, the generator is most likely to lose synchronism. When the complex impedance $Z(R, X)$ enters the lens the start output signal (START) is set to 1 (TRUE).

- **TripAngle**: The setting TripAngle specifies the value of the rotor angle where the trip command is sent to the circuit breaker in order to minimize the stress to which the breaker is exposed when breaking the currents. The range of this value is from 15° to 90°, with higher values suitable for longer breaker opening times. If a breaker opening is initiated at for example 60°, then the circuit breaker opens its contacts closer to 0°, where the currents are smaller. If the breaker opening time $t_{\text{Breaker}}$ is known, then it is possible to calculate more exactly when opening must be initiated in order to open the circuit breaker contacts as close as possible to 0°, where the currents are smallest. If the breaker opening time $t_{\text{Breaker}}$ is specified (that is, higher than the default 0.0 s, where 0.0 s means that $t_{\text{Breaker}}$ is unknown), then this alternative way to determine the moment when a command to open the breaker is sent, is automatically chosen instead of the more approximate method, based on the TripAngle.

- **tReset**: Interval of time since the last pole-slip detected, when the Out-of-step protection is reset. If there is no more pole slips detected under the time interval specified by $t_{\text{Reset}}$ since the previous one, the function is reset. All outputs are set to 0 (FALSE). If no pole slip at all is detected under interval of time specified by $t_{\text{Reset}}$ since the start signal has been set (for example a stable case with synchronism retained), the function is as well reset, which includes the start output signal (START), which is reset to 0 (FALSE) after $t_{\text{Reset}}$ interval of time has elapsed. However, the measurements of analogue quantities such as R, X, P, Q, and so on continue without interruptions. Recommended setting of $t_{\text{Reset}}$ is in the range of 6 to 12 seconds.

- **NoOfSlipsZ1**: Maximum number of pole slips with centre of electromechanical oscillation within zone 1 required for a trip. Usually, $\text{NoOfSlipsZ1} = 1$.

- **NoOfSlipsZ2**: Maximum number of pole slips with centre of electromechanical oscillation within zone 2 required for a trip. The reason for the existence of two zones of operation is selectivity, required particularly for successful islanding. If there are several pole slip (out-of-step) relays in the power system, then selectivity between relays is obtained by the relay reach (for example zone 1) rather then by time grading. In a system, as in Table 8, the number of allowed pole slips in zone 2 can be the same as in zone 1. Recommended value: $\text{NoOfSlipsZ2} = 2$ or 3.

- **Operation**: With the setting Operation OOSPPAM function can be set On/Off.

- **OperationZ1**: Operation zone 1 On, Off. If OperationZ1 = Off, all pole-slips with centre of the electromechanical oscillation within zone 1 are ignored. Default setting = On. More likely to be used is the option to extend zone 1 so that zone 1 even covers zone 2. This feature is activated by the input to extend the zone 1 (EXTZ1).
• **OperationZ2**: Operation zone 2 On, Off. If OperationZ1 = Off, all pole-slips with centre of the electromechanical oscillation within zone 2 are ignored. Default setting = On.

• **tBreaker**: Circuit breaker opening time. Use the default value $t_{\text{Breaker}} = 0.000$ s if unknown. If the value is known, then a value higher than 0.000 is specified, for example $t_{\text{Breaker}} = 0.040$ s: the out-of-step function gives a trip command approximately 0.040 seconds before the currents reach their minimum value. This in order to decrease the stress imposed to the circuit breaker.

• **GlobalBaseSel**: This setting identifies the Global Base Values Group where $U_{\text{Base}}$ and $I_{\text{Base}}$ are defined. In particular: $U_{\text{Base}}$ is the voltage at the point where the Out-of-step protection is connected. If the protection is connected to the generator output terminals, then $U_{\text{Base}}$ is the nominal (rated) phase to phase voltage of the protected generator. All the resistances and reactances are measured and displayed referred to voltage $U_{\text{base}}$. Observe that $\text{ReverseX}$, $\text{ForwardX}$, $\text{ReverseR}$, and $\text{ForwardR}$ must be given referred to $U_{\text{Base}}$. $I_{\text{Base}}$ is the protected generator nominal (rated) current, if the Out-of-step protection belongs to a generator protection scheme.

• **InvertCTCurr**: If the currents fed to the Out-of-step protection are measured on the protected generator neutral side (LV-side) then inversion is not necessary ($\text{InvertCTCurr} = \text{Off}$), provided that the CT’s star point earthing complies with ABB recommendations, as it is shown in Table 8. If the currents fed to the Out-of-step protection are measured on the protected generator terminals side, then inversion is necessary ($\text{InvertCTCurr} = \text{On}$), provided that the CT’s star point earthing complies with ABB recommendations, as it is shown in Table 8.
Section 8  Current protection

8.1  Four step phase overcurrent protection 3-phase output OC4PTOC

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>Four step phase overcurrent protection 3-phase output</td>
<td>OC4PTOC</td>
<td></td>
<td>51/67</td>
</tr>
</tbody>
</table>

8.1.2  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.

### 8.1.3 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.

In version 2.0, a typical starting time delay of 24ms is subtracted from the set trip time delay, so that the resulting trip time will take the internal IED start time into consideration.
The parameters for Four step phase overcurrent protection 3-phase output OC4PTOC are set via the local HMI or PCM600.

The following settings can be done for OC4PTOC.

*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 *Off* or *On*

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

*AngleROA*: Angle value, given in degrees, to define the angle sector of the directional function, see figure 50.

*IminOpPhSel*: Minimum current for phase selection set in % of IBase. This setting should be less than the lowest step setting. Default setting is 7%.

*StartPhSel*: Number of phases, with high current, required for operation. The setting possibilities are: *Not used*, *1 out of 3*, *2 out of 3* and *3 out of 3*. Default setting is *1 out of 3*.

*2ndHarmStab*: Operate level of 2nd harmonic current restrain set in % of the fundamental current. The setting range is 5 - 100% in steps of 1%. Default setting is 20%.
Figure 50: Directional function characteristic

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

8.1.3.1 Settings for each step

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

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

Characteristics: Selection of time characteristic for step $x$. Definite time delay and different types of inverse time characteristics are available according to table 9.
Table 9: 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>

The different characteristics are described in Technical reference manual.

$I1>MinEd2Set$: Minimum settable operating phase current level for step 1 in % of $IBase$, for 61850 Ed.2 settings

$I1>MaxEd2Set$: Maximum settable operating phase current level for step 1 in % of $IBase$, for 61850 Ed.2 settings

$I2>MinEd2Set$: Minimum settable operating phase current level for step 2 in % of $IBase$, for 61850 Ed.2 settings

$I2>MaxEd2Set$: Maximum settable operating phase current level for step 2 in % of $IBase$, for 61850 Ed.2 settings

$I3>MinEd2Set$: Minimum settable operating phase current level for step 3 in % of $IBase$, for 61850 Ed.2 settings

$I3>MaxEd2Set$: Maximum settable operating phase current level for step 3 in % of $IBase$, for 61850 Ed.2 settings

$I4>MinEd2Set$: Minimum settable operating phase current level for step 4 in % of $IBase$, for 61850 Ed.2 settings

$I4>MaxEd2Set$: Maximum settable operating phase current level for step 4 in % of $IBase$, for 61850 Ed.2 settings
Ix>: Operate phase current level for step $x$ given in % of $I_{Base}$.

$tx$: Definite time delay for step $x$. The definite time $tx$ is added to the inverse time when inverse time characteristic is selected.

$kx$: Time multiplier for inverse time delay for step $x$.

$I_{Minx}$: Minimum operate current for step $x$ in % of $I_{Base}$. Set $I_{Minx}$ below $Ix>$ for every step to achieve ANSI reset characteristic according to standard. If $I_{Minx}$ is set above $Ix>$ for any step the ANSI reset works as if current is zero when current drops below $I_{Minx}$.

$IxMult$: Multiplier for scaling of the current setting value. If a binary input signal (enableMultiplier) is activated the current operation level is increase by this setting constant. Setting range: 1.0-10.0

$txMin$: 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.

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

$ResetTypeCrvx$: The reset of the delay timer can be made in different ways. By choosing setting the possibilities are according to table 10.
Table 10: 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 the technical reference manual. There are some restrictions regarding the choice of reset delay.

For the definite time delay characteristics the possible delay time settings are 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.

\( \text{HarmRestrain}_x \): Enable block of step \( x \) from the harmonic restrain function (2nd harmonic). This function should be used when there is a risk if power transformer inrush currents might cause unwanted trip. Can be set Off/On.

\( tPCrv_x, tACrv_x, tBCrv_x, tCCrv_x \): Parameters for customer creation of inverse time characteristic curve (Curve type = 17). See equation 36 for the time characteristic equation.

\[
I[s] = \left( \frac{A}{\left( \frac{i}{in>} \right)^n} + B \right) \cdot IxMult
\]

(Equation 36)

For more information, refer to the technical reference manual.

\( tPRCrv_x, tTRCrv_x, tCRCrv_x \): Parameters for customer creation of inverse reset time characteristic curve (Reset Curve type = 3). Further description can be found in the technical reference manual.
8.2 Four step residual overcurrent protection, (Zero sequence or negative sequence directionality) EF4PTOC

8.2.1 Identification

Function description | IEC 61850 identification | IEC 60617 identification | ANSI/IEEE C37.2 device number
--- | --- | --- | ---
Four step residual overcurrent protection | EF4PTOC | | 51N/67N

8.2.2 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 of utmost importance to set the definite time delay for that stage to zero.

In version 2.0, a typical starting time delay of 24ms is subtracted from the set trip time delay, so that the resulting trip time will take the internal IED start time into consideration.

The parameters for the four step residual overcurrent protection, zero or negative sequence direction EF4PTOC are set via the local HMI or PCM600.

The following settings can be done for the four step residual overcurrent protection.

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

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

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

*Characteristic*: 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 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 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.

$IN_x$ ($IN_x \geq I_{Base}$): Operate residual current level for step $x$ given in % of $I_{Base}$.

$k_x$: Time multiplier for the dependent (inverse) characteristic for step $x$.

$IM_{minx}$: Minimum operate current for step $x$ in % of $I_{Base}$. Set $IM_{minx}$ below $I_x \geq I_{Base}$ for every step to achieve ANSI reset characteristic according to standard. If $IM_{minx}$ is set above $I_x \geq I_{Base}$ for any step then signal will reset at current equals to zero.

$IN_xMult$: 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.

$txMin$: 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 52: Minimum operate current and operate time for inverse time characteristics

In order to fully comply with 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 $kx$.

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

$tPCr.vx, tACr.vx, tBCr.vx, tCCr.vx$: Parameters for user programmable of inverse time characteristic curve. The time characteristic equation is according to equation 37:

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

(Equation 37)

Further description can be found in the technical reference manual.

$tPRCr.vx, tTRCr.vx, tCRCr.vx$: Parameters for user programmable of inverse reset time characteristic curve. Further description can be found in the technical reference manual.

8.2.2.2 Common settings for all steps

$tx$: Definite time delay for step $x$. Used if definite time characteristic is chosen.
**AngleRCA:** Relay characteristic angle given in degree. This angle is defined as shown in figure 53. The angle is defined positive when the residual current lags the reference voltage (Upol = 3U₀ or U₂)

![Relay characteristic angle given in degree](image)

**Figure 53:** 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 \((ZS_1 - ZS_0)/3\), that is the earth return impedance of the source behind the protection. The maximum earth-fault current at the local source can be used to calculate the value of \(ZN\) as \(U/(\sqrt{3} \cdot 3I_0)\). Typically, the minimum \(ZN\) (3 · zero sequence source) is set. Setting is in primary ohms.

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

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

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

\(I>Dir\): 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 \(IN_x>\) 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.

### 8.2.2.3 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 2\(^{nd}\) 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.

### 8.2.2.4 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 2\(^{nd}\) harmonic of the inrush currents of the two transformers will be in phase opposition. The summation of the two currents will thus give a small 2\(^{nd}\) harmonic current. The
residual fundamental current will however be significant. The inrush current of the transformer in service before the parallel transformer energizing, will be a little delayed compared to the first transformer. Therefore we will have high 2nd harmonic current initially. After a short period this current will however be small and the normal 2nd harmonic blocking will reset.

![Diagram](en05000136.vsd)

**Figure 54: 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.

### 8.2.2.5 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 restraint 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.

**Activation SOTF:** 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

### 8.3 Four step directional negative phase sequence overcurrent protection NS4PTOC

#### 8.3.1 Identification

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

#### 8.3.2 Application

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

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

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

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

<table>
<thead>
<tr>
<th>Curve name</th>
<th>Inverse time characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANSI Extremely Inverse</td>
<td></td>
</tr>
<tr>
<td>ANSI Very Inverse</td>
<td></td>
</tr>
<tr>
<td>ANSI Normal Inverse</td>
<td></td>
</tr>
<tr>
<td>ANSI Moderately Inverse</td>
<td></td>
</tr>
<tr>
<td>ANSI/IEEE Definite time</td>
<td></td>
</tr>
<tr>
<td>ANSI Long Time Extremely Inverse</td>
<td></td>
</tr>
<tr>
<td>ANSI Long Time Very Inverse</td>
<td></td>
</tr>
</tbody>
</table>

Table continues on next page
There is also a user programmable inverse time characteristic.

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

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

### 8.3.3 Setting guidelines

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

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

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

Common base IED values for primary current \((I_{Base})\), primary voltage \((U_{Base})\) and primary power \((S_{Base})\) are set in Global base values for settings function GBASVAL. *GlobalBaseSel:* It is used to select a GBASVAL function for reference of base values.

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 of utmost importance to set the definite time delay for that stage to zero.
In version 2.0, a typical starting time delay of 24ms is subtracted from the set trip time delay, so that the resulting trip time will take the internal IED start time into consideration.

8.3.3.1 Settings for each step

x means step 1, 2, 3 and 4.

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

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

Table 12: Inverse time characteristics

<table>
<thead>
<tr>
<th>Curve name</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANSI Extremely Inverse</td>
</tr>
<tr>
<td>ANSI Very Inverse</td>
</tr>
<tr>
<td>ANSI Normal Inverse</td>
</tr>
<tr>
<td>ANSI Moderately Inverse</td>
</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>

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

$Ix^>$: Operation negative sequence current level for step $x$ given in % of $IBase$. 
Definite time delay for step x. The definite time $tx$ is added to the inverse time when inverse time characteristic is selected. Note that the value set is the time between activation of the start and the trip outputs.

$kx$: Time multiplier for the dependent (inverse) characteristic.

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

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

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

![Graph of Minimum operate current and operation time for inverse time characteristics](image)

**Figure 55:** Minimum operate current and operation time for inverse time characteristics

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

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

The different reset characteristics are described in the Technical Reference Manual (TRM). There are some restrictions regarding the choice of reset delay.
For the independent time delay characteristics the possible delay time settings are instantaneous (1) and IEC (2 = set constant time reset).

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

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

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

\[ tPCrvx, tACrvx, tBCrvx, tCCrvx: \text{Parameters for programmable inverse time characteristic curve. The time characteristic equation is according to equation 37:} \]

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

(Equation 38)

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

\( tPRCrvx, tTRCrvx, tCRCrvx: \text{Parameters for customer creation of inverse reset time characteristic curve. Further description can be found in the Technical Reference Manual.} \)

### 8.3.3.2 Common settings for all steps

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

\( AngleRCA: \text{Relay characteristic angle given in degrees. This angle is defined as shown in figure 53. The angle is defined positive when the residual current lags the reference voltage (Upol = -U2)} \)
Figure 56: Relay characteristic angle given in degree

In a transmission network a normal value of RCA is about 80°.

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

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

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

8.4.2 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 $-90^\circ$ phase shift compared to the residual voltage ($3U_0$). The characteristic angle is chosen to $-90^\circ$ 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 $0^\circ$.

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 IBase,
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.

![Diagram](image.png)

**Figure 57:** Connection of SDEPSDE to analog preprocessing function block

Overcurrent functionality uses true $3I_0$, i.e. sum of $GRPxL_1$, $GRPxL_2$ and $GRPxL_3$. 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 $GRPxN$ this signal is used, else if connection is made to all inputs $GRPxL_1$, $GRPxL_2$ and $GRPxL_3$ the internally calculated sum of these inputs ($3I_0$ and $3U_0$) will be used.

### 8.4.3 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:

\[
U_\theta = \frac{U_{\text{phase}}}{1 + \frac{3 \cdot R_f}{Z_0}} \tag{Equation 39}
\]

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:

\[
I_j = 3I_n = \frac{3 \cdot U_{\text{phase}}}{Z_0 + 3 \cdot R_f} \tag{Equation 40}
\]

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:

\[
Z_0 = -jX_c = -j \frac{3 \cdot U_{\text{phase}}}{I_j} \tag{Equation 41}
\]

Where
- \(I_j\) 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:
\[ Z_0 = \frac{-jX_n \cdot 3R_n}{-jX_n + 3R_n} \]

(Equation 42)

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:

\[ Z_0 = \frac{-jX_n}{3R_n} \div \frac{j3X_n}{3X_nX_c + j3R_n \cdot (3X_n - X_c)} \]

(Equation 43)

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 58.
Figure 58: Equivalent of power system for calculation of setting

The residual fault current can be written:

\[
3I_0 = \frac{3U}{2 \cdot Z_1 + Z_0 + 3 \cdot R_f}
\]

(Equation 44)

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:

\[
U_{0A} = 3I_0 \cdot \left( Z_{T,0} + 3R_N \right)
\]

(Equation 45)

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

(Equation 46)
The residual power, measured by the sensitive earth fault protections in A and B will be:

\[ S_{0A} = 3U_{0A} \cdot 3I_0 \]  
(Equation 47)

\[ S_{0B} = 3U_{0B} \cdot 3I_0 \]  
(Equation 48)

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:

\[ S_{0A,prot} = 3U_{0A} \cdot 3I_0 \cdot \cos \phi_A \]  
(Equation 49)

\[ S_{0B,prot} = 3U_{0B} \cdot 3I_0 \cdot \cos \phi_B \]  
(Equation 50)

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:

\[ t_{inv} = \frac{kSN \cdot (3I_0 \cdot 3U_0 \cdot \cos \phi(\text{reference}))}{3I_0 \cdot 3U_0 \cdot \cos \phi(\text{measured})} \]  
(Equation 51)

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 \( 3U_0 \) by 0 or 180 degrees. This parameter is set to 180 degrees by default in order to inverse the residual voltage \( 3U_0 \) to calculate the reference voltage \( -3U_0 \cdot e^{-jRCADir} \). 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 $3I_0\cos fi$ 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 59.

![Diagram showing characteristic for RCADir equal to 0°](IEC06000648-4-en.vsd)

**Figure 59: Characteristic for RCADir equal to 0°**

The characteristic is for $RCADir$ equal to -90° is shown in Figure 60.

![Diagram showing characteristic for RCADir equal to -90°](IEC06000649_3_en.vsd)

**Figure 60: Characteristic for RCADir equal to -90°**

When *OpMode* is set to $3U_03I_0\cos fi$ the apparent residual power component in the direction is measured.

When *OpMode* is set to $3I_0$ and $fi$ the function will operate if the residual current is larger than the setting $INDir>$ and the residual current angle is within the sector $RCADir \pm ROADir$. 

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The characteristic for this OpMode when $RCADir = 0^\circ$ and $ROADir = 80^\circ$ is shown in figure 61.

Figure 61: 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 $UBase$. This setting should be chosen smaller than or equal to the lowest fault residual voltage to be detected.

$tDef$ is the definite time delay, given in s, for the directional residual current protection.

$tReset$ is the time delay before the definite timer gets reset, given in s. With a $tReset$ 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 $tReset$ 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 $0^\circ$ 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 $-90^\circ$ 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 \(3I0Cos\). The setting is given in % of **IBase**. 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 \(3I03U0Cos\). The setting is given in % of **SBase**. 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. **SRef** is the reference residual power, given in % of **SBase**. **kSN** is the time multiplier. The time delay will follow the following expression:

\[
t_{on} = \frac{kSN \cdot Sref}{3I_0 \cdot 3U_0 \cdot \cos \phi \text{(measured)}}
\]

(Equation 52)

**INDir** is the operate current level for the directional function when **OpMode** is set \(3I0\) and \(fi\). The setting is given in % of **IBase**. 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 **IBase**. 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>
<thead>
<tr>
<th>Curve name</th>
<th>Inverse time characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANSI Extremely Inverse</td>
<td></td>
</tr>
<tr>
<td>ANSI Very Inverse</td>
<td></td>
</tr>
<tr>
<td>ANSI Normal Inverse</td>
<td></td>
</tr>
<tr>
<td>Table continues on next page</td>
<td></td>
</tr>
</tbody>
</table>
Curve name
ANSI Moderately Inverse
ANSI/IEEE Definite time
ANSI Long Time Extremely Inverse
ANSI Long Time Very Inverse
ANSI Long Time Inverse
IEC Normal Inverse
IEC Very Inverse
IEC Inverse
IEC Extremely Inverse
IEC Short Time Inverse
IEC Long Time Inverse
IEC Definite Time
User Programmable
ASEA RI
RXIDG (logarithmic)

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:

\[
t[s] = \left( \frac{A}{\left( \frac{i}{in >} \right)^r - C} \right) \cdot \text{InMult}
\]

(Equation 53)

tINNonDir 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.

\( t\text{UN} \) is the definite time delay for the trip function of the residual voltage protection, given in s.

8.5 Thermal overload protection, one time constant, Celsius/Fahrenheit LCPTTR/LFPTTR
8.5.1 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>Thermal overload protection, one time constant, Celsius</td>
<td>LCPTTR</td>
<td></td>
<td>26</td>
</tr>
<tr>
<td>Thermal overload protection, one time constant, Fahrenheit</td>
<td>LFPTTR</td>
<td></td>
<td>26</td>
</tr>
</tbody>
</table>

8.5.2 Application

Lines and cables in the power system are designed for a certain maximum load current level. If the current exceeds this level the losses will be higher than expected. As a consequence the temperature of the conductors will increase. If the temperature of the lines and cables reaches too high values the equipment might be damaged:

- The sag of overhead lines can reach unacceptable value.
- If the temperature of conductors, for example aluminium conductors, gets too high the material will be destroyed.
- In cables the insulation can be damaged as a consequence of the overtemperature. As a consequence of this phase to phase or phase to earth faults can occur.

In stressed situations in the power system it can be required to overload lines and cables for a limited time. This should be done while managing the risks safely.

The thermal overload protection provides information that makes a temporary overloading of cables and lines possible. The thermal overload protection estimates the conductor temperature continuously, in Celsius or Fahrenheit depending on whether LCPTTR or LFPTTR is chosen. This estimation is made by using a thermal model of the line/cable based on the current measurement.

If the temperature of the protected object reaches a set warning level $\text{AlarmTemp}$, a signal ALARM can be given to the operator. This enables actions in the power system to be taken before dangerous temperatures are reached. If the temperature continues to increase to the trip value $\text{TripTemp}$, the protection initiates trip of the protected line.

8.5.3 Setting guideline

The parameters for the Thermal overload protection, one time constant, Celsius/Fahrenheit LCPTTR/LFPTTR are set via the local HMI or PCM600.

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

*Operation: Off/On*
GlobalBaseSel is used to select a GBASVAL function for reference of base values, primary current (IBase), primary voltage (UBase) and primary power (SBase).

Imult: Enter the number of lines in case the protection function is applied on multiple parallel lines sharing one CT.

IRef: Reference, steady state current, given in % of IBase that will give a steady state (end) temperature rise TRef. It is suggested to set this current to the maximum steady state current allowed for the line/cable under emergency operation (a few hours per year).

TRef: Reference temperature rise (end temperature) corresponding to the steady state current IRef. From cable manuals current values with corresponding conductor temperature are often given. These values are given for conditions such as earth temperature, ambient air temperature, way of laying of cable and earth thermal resistivity. From manuals for overhead conductor temperatures and corresponding current is given.

Tau: The thermal time constant of the protected circuit given in minutes. Please refer to manufacturers manuals for details.

TripTemp: Temperature value for trip of the protected circuit. For cables, a maximum allowed conductor temperature is often stated to be 90°C (194°F). For overhead lines, the critical temperature for aluminium conductor is about 90 - 100°C (194-212°F). For a copper conductor a normal figure is 70°C (158°F).

AlarmTemp: Temperature level for alarm of the protected circuit. ALARM signal can be used as a warning before the circuit is tripped. Therefore the setting shall be lower than the trip level. It shall at the same time be higher than the maximum conductor temperature at normal operation. For cables this level is often given to 65°C (149°F). Similar values are stated for overhead lines. A suitable setting can be about 15°C (59°F) below the trip value.

ReclTemp: Temperature where lockout signal LOCKOUT from the protection is released. When the thermal overload protection trips a lock-out signal is activated. This signal is intended to block switch in of the protected circuit as long as the conductor temperature is high. The signal is released when the estimated temperature is below the set value. This temperature value should be chosen below the alarm temperature.

8.6 Directional underpower protection GUPPDUP
8.6.1 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>Directional underpower protection</td>
<td>GUPPDP</td>
<td>37</td>
<td></td>
</tr>
</tbody>
</table>

8.6.2 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 62 illustrates the reverse power protection with underpower protection and with overpower 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 overpower protection (reference angle set to 180) to trip if the power flow from the network to the generator is higher than 1%.
8.6.3 Setting guidelines

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 14.

Table 14: 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>$\bar{S} = \overline{U}<em>{L1} \cdot T</em>{L1}^* + \overline{U}<em>{L2} \cdot T</em>{L2}^* + \overline{U}<em>{L3} \cdot T</em>{L3}^*$</td>
</tr>
<tr>
<td></td>
<td>(Equation 55)</td>
</tr>
<tr>
<td>Arone</td>
<td>$\bar{S} = \overline{U}<em>{L1L2} \cdot T</em>{L1}^* - \overline{U}<em>{L2L3} \cdot T</em>{L3}^*$</td>
</tr>
<tr>
<td></td>
<td>(Equation 56)</td>
</tr>
<tr>
<td>PosSeq</td>
<td>$\bar{S} = 3 \cdot \overline{U}<em>{PosSeq} \cdot T</em>{PosSeq}^*$</td>
</tr>
<tr>
<td></td>
<td>(Equation 57)</td>
</tr>
<tr>
<td>L1L2</td>
<td>$\bar{S} = \overline{U}<em>{L1L2} \cdot (T</em>{L1}^* - T_{L2}^*)$</td>
</tr>
<tr>
<td></td>
<td>(Equation 58)</td>
</tr>
<tr>
<td>L2L3</td>
<td>$\bar{S} = \overline{U}<em>{L2L3} \cdot (T</em>{L2}^* - T_{L3}^*)$</td>
</tr>
<tr>
<td></td>
<td>(Equation 59)</td>
</tr>
<tr>
<td>L3L1</td>
<td>$\bar{S} = \overline{U}<em>{L3L1} \cdot (T</em>{L3}^* - T_{L1}^*)$</td>
</tr>
<tr>
<td></td>
<td>(Equation 60)</td>
</tr>
</tbody>
</table>

Table continues on next page
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)

<table>
<thead>
<tr>
<th>Set value Mode</th>
<th>Formula used for complex power calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>( \vec{S} = 3 \cdot \vec{U}<em>{L1} \cdot \vec{I}</em>{L1}^* ) [(Equation 61)]</td>
</tr>
<tr>
<td>L2</td>
<td>( \vec{S} = 3 \cdot \vec{U}<em>{L2} \cdot \vec{I}</em>{L2}^* ) [(Equation 62)]</td>
</tr>
<tr>
<td>L3</td>
<td>( \vec{S} = 3 \cdot \vec{U}<em>{L3} \cdot \vec{I}</em>{L3}^* ) [(Equation 63)]</td>
</tr>
</tbody>
</table>

Figure 63: 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 64.

Minimum recommended setting is 0.2% of \( S_N \) when metering class CT inputs into the IED are used.
The setting \( \text{Angle}1(2) \) 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.

![Diagram showing the relationship between power and angle](en06000556.vsd)

**Figure 64:** For low forward power the set angle should be 0° in the underpower function

\( \text{TripDelay}1(2) \) is set in seconds to give the time delay for trip of the stage after pick up. \( \text{Hysteresis}1(2) \) is given in p.u. of generator rated power according to equation 65.

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

(Equation 65)

The drop out power will be \( \text{Power}1(2) + \text{Hysteresis}1(2) \).

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 66)

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:

- \( I_{\text{AmpComp5}}, I_{\text{AmpComp30}}, I_{\text{AmpComp100}} \)
- \( U_{\text{AmpComp5}}, U_{\text{AmpComp30}}, U_{\text{AmpComp100}} \)
- \( I_{\text{AngComp5}}, I_{\text{AngComp30}}, I_{\text{AngComp100}} \)

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.

### 8.7 Directional overpower protection GOPPDOP

#### 8.7.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 80687 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directional overpower protection</td>
<td>GOPPDOP</td>
<td>P &gt; 2</td>
<td>32</td>
</tr>
</tbody>
</table>

#### 8.7.2 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
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consumption will be about 2% of rated power. Even if the turbine rotates in vacuum,
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the turbine loses the vacuum.

The critical time to overheating of 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 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.

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 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 65 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 65: Reverse power protection with underpower IED and overpower IED](IEC06000315-2-en.vsd)

8.7.3 Setting guidelines

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 15.
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 $Power1(2)$.
The setting $\text{Power1(2)}$ gives the power component pick up value in the $\text{Angle1(2)}$ direction. The setting is given in p.u. of the generator rated power, see equation 77.

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 77)

The setting $\text{Angle1(2)}$ 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 67: 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 78.

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

(Equation 78)

The drop out power will be \( \text{Power1}(2) - \text{Hysteresis1}(2) \).

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 79)

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:

$I_{\text{AmpComp5}}, I_{\text{AmpComp30}}, I_{\text{AmpComp100}}$

$U_{\text{AmpComp5}}, U_{\text{AmpComp30}}, U_{\text{AmpComp100}}$

$I_{\text{AngComp5}}, I_{\text{AngComp30}}, I_{\text{AngComp100}}$

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.
Section 9 Voltage protection

9.1 Two step undervoltage protection UV2PTUV

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>Two step undervoltage protection</td>
<td>UV2PTUV</td>
<td></td>
<td>27</td>
</tr>
</tbody>
</table>

9.1.2 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.

9.1.3 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 $U_{Base}$, 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.

9.1.3.1 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.

9.1.3.2 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.

9.1.3.3 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.

9.1.3.4 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.

9.1.3.5 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.
9.1.3.6 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.

**UBase** (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 UBase. When ConnType is set to `PhN DFT` or `PhN RMS` then the IED automatically divides set value for UBase by \( \sqrt{3} \). UBase is used when ConnType is set to `PhPh DFT` or `PhPh RMS`. Therefore, always set UBase as rated primary phase-to-phase voltage of the protected object. This means operation for phase-to-earth voltage under:

\[
U < \left( \frac{\%}{\%} \cdot \text{UBase(kV)} \right) \frac{1}{\sqrt{3}}
\]

(Equation 80)

and operation for phase-to-phase voltage under:

\[
U < \left( \frac{\%}{\%} \cdot \text{UBase(kV)} \right)
\]

(Equation 81)

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 $t1Min$ longer than the operation time for other protections such unselective tripping can be avoided.

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

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

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

$ACrvn$, $BCrvn$, $CCrvn$, $DCrvn$, $PCrvn$: Parameters to 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 $Un< \text{ down to } Un< \times (1.0 - \text{CrvSatn}/100)$ the used voltage will be: $Un< \times (1.0 - \text{CrvSatn}/100)$. If the programmable curve is used this parameter must be calculated so that:

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

(Equation 82)

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

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

$tBlkUVn$: Time delay to block the undervoltage step $n$ when the voltage level is below $IntBlkStValn$, given in s. It is important that this delay is shorter than the operate time delay of the undervoltage protection step.
9.2 Two step overvoltage protection OV2PTOV

9.2.1 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>
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<tbody>
<tr>
<td>Two step overvoltage protection</td>
<td>OV2PTOV</td>
<td>3U&gt;</td>
<td>59</td>
</tr>
</tbody>
</table>

9.2.2 Application

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

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

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

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

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

9.2.3 Setting guidelines

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

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

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

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

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

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

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

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

9.2.3.2 Equipment protection, capacitors

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

9.2.3.3 Power supply quality

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

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

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

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

*Operation*: Off/On.

*UBase* (given in *GlobalBaseSel*): Base voltage phase to phase in primary kV. This voltage is used as reference for voltage setting. OV2PTOV measures selectively phase-to-earth voltages, or phase-to-phase voltage chosen by the setting *ConnType*. The function will operate if the voltage gets lower than the set percentage of *UBase*. When *ConnType* is set to *PhN DFT* or *PhN RMS* then the IED automatically divides set value for *UBase* by $\sqrt{3}$. When *ConnType* is set to *PhPh DFT* or *PhPh RMS* then set value for *UBase* is used. Therefore, always set *UBase* as rated primary phase-to-phase voltage of the protected object. If phase to neutral (PhN) measurement is selected as setting, the operation of phase-to-earth over voltage is automatically divided by sqrt3. This means operation for phase-to-earth voltage over:

$$ U > (\%) \cdot \frac{U_{Base}(kV)}{\sqrt{3}} $$

and operation for phase-to-phase voltage over:

$$ U > (\%) \cdot U_{Base}(kV) $$

(Equation 84)

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*, *Inverse Curve C* or *I/Prog. inv. curve*. The choice is highly dependent of the protection application.

*OpModen*: This parameter describes how many of the three measured voltages that should be above the set level to give operation. The setting can be *1 out of 3*, *2 out of 3*, *3 out of 3*. In most applications it is sufficient that one phase voltage is high to give operation. If the function shall be insensitive for single phase-to-earth faults *1 out of 3* can be chosen, because the voltage will normally rise in the non-faulted phases at single phase-to-earth faults. In subtransmission and transmission networks the UV function is mainly a system supervision function and 3 out of 3 is selected.
Un>: Set operate overvoltage operation value for step n, given as % of UBase. The setting is highly dependent of the protection application. Here it is essential to consider the maximum voltage at non-faulted situations. Normally this voltage is less than 110% of nominal voltage.

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

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

tnMin: Minimum operation time for inverse time characteristic for step n, given in s. For very high voltages the overvoltage function, using inverse time characteristic, can give very short operation time. This might lead to unselective trip. By setting t1Min longer than the operation time for other protections such unselective tripping can be avoided.

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

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

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

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

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

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

(Equation 85)

HystAbsn: Absolute hysteresis set in % of UBase. The setting of this parameter is highly dependent of the application. If the function is used as control for automatic switching of reactive compensation devices the hysteresis must be set smaller than the voltage change after switching of the compensation device.
Section 10  Frequency protection

10.1  Underfrequency protection SAPTUF

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>Underfrequency protection</td>
<td>SAPTUF</td>
<td></td>
<td>81</td>
</tr>
</tbody>
</table>

10.1.2  Application

Underfrequency protection SAPTUF is applicable in all situations, where reliable detection of low fundamental power system frequency is needed. The power system frequency, and the rate of change of frequency, is a measure of the unbalance between the actual generation and the load demand. Low fundamental frequency in a power system indicates that the available generation is too low to fully supply the power demanded by the load connected to the power grid. SAPTUF detects such situations and provides an output signal, suitable for load shedding, generator boosting, HVDC-set-point change, gas turbine start up and so on. Sometimes shunt reactors are automatically switched in due to low frequency, in order to reduce the power system voltage and hence also reduce the voltage dependent part of the load.

SAPTUF is very sensitive and accurate and is used to alert operators that frequency has slightly deviated from the set-point, and that manual actions might be enough. The underfrequency signal is also used for overexcitation detection. This is especially important for generator step-up transformers, which might be connected to the generator but disconnected from the grid, during a roll-out sequence. If the generator is still energized, the system will experience overexcitation, due to the low frequency.

10.1.3  Setting guidelines

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

There are two specific application areas for SAPTUF:
1. to protect equipment against damage due to low frequency, such as generators, transformers, and motors. Overexcitation is also related to low frequency
2. to protect a power system, or a part of a power system, against breakdown, by shedding load, in generation deficit situations.

The under frequency START value is set in Hz. All voltage magnitude related settings are made as a percentage of a global base voltage parameter. The UBase value should be set as a primary phase-to-phase value.

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

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

The setting has to be well below the lowest occurring "normal" frequency and well above the lowest acceptable frequency for the equipment.

**Power system protection, by load shedding**

The setting has to be below the lowest occurring "normal" frequency and well above the lowest acceptable frequency for power stations, or sensitive loads. The setting level, the number of levels and the distance between two levels (in time and/or in frequency) depends very much on the characteristics of the power system under consideration. The size of the "largest loss of production" compared to "the size of the power system" is a critical parameter. In large systems, the load shedding can be set at a fairly high frequency level, and the time delay is normally not critical. In smaller systems the frequency START level has to be set at a lower value, and the time delay must be rather short.

The voltage related time delay is used for load shedding. The settings of SAPTUF could be the same all over the power system. The load shedding is then performed firstly in areas with low voltage magnitude, which normally are the most problematic areas, where the load shedding also is most efficient.

### 10.2 Overfrequency protection SAPTOF

#### 10.2.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 80617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overfrequency protection</td>
<td>SAPTOF</td>
<td></td>
<td>81</td>
</tr>
</tbody>
</table>
10.2.2 Application

Overfrequency protection function SAPTOF is applicable in all situations, where reliable detection of high fundamental power system frequency is needed. The power system frequency, and rate of change of frequency, is a measure of the unbalance between the actual generation and the load demand. High fundamental frequency in a power system indicates that the available generation is too large compared to the power demanded by the load connected to the power grid. SAPTOF detects such situations and provides an output signal, suitable for generator shedding, HVDC-set-point change and so on. SAPTOF is very sensitive and accurate and can also be used to alert operators that frequency has slightly deviated from the set-point, and that manual actions might be enough.

10.2.3 Setting guidelines

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

There are two application areas for SAPTOF:

1. to protect equipment against damage due to high frequency, such as generators, and motors
2. to protect a power system, or a part of a power system, against breakdown, by shedding generation, in over production situations.

The overfrequency start value is set in Hz. All voltage magnitude related settings are made as a percentage of a settable global base voltage parameter $U_{Base}$. The $U_{Base}$ value should be set as a primary phase-to-phase value.

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

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

The setting has to be well above the highest occurring "normal" frequency and well below the highest acceptable frequency for the equipment.

**Power system protection, by generator shedding**

The setting must be above the highest occurring "normal" frequency and below the highest acceptable frequency for power stations, or sensitive loads. The setting level, the number of levels and the distance between two levels (in time and/or in frequency) depend very much on the characteristics of the power system under consideration. The size of the "largest loss of load" compared to "the size of the power system" is a critical parameter. In large systems, the generator shedding can be set at a fairly low frequency level, and the time delay is normally not critical. In smaller systems the frequency START level has to be set at a higher value, and the time delay must be rather short.
10.3 Rate-of-change frequency protection SAPFRC

10.3.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate-of-change frequency protection</td>
<td>SAPFRC</td>
<td>df/dt &gt;</td>
<td>81</td>
</tr>
</tbody>
</table>

10.3.2 Application

Rate-of-change frequency protection (SAPFRC), is applicable in all situations, where reliable detection of change of the fundamental power system voltage frequency is needed. SAPFRC can be used both for increasing frequency and for decreasing frequency. SAPFRC provides an output signal, suitable for load shedding or generator shedding, generator boosting, HVDC-set-point change, gas turbine start up and so on. Very often SAPFRC is used in combination with a low frequency signal, especially in smaller power systems, where loss of a fairly large generator will require quick remedial actions to secure the power system integrity. In such situations load shedding actions are required at a rather high frequency level, but in combination with a large negative rate-of-change of frequency the underfrequency protection can be used at a rather high setting.

10.3.3 Setting guidelines

The parameters for Rate-of-change frequency protection SAPFRC are set via the local HMI or through the Protection and Control Manager (PCM600).

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

There are two application areas for SAPFRC:

1. to protect equipment against damage due to high or too low frequency, such as generators, transformers, and motors
2. to protect a power system, or a part of a power system, against breakdown by shedding load or generation, in situations where load and generation are not in balance.

SAPFRC is normally used together with an overfrequency or underfrequency function, in small power systems, where a single event can cause a large imbalance between load and generation. In such situations load or generation shedding has to
take place very quickly, and there might not be enough time to wait until the frequency
signal has reached an abnormal value. Actions are therefore taken at a frequency level
closer to the primary nominal level, if the rate-of-change frequency is large (with
respect to sign).

SAPFRCSTART value is set in Hz/s. All voltage magnitude related settings are made
as a percentage of a settable base voltage, which normally is set to the primary nominal
voltage level (phase-phase) of the power system or the high voltage equipment under
consideration.

SAPFRC is not instantaneous, since the function needs some time to supply a stable
value. It is recommended to have a time delay long enough to take care of signal noise.
However, the time, rate-of-change frequency and frequency steps between different
actions might be critical, and sometimes a rather short operation time is required, for
example, down to 70 ms.

Smaller industrial systems might experience rate-of-change frequency as large as 5
Hz/s, due to a single event. Even large power systems may form small islands with a
large imbalance between load and generation, when severe faults (or combinations of
faults) are cleared - up to 3 Hz/s has been experienced when a small island was isolated
from a large system. For more “normal” severe disturbances in large power systems,
rate-of-change of frequency is much less, most often just a fraction of 1.0 Hz/s.

10.4 Frequency time accumulation protection function FTAQFVR

10.4.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60617 identification</th>
<th>ANSI/IEEE identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency time accumulation protection</td>
<td>FTAQFVR</td>
<td>&lt;&gt;</td>
<td>81A</td>
</tr>
</tbody>
</table>

10.4.2 Application

Generator prime movers are affected by abnormal frequency disturbances. Significant
frequency deviations from rated frequency occur in case of major disturbances in the
system. A rise of frequency occurs in case of generation surplus, while a lack of
generation results in a drop of frequency.

The turbine blade is designed with its natural frequency adequately far from the rated
speed or multiples of the rated speed of the turbine. This design avoids the mechanical
resonant condition, which can lead to an increased mechanical stress on turbine blade.
If the ratio between the turbine resonant frequencies to the system operating frequency
is nearly equal to 1, mechanical stress on the blades is approximately 300 times the
nonresonant operating condition stress values. The stress magnification factor is
shown in the typical resonance curve in Figure 68.
Each turbine manufactured for different design of blades has various time restriction limits for various frequency bands. The time limits depend on the natural frequencies of the blades inside the turbine, corrosion and erosion of the blade edges and additional loss of blade lifetime during the abnormal operating conditions.

The frequency limitations and their time restrictions for different types of turbines are similar in many aspects with steam turbine limitations. Certain differences in design and applications may result in different protective requirements. Therefore, for different type of turbine systems, different recommendations on the time restriction limits are specified by the manufacturer.

However, the IEEE/ANSI C37.106-2003 standard "Guide for Abnormal Frequency Protection for Power Generating Plants" provides some examples where the time accumulated within each frequency range is as shown in Figure 69.
Another application for the FTAQFVR protection function is to supervise variations from rated voltage-frequency. Generators are designed to accommodate the IEC 60034-3:1996 requirement of continuous operation within the confines of their capability curves over the ranges of +/-5% in voltage and +/-2% in frequency. Operation of the machine at rated power outside these voltage-frequency limits lead to increased temperatures and reduction of insulation life.

10.4.3 Setting guidelines

Among the generator protection functions, the frequency time accumulation protection FTAQFVR may be used to protect the generator as well as the turbine. Abnormal frequencies during normal operation cause material fatigue on turbine blades, trip points and time delays should be established based on the turbine manufacture’s requirements and recommendations.

Continuous operation of the machine at rated power outside voltage-frequency limits lead to increased rotor temperatures and reduction of insulation life. Setting of extent, duration and frequency of occurrence should be set according to manufacture’s requirements and recommendations.
Setting procedure on the IED

The parameters for the frequency time accumulation protection FTAQFVR are set using the local HMI or through the dedicated software tool in Protection and Control Manager (PCM600).

Common base IED values for primary current IBase and primary voltage UBase are set in the global base values for settings function GBASVAL. The GlobalBaseSel is used to select GBASVAL for the reference of base values.

FTAQFVR used to protect a turbine:

Frequency during start-up and shutdown is normally not calculated, consequently the protection function is blocked by CB position, parameter CBCheck enabled. If the generator supply any load when CB is in open position e.g. excitation equipment and auxiliary services this may be considered as normal condition and CBCheck is ignored when the load current is higher then the set value of CurrStartLevel. Set the current level just above minimum load.

EnaVoltCheck set to Disable.

tCont: to be coordinated to the grid requirements.

AccLimit, FreqHighLimit and FreqLowLimit setting is derived from the turbine manufacturer's operating requirements, note that FreqLowLimit setting must always be lower than the set value of FreqHighLimit.

FTAQFVR used to protect a generator:

Frequency during start-up and shutdown is normally not calculated, consequently the protection function is blocked by CB position, parameter CBCheck enabled.

CurrStartLevel set to Disable.

EnaVoltCheck set to Enable, voltage and frequency limits set according to the generators manufacturer's operating requirements. Voltage and frequency settings should also be coordinated with the starting values for over and underexcitation protection.

AccLimit, FreqHighLimit and FreqLowLimit setting is derived from the generator manufacturer's operating requirements.
Section 11  Multipurpose protection

11.1 General current and voltage protection CVGAPC

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

11.1.2 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:
   • Definite time delay for both steps

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 16 and table 17). 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).

11.1.2.1 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 16.
### Table 16: Available selection for current quantity within CVGAPC function

<table>
<thead>
<tr>
<th>Set value for parameter <em>CurrentInput</em></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>
<tr>
<td>12 phase3-phase1</td>
<td>CVGAPC function will measure the current phasor internally calculated as the vector difference between the phase L3 current phasor and phase L1 current phasor (IL3-IL1)</td>
</tr>
<tr>
<td>13 MaxPh-Ph</td>
<td>CVGAPC function will measure ph-ph current phasor with the maximum magnitude</td>
</tr>
<tr>
<td>14 MinPh-Ph</td>
<td>CVGAPC function will measure ph-ph current phasor with the minimum magnitude</td>
</tr>
<tr>
<td>15 UnbalancePh-Ph</td>
<td>CVGAPC function will measure magnitude of unbalance current, which is internally calculated as the algebraic magnitude difference between the ph-ph current phasor with maximum magnitude and ph-ph current phasor with minimum magnitude. Phase angle will be set to 0° all the time</td>
</tr>
</tbody>
</table>

The user can select, by a setting parameter *VoltageInput*, to measure one of the following voltage quantities shown in table 17.

### Table 17: Available selection for voltage quantity within CVGAPC function

<table>
<thead>
<tr>
<th>Set value for parameter <em>VoltageInput</em></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>
</tbody>
</table>

Table continues on next page
<table>
<thead>
<tr>
<th>Set value for parameter &quot;VoltageInput&quot;</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>PosSeq</td>
<td>CVGAPC function will measure internally calculated positive sequence voltage phasor</td>
</tr>
<tr>
<td>-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>-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>MaxPh</td>
<td>CVGAPC function will measure voltage phasor of the phase with maximum magnitude</td>
</tr>
<tr>
<td>MinPh</td>
<td>CVGAPC function will measure voltage phasor of the phase with minimum magnitude</td>
</tr>
<tr>
<td>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>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>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>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>
<tr>
<td>MaxPh-Ph</td>
<td>CVGAPC function will measure ph-ph voltage phasor with the maximum magnitude</td>
</tr>
<tr>
<td>MinPh-Ph</td>
<td>CVGAPC function will measure ph-ph voltage phasor with the minimum magnitude</td>
</tr>
<tr>
<td>UnbalancePh-Ph</td>
<td>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</td>
</tr>
</tbody>
</table>

It is important to notice that the voltage selection from table 17 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.

### 11.1.2.2 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 16.
2. rated phase current of the protected object in primary amperes multiplied by √3 (1.732 x Iphase), when the measured Current Quantity is selected from 10 to 15, as shown in table 16.

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 17.
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 17.

### 11.1.2.3 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/Restrained 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/Inadvertent-Energizing protection
   - Breaker head flashover protection
11.1.2.4 Inadvertent 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.
11.1.3 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 of utmost importance to set the definite time delay for that stage to zero.

In version 2.0, a typical starting time delay of 24ms is subtracted from the set trip time delay, so that the resulting trip time will take the internal IED start time into consideration.

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

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

11.1.3.1 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 $\text{NegSeq}$ (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 $\text{-NegSeq}$ (please note that the negative sequence voltage phasor is intentionally inverted in order to simplify directionality)
4. Set base current $I_{Base}$ value equal to the rated primary current of power line CTs
5. Set base voltage $U_{Base}$ 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.

### 11.1.3.2 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:

\[
 t_{op} = \frac{k}{\left(\frac{I_{NS}}{I_r}\right)^2}
\]

(Equation 86)

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 87)

Equation 86 can be re-written in the following way without changing the value for the operate time of the negative sequence inverse overcurrent IED:
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

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

(Equation 88)

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

(Equation 89)

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 86 is compared with the equation 88 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).

11.1.3.3 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 90)

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 91)

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:

$$t_{op} = \frac{k \cdot \frac{1}{x^2}}{\left( \frac{I_m}{x \cdot I_r} \right)^2 - \frac{1}{x^2}}$$  
(Equation 92)

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 $\text{CurrentInput}$ to value $\text{PosSeq}$
3. Set base current value to the rated generator current in primary amperes
4. Enable one overcurrent step (for example OC1)
5. Select parameter $\text{CurveType_OC1}$ to value $\text{Programmable}$

$$t_{op} = k \cdot \left( \frac{A}{M^p} - C + B \right)$$  
(Equation 93)

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 92 is compared with the equation 93 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 $A\_OC1$ equal to the value $1/x^2$
3. set parameter $C\_OC1$ equal to the value $1/x^2$
4. set parameters $B\_OC1 = 0.0$ and $P\_OC1=2.0$
5. set $\text{StartCurr\_OC1}$ equal to the value $x$
then the OC1 step of the CVGAPC function can be used for generator negative sequence inverse overcurrent protection.

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.

11.1.3.4 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 pre-set 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.

11.1.3.5 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. Set 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.
11.1.3.6 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 70 shows overall protection characteristic

Furthermore the other build-in protection elements can be used for other protection and alarming purposes.
Section 11
Multipurpose protection

Figure 70: Loss of excitation
Section 12 System protection and control

12.1 Multipurpose filter SMAIHPAC

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>Multipurpose filter</td>
<td>SMAIHPAC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

12.1.2 Application

The multi-purpose filter, function block with name SMAI HPAC, is arranged as a three-phase filter. It has very much the same user interface (e.g. function block outputs) as the standard pre-processing function block SMAI. However the main difference is that it can be used to extract any frequency component from the input signal. For all four analogue input signals into this filter (i.e. three phases and the residual quantity) the input samples from the TRM module, which are coming at rate of 20 samples per fundamental system cycle, are first stored. When enough samples are available in the internal memory, the phasor values at set frequency defined by the setting parameter *SetFrequency* are calculated. The following values are internally available for each of the calculated phasors:

- Magnitude
- Phase angle
- Exact frequency of the extracted signal

The SMAI HPAC filter is always used in conjunction with some other protection function (e.g. multi-purpose protection function or overcurrent function or over-voltage function or over-power function). In this way many different protection applications can be arranged. For example the following protection, monitoring or measurement features can be realized:

- Sub-synchronous resonance protection for turbo generators
- Sub-synchronous protection for wind turbines/wind farms
- Detection of sub-synchronous oscillation between HVDC links and synchronous generators
- Super-synchronous protection
- Detection of presence of the geo-magnetic induced currents
• Overcurrent or overvoltage protection at specific frequency harmonic, sub-harmonic, inter-harmonic etc.
• Presence of special railway frequencies (e.g. 16.7Hz or 25Hz) in the three-phase power system
• Sensitive reverse power protection
• Stator or rotor earth fault protection for special injection frequencies (e.g. 25Hz)
• etc.

The filter output can also be connected to the measurement function blocks such as CVMMXN (Measurements), CMMXU (Phase current measurement), VMMXU (Phase-phase voltage measurement), etc. in order to report the extracted phasor values to the supervisory system (e.g. MicroSCADA).

The following figure shoes typical configuration connections required to utilize this filter in conjunction with multi-purpose function as non-directional overcurrent protection.

![Figure 71: Required ACT configuration](image)

Such overcurrent arrangement can be for example used to achieve the subsynchronous resonance protection for turbo generators.

### 12.1.3 Setting guidelines

#### 12.1.3.1 Setting example

A relay type used for generator subsynchronous resonance overcurrent protection shall be replaced. The relay had inverse time operating characteristic as given with the following formula:

\[ t_{op} = T_{q1} + \frac{K}{I_s} \]

(Equation 94)

Where:
The existing relay was applied on a large 50Hz turbo generator which had shaft mechanical resonance frequency at 18.5Hz. The relay settings were $T_{01} = 0.64$ seconds, $K = 35566$ Amperes and minimal subsynchronous current trip level was set at $I_{S0} = 300$ Amperes primary.

Solution:

First the IED configuration shall be arranged as shown in Figure 71. Then the settings for SMAI HPAC filter and multipurpose function shall be derived from existing relay settings in the following way:

The subsynchronous current frequency is calculated as follows:

$$f_s = 50\text{Hz} - 18.5\text{Hz} = 31.5\text{Hz}$$

(Equation 95)

In order to properly extract the weak subsynchronous signal in presence of the dominating 50Hz signal the SMAI HPAC filter shall be set as given in the following table:

Table 18: Proposed settings for SMAI HPAC

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>ConnectionType</td>
<td>Ph — N</td>
</tr>
<tr>
<td>SetFrequency</td>
<td>31.5</td>
</tr>
<tr>
<td>FreqBandWidth</td>
<td>0.0</td>
</tr>
<tr>
<td>FilterLength</td>
<td>1.0 s</td>
</tr>
<tr>
<td>OverLap</td>
<td>75</td>
</tr>
<tr>
<td>Operation</td>
<td>On</td>
</tr>
</tbody>
</table>

Now the settings for the multi-purpose overcurrent stage one shall be derived in order to emulate the existing relay operating characteristic. To achieve exactly the same inverse time characteristic the programmable IDMT characteristic is used which for multi-purpose overcurrent stage one, which has the following equation (for more information see Section “Inverse time characteristics” in the TRM).

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

(Equation 96)
In order to adapt to the previous relay characteristic the above equation can be re-written in the following way:

\[
\left[ \frac{K}{I_{so}} \right] = \left\{ \frac{I_s}{I_{so}} \right\} - 0 + T_{01} \cdot 1
\]

(Equation 97)

Thus if the following rules are followed when multi-purpose overcurrent stage one is set:

- \( i_n > I_{so} = 300A \)
- \( A = K \frac{35566}{300} = 118.55 \)
- \( B = T_{01} = 0.64 \)
- \( C = 0.0 \)
- \( p = 1.0 \)
- \( k = 1.0 \)

then exact replica of the existing relay will be achieved. The following table summarizes all required settings for the multi-purpose function:

<table>
<thead>
<tr>
<th>Setting Group1</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td>On</td>
</tr>
<tr>
<td>CurrentInput</td>
<td>MaxPh</td>
</tr>
<tr>
<td>IBase</td>
<td>1000</td>
</tr>
<tr>
<td>VoltageInput</td>
<td>MaxPh</td>
</tr>
<tr>
<td>UBase</td>
<td>20.50</td>
</tr>
<tr>
<td>OPerHarmRestr</td>
<td>Off</td>
</tr>
<tr>
<td>I_2ndl_fund</td>
<td>20.0</td>
</tr>
<tr>
<td>BlkLevel2nd</td>
<td>5000</td>
</tr>
<tr>
<td>EnRestrainCurr</td>
<td>Off</td>
</tr>
<tr>
<td>RestrCurrInput</td>
<td>PosSeq</td>
</tr>
<tr>
<td>RestrCurrCoeff</td>
<td>0.00</td>
</tr>
<tr>
<td>RCADir</td>
<td>-75</td>
</tr>
<tr>
<td>ROADir</td>
<td>75</td>
</tr>
<tr>
<td>LowVolt_VM</td>
<td>0.5</td>
</tr>
<tr>
<td>Setting Group1</td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>Operation_OC1</td>
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</tr>
<tr>
<td>StartCurr_OC1</td>
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</tr>
<tr>
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</tr>
<tr>
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</tr>
<tr>
<td>k_OC1</td>
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<tr>
<td>tMin1</td>
<td>30</td>
</tr>
<tr>
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<tr>
<td>ResCrvType_OC1</td>
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</tr>
<tr>
<td>tResetDef_OC1</td>
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</tr>
<tr>
<td>P_OC1</td>
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<tr>
<td>A_OC1</td>
<td>118.55</td>
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<tr>
<td>B_OC1</td>
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<tr>
<td>C_OC1</td>
<td>0.000</td>
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</tbody>
</table>
Section 13 Secondary system supervision

13.1 Current circuit supervision CCSSPVC

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

13.1.2 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.
13.1.3 Setting guidelines

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, $I_{\text{MinOp}}$, 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 $I_p > Block$ 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.

13.2 Fuse failure supervision FUFSPVC

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

13.2.2 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, located as close as possible to the voltage instrument transformers, are one of them. 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 (SDDRFUF).

SDDRFUF 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
The negative sequence detection algorithm, based on the negative-sequence measuring quantities, a high value of voltage $3U_2$ without the presence of the negative-sequence current $3I_2$, is recommended for use in isolated or high-impedance earthed networks.

The zero sequence detection algorithm, based on the zero sequence measuring quantities, a high value of voltage $3U_0$ without the presence of the residual current $3I_0$, is recommended for use in directly or low impedance earthed networks. 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.

13.2.3 Setting guidelines

13.2.3.1 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.

13.2.3.2 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 \textit{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 \textit{OpMode} is set to either \textit{UNsINs} for selecting negative sequence algorithm or \textit{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 \textit{OpMode} is set to \textit{UZsIZs OR UNsINs or OptimZsNs}. In mode \textit{UZsIZs OR UNsINs} both negative and zero sequence based algorithms are activated and working in an OR-condition. Also in mode \textit{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 \textit{OpMode} can be selected to \textit{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.

13.2.3.3 Negative sequence based

The relay setting value $3U2>\text{ is given in percentage of the base voltage } UBase \text{ and should not be set lower than the value that is calculated according to equation 98.}$

$$3U2 > = \frac{U2}{U_{Base}/\sqrt{3}} \cdot 100$$

(Equation 98)

where:

- $U2$ is the maximal negative sequence voltage during normal operation conditions, plus a margin of 10...20%
- $UBase$ is the base voltage for the function according to the setting \textit{GlobalBaseSel}

The setting of the current limit $3I2<$ is in percentage of parameter $IBase$. The setting of $3I2<$ must be higher than the normal unbalance current that might exist in the system and can be calculated according to equation 99.
\[ 3I2 \leq \frac{I2}{IBase} \cdot 100 \]  
(Equation 99)

where:
- \( I2 \) is the maximal negative sequence current during normal operating conditions, plus a margin of 10...20%.
- \( IBase \) is the base current for the function according to the setting \( GlobalBaseSel \).

### 13.2.3.4 Zero sequence based

The IED setting value \( 3U0^> \) is given in percentage of the base voltage \( UBase \). The setting of \( 3U0^> \) should not be set lower than the value that is calculated according to equation 100.

\[ 3U0^> \geq \frac{3U0}{UBase / \sqrt{3}} \cdot 100 \]  
(Equation 100)

where:
- \( 3U0 \) is the maximal zero sequence voltage during normal operation conditions, plus a margin of 10...20%.
- \( UBase \) is the base voltage for the function according to the setting \( GlobalBaseSel \).

The setting of the current limit \( 3I0^< \) is done in percentage of \( IBase \). The setting of \( 3I0^< \) must be higher than the normal unbalance current that might exist in the system. The setting can be calculated according to equation 101.

\[ 3I0^< = \frac{3I0}{IBase} \cdot 100 \]  
(Equation 101)

where:
- \( 3I0^< \) is the maximal zero sequence current during normal operating conditions, plus a margin of 10...20%.
- \( IBase \) is the base current for the function according to the setting \( GlobalBaseSel \).

### 13.2.3.5 Delta U and delta I

Set the operation mode selector \( OpDUDI \) to \( On \) if the delta function shall be in operation.
The setting of $DU>$ should be set high (approximately 60% of $U_{Base}$) and the current threshold $DI<$ 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 $DU>$ and $DI<$ will be given according to equation 102 and equation 103.

$$DU> = \frac{U_{Set\_prim}}{U_{Base}} \times 100$$

(Equation 102)

$$DI< = \frac{I_{Set\_prim}}{I_{Base}} \times 100$$

(Equation 103)

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 $I_{Min\_Op}$ for the distance protection function. A 5...10% lower value is recommended.

### 13.2.3.6 Dead line detection

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

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

Set the $UDLD<$ with a sufficient margin below the minimum expected operating voltage. A safety margin of at least 15% is recommended.
Section 14 Control

14.1 Logic rotating switch for function selection and LHMI presentation SLGAPC

14.1.1 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 $t_{\text{Pulse}}$.

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

14.1.2 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.

$t_{\text{Pulse}}$: 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.

### 14.2 Selector mini switch VSGAPC

#### 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>
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<tbody>
<tr>
<td>Selector mini switch</td>
<td>VSGAPC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 14.2.2 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 72. The I and O buttons on the local HMI are normally used for on–off operations of the circuit breaker.

![Diagram of Selector mini switch VSGAPC](IEC07000112-3-en.vsd)

*Figure 72: 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.

### 14.2.3 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.

### 14.3 Generic communication function for Double Point indication DPGAPC

#### 14.3.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
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<th>IEC 60817 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
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<td>Generic communication function for Double Point indication</td>
<td>DPGAPC</td>
<td>-</td>
<td>-</td>
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</tbody>
</table>

#### 14.3.2 Application

DPGAPC function block is used to combine three logical input signals into a two bit position indication, and publish the position indication to other systems, equipment or functions in the substation. The three inputs are named OPEN, CLOSE and VALID. DPGAPC is intended to be used as a position indicator block in the interlocking stationwide logics.

The OPEN and CLOSE inputs set one bit each in the two bit position indication, POSITION. If both OPEN and CLOSE are set at the same time the quality of the output is set to invalid. The quality of the output is also set to invalid if the VALID input is not set.

#### 14.3.3 Setting guidelines

The function does not have any parameters available in the local HMI or PCM600.

### 14.4 Single point generic control 8 signals SPC8GAPC
14.4.1 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>
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<tbody>
<tr>
<td>Single point generic control 8 signals</td>
<td>SPC8GAPC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

14.4.2 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.

14.4.3 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).

14.5 AutomationBits, command function for DNP3.0 AUTOBITS

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>AutomationBits, command function for DNP3</td>
<td>AUTOBITS</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
14.5.2 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.

14.5.3 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.

14.6 Single command, 16 signals SINGLECMD

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>Single command, 16 signals</td>
<td>SINGLECMD</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

14.6.2 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 73 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 73 shows a close operation. An open breaker operation is performed in a similar way but without the synchro-check condition.

**Figure 73:** Application example showing a logic diagram for control of a circuit breaker via configuration logic circuits

Figure 74 and figure 75 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.
14.6.3 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 CMDOUT\text{\textsubscript{y}} 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 15  Logic

15.1  Tripping logic common 3-phase output SMPPTRC

15.1.1  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.

To meet the different double, 1½ breaker and other multiple circuit breaker arrangements, two identical SMPPTRC function blocks may be provided within the IED.

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.

### 15.1.1.1 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, \( t_{TripMin} = 150ms \).

For special applications such as Lock-out refer to the separate section below. The typical connection is shown below in figure 76. Signals that are not used are dimmed.

---

**Figure 76:** Tripping logic SMPPTRC is used for a simple three-phase tripping application
15.1.1.2 **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 77.
15.1.1.3 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.

15.1.1.4 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.

15.1.1.5 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.

15.1.2 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.

15.2 Trip matrix logic TMAGAPC

15.2.1 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>
15.3  Logic for group alarm ALMCALH

15.3.1  Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 80817 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>

15.3.2  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.

15.3.3  Setting guidelines

Operation: On or Off

15.4  Logic for group alarm WRNCALH

15.4.1  Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 80817 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>

15.4.1.1  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.

15.4.1.2  Setting guidelines

Operation: On or Off
15.5 Logic for group indication INDCALH

15.5.1 Identification

Function description | IEC 61850 identification | IEC 80617 identification | ANSI/IEEE C37.2 device number
--- | --- | --- | ---
Logic for group indication | INDCALH | - | -

15.5.1.1 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.

15.5.1.2 Setting guidelines

*Operation: On or Off*

15.6 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.

15.6.1 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.

15.6.2 Setting guidelines

There are no settings for AND gates, OR gates, inverters or XOR gates.

For normal On/Off delay and pulse timers the time delays and pulse lengths are set from the local HMI or via the PST tool.
Both timers in the same logic block (the one delayed on pick-up and the one delayed on drop-out) always have a common setting value.

For controllable gates, settable timers and SR flip-flops with memory, the setting parameters are accessible via the local HMI or via the PST tool.

15.6.2.1 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 a 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 78:** 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.
15.7     Fixed signal function block FXDSIGN

15.7.1     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>

15.7.2     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.

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.

![Diagram of REFPDIF function inputs for autotransformer application](IEC09000619_3_en.vsd)

*Figure 79: 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.
15.8 Boolean 16 to Integer conversion B16I

15.8.1 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>

15.8.2 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 $1 \leq x \leq 16$ 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 $1 \leq x \leq 16$. 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 $1 \leq x \leq 16$ are activated that is $= \text{Boolean 1}$ 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 $1 \leq x \leq 16$.

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.

15.9 Boolean 16 to Integer conversion with logic node representation BTIGAPC

15.9.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 60817 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boolean 16 to integer conversion with logic node representation</td>
<td>BTIGAPC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

15.9.2 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>
<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 BTIGAPC function block.

15.10 Integer to Boolean 16 conversion IB16
15.10.1 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>

15.10.2 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: \( \text{IN}_x = 2^{x-1} \) 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 $1 \leq x \leq 16$) 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.

15.11 Integer to Boolean 16 conversion with logic node representation ITBGAPC

15.11.1 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</td>
<td>ITBGAPC</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>representation</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

15.11.2 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 $1 \leq x \leq 16$.

The values of the different OUTx are according to the Table 19.

If the BLOCK input is activated, it freezes the logical outputs at the last value.

<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>
</tbody>
</table>

Table continues on next page
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.

15.12 Elapsed time integrator with limit transgression and overflow supervision TEIGAPC

15.12.1 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>Elapsed time integrator</td>
<td>TEIGAPC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

15.12.2 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.

15.12.3 Setting guidelines

The settings \( t_{Alarm} \) and \( t_{Warning} \) 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

\[
1.00 \text{ second} \leq t_{Alarm} \leq 99\,999.99 \text{ seconds}
\]
$1.00 \text{ second} \leq t_{\text{Warning}} \leq 99\,999.99 \text{ seconds.}$

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.
Section 16  Monitoring

16.1  Measurement

16.1.1  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>P, Q, S, I, U, f</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>

16.1.2  Application

Measurement functions is 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 than 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).

### 16.1.3 Zero clamping

The measuring functions, CVMMXN, CMMXU, VMMXU and VNMMXU have no interconnections regarding any setting or parameter.

Zero clampings 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 Monitoring/Servicevalues/SRV1:

- **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 Setting/General setting/Monitoring/Service values/SRV1

It can be seen that:
• When system voltage falls below $UGenZeroDB$, 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 $IGenZeroDB$, 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 $SZeroDb$ the value for S on the local HMI is forced to zero.

### 16.1.4 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.

**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.

* **UBase:** Base voltage in primary kV. This voltage is used as reference for voltage setting. It can be suitable to set this parameter to the rated primary voltage supervised object.

* **IBase:** Base current in primary A. This current is used as reference for current setting. It can be suitable to set this parameter to the rated primary current of the supervised object.
**SBase:** Base setting for power values in MVA.

**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.

Parameters **IBase, Ubase and SBase** have been implemented as a settings instead of a parameters, which means that if the values of the parameters are changed there will be no restart of the application. As restart is required to activate new parameters values, the IED must be restarted in some way. Either manually or by changing some other parameter at the same time.

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.

**Calibration curves**

It is possible to calibrate the functions (CVMMXN, CMMXU, VNMMXU and VMMXU) 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 81 (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.
16.1.4.1 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 82:
In order to monitor, supervise and calibrate the active and reactive power as indicated in figure 82 it is necessary to do the following:

1. Set correctly CT and VT data and phase angle reference channel \textit{PhaseAngleRef} using PCM600 for analog input channels
2. Connect, in PCM600, measurement function to three-phase CT and VT inputs
3. Set under General settings parameters for the Measurement function:
   - general settings as shown in table 20.
   - level supervision of active power as shown in table 21.
   - calibration parameters as shown in table 22.

\textbf{Figure 82: Single line diagram for 110kV OHL application}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{110kV_Busbar_OHL.png}
\caption{Single line diagram for 110kV OHL application}
\end{figure}

\begin{table}[h]
\centering
\caption{General settings parameters for the Measurement function}
\begin{tabular}{|c|c|c|c|}
\hline
\textbf{Setting} & \textbf{Short Description} & \textbf{Selected value} & \textbf{Comments} \\
\hline
Operation & Operation Off/On & On & Function must be On \\
\hline
PowAmpFact & Amplitude factor to scale power calculations & 1.000 & It can be used during commissioning to achieve higher measurement accuracy. Typically no scaling is required \\
\hline
PowAngComp & Angle compensation for phase shift between measured I & U & 0.0 & It can be used during commissioning to achieve higher measurement accuracy. Typically no angle compensation is required. As well here required direction of P & Q measurement is towards protected object (as per IED internal default direction) \\
\hline
Mode & Selection of measured current and voltage & L1, L2, L3 & All three phase-to-earth VT inputs are available \\
\hline
k & Low pass filter coefficient for power measurement, U and I & 0.00 & Typically no additional filtering is required \\
\hline
\end{tabular}
\end{table}
<table>
<thead>
<tr>
<th>Setting</th>
<th>Short Description</th>
<th>Selected value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>UGenZeroDb</td>
<td>Zero point clamping in % of Ubase</td>
<td>25</td>
<td>Set minimum voltage level to 25%. Voltage below 25% will force S, P and Q to zero.</td>
</tr>
<tr>
<td>IGenZeroDb</td>
<td>Zero point clamping in % of Ibase</td>
<td>3</td>
<td>Set minimum current level to 3%. Current below 3% will force S, P and Q to zero.</td>
</tr>
<tr>
<td>UBase (set in Global base)</td>
<td>Base setting for voltage level in kV</td>
<td>400.00</td>
<td>Set rated OHL phase-to-phase voltage</td>
</tr>
<tr>
<td>IBase (set in Global base)</td>
<td>Base setting for current level in A</td>
<td>800</td>
<td>Set rated primary CT current used for OHL</td>
</tr>
</tbody>
</table>

**Table 21: 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>PDbReplInt</td>
<td>Cyc: 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>PHIHiLim</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 (common for all limits)</td>
<td>2</td>
<td>Set ±Δ Hysteresis MW that is, 2%</td>
</tr>
</tbody>
</table>

**Table 22: 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>UAmplComp5</td>
<td>Amplitude factor to calibrate voltage at 5% of Ur</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>UAmplComp30</td>
<td>Amplitude factor to calibrate voltage at 30% of Ur</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

Table continues on next page
### Setting

<table>
<thead>
<tr>
<th>Setting</th>
<th>Short Description</th>
<th>Selected value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<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 83.
In order to measure the active and reactive power as indicated in figure 83, it is necessary to do the following:

1. Set correctly all CT and VT and phase angle reference channel *PhaseAngleRef* data using PCM600 for analog input channels
2. Connect, in PCM600, measurement function to LV side CT & VT inputs
3. Set the setting parameters for relevant Measurement function as shown in the following table 23:
### Table 23: 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 alignment 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>

### Measurement function application for a generator

Single line diagram for this application is given in figure 84.
In order to measure the active and reactive power as indicated in figure 84, it is necessary to do the following:

1. Set correctly all CT and VT data and phase angle reference channel PhaseAngleRef using PCM600 for analog input channels
2. Connect, in PCM600, measurement function to the generator CT & VT inputs
3. Set the setting parameters for relevant Measurement function as shown in the following table:
### Table 24: 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>1.00</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>0.0</td>
<td>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>Arone</td>
<td>Generator VTs are connected between phases (V-connected)</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>15.65</td>
<td>Set generator 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>3690</td>
<td>Set generator rated current</td>
</tr>
</tbody>
</table>

### 16.2 Gas medium supervision SSIMG

#### 16.2.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 80617 identification</th>
<th>ANSI/IEEE C37.2 device number</th>
</tr>
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<tbody>
<tr>
<td>Gas medium supervision</td>
<td>SSIMG</td>
<td>-</td>
<td>63</td>
</tr>
</tbody>
</table>

#### 16.2.2 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.

#### 16.2.3 Setting guidelines

The parameters for the gas medium supervision SSIMG are set via the local HMI or PCM600.
16.3 Liquid medium supervision SSIML

16.3.1 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>
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<tbody>
<tr>
<td>Liquid medium supervision</td>
<td>SSIML</td>
<td>-</td>
<td>71</td>
</tr>
</tbody>
</table>

16.3.2 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.

16.3.3 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
- **TempAlmLimit**: 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
• \( t_{\text{TempAlarm}} \): Time delay for temperature alarm of the liquid medium
• \( t_{\text{TempLockOut}} \): Time delay for temperature lockout of the liquid medium
• \( t_{\text{ResetLevelAlm}} \): Reset time delay for level alarm of the liquid medium
• \( t_{\text{ResetLevelLO}} \): Reset time delay for level lockout of the liquid medium
• \( t_{\text{ResetTempAlm}} \): Reset time delay for temperature lockout of the liquid medium
• \( t_{\text{ResetTempLO}} \): Reset time delay for temperature alarm of the liquid medium

16.4 Breaker monitoring SSCBR

16.4.1 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>
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<tbody>
<tr>
<td>Breaker monitoring</td>
<td>SSCBR</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

16.4.2 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 85.

![Diagram showing number of make-break operations at various interrupted currents](IEC12000623_1_en.vsd)

**Figure 85:** 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 10kA 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.

**16.4.3 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.

16.4.3.1 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 ($I_{\text{Base}}$), primary voltage ($U_{\text{Base}}$) and primary power ($S_{\text{Base}}$) are set in Global base values for settings function GBASVAL.

$\text{GlobalBaseSel}$: It is used to select a GBASVAL function for reference of base values.

$\text{Operation}$: $\text{On}$ or $\text{Off}$.

$I_{\text{Base}}$: Base phase current in primary A. This current is used as reference for current settings.

$\text{OpenTimeCorr}$: Correction factor for circuit breaker opening travel time.

$\text{CloseTimeCorr}$: Correction factor for circuit breaker closing travel time.

$t_{\text{TrOpenAlm}}$: Setting of alarm level for opening travel time.

$t_{\text{TrCloseAlm}}$: Setting of alarm level for closing travel time.

$\text{OperAlmLevel}$: Alarm limit for number of mechanical operations.

$\text{OperLOLevel}$: Lockout limit for number of mechanical operations.

$\text{CurrExponent}$: Current exponent setting for energy calculation. It varies for different types of circuit breakers. This factor ranges from $0.5$ to $3.0$.

$\text{AccStopCurr}$: RMS current setting below which calculation of energy accumulation stops. It is given as a percentage of $I_{\text{Base}}$.

$\text{ContTrCorr}$: Correction factor for time difference in auxiliary and main contacts' opening time.

$\text{AlmAccCurrPwr}$: Setting of alarm level for accumulated energy.

$\text{LOAccCurrPwr}$: Lockout limit setting for accumulated energy.

$\text{SpChAlmTime}$: Time delay for spring charging time alarm.

$t_{\text{DGasPresAlm}}$: Time delay for gas pressure alarm.

$t_{\text{DGasPresLO}}$: Time delay for gas pressure lockout.

$\text{DirCoef}$: Directional coefficient for circuit breaker life calculation.

$\text{RatedOperCurr}$: 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.

## 16.5 Disturbance report DRPRDRE

### 16.5.1 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>
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<tbody>
<tr>
<td>Analog input signals</td>
<td>A41RADR</td>
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<td>-</td>
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<tr>
<td>Disturbance report</td>
<td>DRPRDRE</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Disturbance report</td>
<td>A1RADR</td>
<td>-</td>
<td>-</td>
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<td>A2RADR</td>
<td>-</td>
<td>-</td>
</tr>
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<td>A3RADR</td>
<td>-</td>
<td>-</td>
</tr>
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<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
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<td>Disturbance report</td>
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<td>-</td>
</tr>
<tr>
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<td>-</td>
<td>-</td>
</tr>
<tr>
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<td>-</td>
</tr>
<tr>
<td>Disturbance report</td>
<td>B5RBDR</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Disturbance report</td>
<td>B6RBDR</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

### 16.5.2 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
- 96 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).

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 as GOOSE or Report Control data. The same information is obtainable if IEC60870-5-103 is used.

16.5.3 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 96 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 86 shows the relations between Disturbance report, included functions and function blocks. Event list (EL), Event recorder (ER) and Indication (IND) uses information from the binary input function blocks (BxRBDR). Trip value recorder (TVR) uses analog information from the analog input function blocks (AxRADR). Disturbance report function acquires information from both AxRADR and BxRBDR.

![Diagram of Disturbance report functions and related function blocks]

**Figure 86: Disturbance report functions and related function blocks**

For Disturbance report function there are a number of settings which also influences the sub-functions.

Three LED indications placed above the LCD screen makes it possible to get quick status information about the IED.

- **Green LED:**
  - Steady light: In Service
  - Flashing light: Internal failure
  - Dark: No power supply

- **Yellow LED:**
  - Steady light: A Disturbance Report is triggered
  - Flashing light: The IED is in test mode

Table continues on next page
Red LED:
Steady light
Triggered on binary signal N with $SetLEDN = On$

**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 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.
16.5.3.1 Recording times

The different recording times for Disturbance report are set (the pre-fault time, post-fault time, and limit time). These recording times affect all sub-functions more or less but not the Event list (EL) function.

Prefault recording time ($\text{PreFaultRecT}$) is the recording time before the starting point of the disturbance. The setting should be at least $0.1 \text{s}$ to ensure enough samples for the estimation of pre-fault values in the Trip value recorder (TVR) function.

Postfault recording time ($\text{PostFaultRecT}$) is the maximum recording time after the disappearance of the trig-signal (does not influence the Trip value recorder (TVR) function).

Recording time limit ($\text{TimeLimit}$) is the maximum recording time after trig. The parameter limits the recording time if some triggering condition (fault-time) is very long or permanently set (does not influence the Trip value recorder (TVR) function).

Post retrigger ($\text{PostRetrig}$) can be set to $\text{On}$ or $\text{Off}$. Makes it possible to choose performance of Disturbance report function if a new trig signal appears in the post-fault window.

$\text{PostRetrig} = \text{Off}$

The function is insensitive for new trig signals during post fault time.

$\text{PostRetrig} = \text{On}$

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 trip value calculations if installed, in operation and started

Operation in test mode

If the IED is in test mode and $\text{OpModeTest} = \text{Off}$. Disturbance report function does not save any recordings and no LED information is displayed.

If the IED is in test mode and $\text{OpModeTest} = \text{On}$. Disturbance report function works in normal mode and the status is indicated in the saved recording.

16.5.3.2 Binary input signals

Up to 96 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 96 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.

### 16.5.3.3 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.

For retrieving remote data from LDCM module, the Disturbance report function should not be connected to a 3 ms SMAI function block if this is the only intended use for the remote data.

The analog trigger of Disturbance report is not affected if analog input M is to be included in the disturbance recording or not (OperationM = On/Off).

If OperationM = Off, no waveform (samples) will be recorded and reported in graph. However, Trip value, pre-fault and fault value will be recorded and reported. The input channel can still be used to trig the disturbance recorder.

If OperationM = On, waveform (samples) will also be recorded and reported in graph.

**NomValueM**: Nominal value for input M.

**OverTrigOpM, UnderTrigOpM**: Over or Under trig operation, Disturbance report may trig for high/low level of analog input M (On) or not (Off).

**OverTrigLeM, UnderTrigLeM**: Over or under trig level, Trig high/low level relative nominal value for analog input M in percent of nominal value.

### 16.5.3.4 Sub-function parameters

All functions are in operation as long as Disturbance report is in operation.

**Indications**

**IndicationMaN**: Indication mask for binary input N. If set (Show), a status change of that particular input, will be fetched and shown in the disturbance summary on local HMI. If not set (Hide), status change will not be indicated.
SetLEDN: Set red LED on local HMI in front of the IED if binary input N changes status.

Disturbance recorder

OperationM: Analog channel M is to be recorded by the disturbance recorder (On) or not (Off).

If OperationM = Off, no waveform (samples) will be recorded and reported in graph. However, Trip value, pre-fault and fault value will be recorded and reported. The input channel can still be used to trig the disturbance recorder.

If OperationM = On, waveform (samples) will also be recorded and reported in graph.

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.

16.5.3.5 Consideration

The density of recording equipment in power systems is increasing, since the number of modern IEDs, where recorders are included, is increasing. This leads to a vast number of recordings at every single disturbance and a lot of information has to be handled if the recording functions do not have proper settings. The goal is to optimize the settings in each IED to be able to capture just valuable disturbances and to maximize the number that is possible to save in the IED.

The recording time should not be longer than necessary (PostFaultrecT and TimeLimit).

- Should the function record faults only for the protected object or cover more?
- How long is the longest expected fault clearing time?
- Is it necessary to include reclosure in the recording or should a persistent fault generate a second recording (PostRetrig)?

Minimize the number of recordings:

- Binary signals: Use only relevant signals to start the recording that is, protection trip, carrier receive and/or start signals.
- Analog signals: The level triggering should be used with great care, since unfortunate settings will cause enormously number of recordings. If nevertheless
analog input triggering is used, choose settings by a sufficient margin from normal operation values. Phase voltages are not recommended for triggering.

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.

16.6 Logical signal status report BINSTATREP

16.6.1 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>Logical signal status report</td>
<td>BINSTATREP</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

16.6.2 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 87: BINSTATREP logical diagram](IEC09000732-1-en.vsd)

16.6.3 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.
16.7 Limit counter L4UFCNT

16.7.1 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>Limit counter</td>
<td>L4UFCNT</td>
<td></td>
<td>-</td>
</tr>
</tbody>
</table>

16.7.2 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.

16.7.3 Setting guidelines

The parameters for Limit counter L4UFCNT are set via the local HMI or PCM600.
Section 17 Metering

17.1 Pulse-counter logic PCFCNT

17.1.1 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>
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<td>Pulse-counter logic</td>
<td>PCFCNT</td>
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</table>

17.2 Function for energy calculation and demand handling ETPMMTR

17.2.1 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>
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<tbody>
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<td>Function for energy calculation and demand handling</td>
<td>ETPMMTR</td>
<td>W_Varh</td>
<td></td>
</tr>
</tbody>
</table>

17.2.2 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 88.
Figure 88: Connection of energy calculation and demand handling function ETPMMTR to the measurements function (CVMMXN)

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 \( E_{AF}AccPlsQty \), \( E_{AR}AccPlsQty \), \( E_{RF}AccPlsQty \) and \( E_{RR}AccPlsQty \) 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.

17.2.3 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:

**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.
Section 18 Station communication

18.1 670 series 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.

Following communication protocols are available:

- IEC 61850-8-1 communication protocol
- IEC 61850-9-2LE communication protocol
- DNP3.0 communication protocol

Several protocols can be combined in the same IED.

18.2 IEC 61850-8-1 communication protocol

18.2.1 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 89 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 89: SA system with IEC 61850–8–1

Figure 90 shows the GOOSE peer-to-peer communication.

Figure 90: Example of a broadcasted GOOSE message
18.2.2 Setting guidelines

There are two settings related to the IEC 61850–8–1 protocol:

*Operation* User can set IEC 61850 communication to *On* or *Off*.

*GOOSE* has to be set to the Ethernet link where GOOSE traffic shall be send and received.

18.2.3 Generic communication function for Single Point indication

**SPGAPC, SP16GAPC**

18.2.3.1 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.

18.2.3.2 Setting guidelines

There are no settings available for the user for SPGAPC.

18.2.4 Generic communication function for Measured Value

**MVGAPC**

18.2.4.1 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.

18.2.4.2 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.
18.2.5 IEC 61850-8-1 redundant station bus communication

18.2.5.1 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>Parallel Redundancy Protocol Status</td>
<td>PRPSTATUS</td>
<td>RCHLCCH</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Duo driver configuration</td>
<td>PRP</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

18.2.5.2 Application

Parallel redundancy protocol status (PRPSTATUS) together with Duo driver configuration (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.
18.2.5.3 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 [SG1/Common]</th>
<th>PC Value [SG1/Common]</th>
<th>Link</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethernet configuration</td>
<td></td>
<td></td>
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<tr>
<td>1 FRONT:1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✓ IPAddress</td>
<td>10.1.150.3</td>
<td>10.1.150.3</td>
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</tr>
<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>✓ LANCD:1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✓ Mode</td>
<td>PRP</td>
<td>PRP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✓ IPAddress</td>
<td>138.227.103.131</td>
<td>138.227.103.131</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>
<tr>
<td>✓ GATEWAY:1</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>✓ S VLANAddress</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>
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<td></td>
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<td></td>
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<tr>
<td>✓ Operation</td>
<td>On</td>
<td>On</td>
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<td>✓ PRPMode</td>
<td>PRP</td>
<td>PRP</td>
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<td></td>
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</tr>
<tr>
<td>✓ IPAddress</td>
<td>138.227.103.131</td>
<td>138.227.103.131</td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>255.255.254.0</td>
<td>255.255.254.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 92:** PST screen: PRP Operation is set to On, which affect Rear OEM - Port AB and CD which are both set to PRP

## 18.3 IEC 61850-9-2LE communication protocol

### 18.3.1 Introduction

Every IED can be provided with a communication interface enabling it to connect to a process bus, in order to get data from analog data acquisition units close to the process (primary apparatus), commonly known as Merging Units (MU). The protocol used in this case is the IEC 61850-9-2LE communication protocol.

Note that the IEC 61850-9-2LE standard does not specify the quality of the sampled values, only the transportation. Thus, the accuracy of the current and voltage inputs to the merging unit and the inaccuracy added by the merging unit must be coordinated with the requirement for actual type of protection function.

Factors influencing the accuracy of the sampled values from the merging unit are for example anti aliasing filters, frequency range, step response, truncating, A/D conversion inaccuracy, time tagging accuracy etc.
In principle shall the accuracy of the current and voltage transformers, together with the merging unit, have the same quality as direct input of currents and voltages.

The process bus physical layout can be arranged in several ways, described in Annex B of the standard, depending on what are the needs for sampled data in a substation.

The IED can get analog values simultaneously from a classical CT or VT and from a Merging Unit, like in this example:

The merging units (MU) are called so because they can gather analog values from one or more measuring transformers, sample the data and send the data over process bus to other clients (or subscribers) in the system. Some merging units are able to get data from classical measuring transformers, others from non-conventional measuring transducers and yet others can pick up data from both types. The electronic part of a non-conventional measuring transducer (like a Rogowski coil or a capacitive divider) can represent a MU by itself as long as it can send sampled data over process bus.
18.3.2 Setting guidelines

There are several settings related to the Merging Units in local HMI under:

Main menu\Settings\General Settings\Analog Modules\Merging Unit x

where x can take the value 1, 2, 3, 4, 5 or 6.

Figure 94: Example of a station configuration with the IED receiving analog values from both classical measuring transformers and merging units.
18.3.2.1 Specific settings related to the IEC 61850-9-2LE communication

The process bus communication IEC 61850-9-2LE have specific settings, similar to the analog inputs modules.

Besides the names of the merging unit channels (that can be edited only from PCM600, not from the local HMI) there are important settings related to the merging units and time synchronization of the signals:

- When changing the sending (MU unit) MAC address, a reboot of the IED is required.

If there are more than one sample group involved, then time synch is mandatory and the protection functions will be blocked if there is no time synchronization.

*SmpGrp* – this setting parameter is not used

*CTStarPointx*: This parameter specifies the direction to or from object. See also section "Setting of current channels".

*AppSynch*: If this parameter is set to *Synch* and the IED HW-time synchronization is lost or the synchronization to the MU time is lost, the protection functions in the list 25 will be blocked and the output SYNCH will be set.

*SynchMode*: marks how the IED will receive the data coming from a merging unit:

- if it is set to *NoSynch*, then when the sampled values arrive, there will be no check on the “SmpSynch” flag
- If it is set to *Operation*, the “SmpSynch” flag will be checked all time.
- setting *Init*, should not be used

For more information on the settings, see “MU1_4I_4U Non group settings (basic)” table.

18.3.2.2 Loss of communication

If IEC 61850-9-2LE communication is lost, see examples in figures 95, 96 and 97, the protection functions in table 25 are blocked.

Case 1:
Case 2:

Failure of the MU (sample lost) blocks the sending of binary signals through LDCM. The received binary signals are not blocked and processed normally.

→ DTT from the remote end is still processed.

Case 3:

Failure of one MU (sample lost) blocks the sending and receiving of binary signals through LDCM.

→ DTT from the remote end is not working.
Table 25: Blocked protection functions if IEC 61850-9-2LE communication is interrupted.

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>Function description</th>
<th>IEC 61850 identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accidental energizing protection for synchronous generator</td>
<td>AEGPVOC</td>
<td>Two step overvoltage protection</td>
<td>OV2PTOV</td>
</tr>
<tr>
<td>Broken conductor check</td>
<td>BRCPTOC</td>
<td>Four step single phase overcurrent protection</td>
<td>PH4SPTOC</td>
</tr>
<tr>
<td>Capacitor bank protection</td>
<td>CBPGAPC</td>
<td>Radial feeder protection</td>
<td>PAPGAPC</td>
</tr>
<tr>
<td>Pole discordance protection</td>
<td>CCPDSC</td>
<td>Instantaneous phase overcurrent protection</td>
<td>PHPIOC</td>
</tr>
<tr>
<td>Breaker failure protection</td>
<td>CCRBRF</td>
<td>PoleSlip/Out-of-step protection</td>
<td>PSPPPAM</td>
</tr>
<tr>
<td>Breaker failure protection, single phase version</td>
<td>CCSRBRF</td>
<td>Restricted earth fault protection, low impedance</td>
<td>REFPDIF</td>
</tr>
<tr>
<td>Current circuit supervision</td>
<td>CCSSPVC</td>
<td>Two step residual overvoltage protection</td>
<td>ROV2PTOV</td>
</tr>
<tr>
<td>Compensated over- and undervoltage protection</td>
<td>COUVGAPC</td>
<td>Rate-of-change frequency protection</td>
<td>SAPFRC</td>
</tr>
<tr>
<td>General current and voltage protection</td>
<td>CVGAPC</td>
<td>Overfrequency protection</td>
<td>SAPTOF</td>
</tr>
<tr>
<td>Current reversal and weaken infeed logic for residual overcurrent protection</td>
<td>ECRWPSCH</td>
<td>Underfrequency protection</td>
<td>SAPTUF</td>
</tr>
<tr>
<td>Four step residual overcurrent protection</td>
<td>EF4PTOC</td>
<td>Sudden change in current variation</td>
<td>SCCVPTOC</td>
</tr>
<tr>
<td>Instantaneous residual overcurrent protection</td>
<td>EFPIOC</td>
<td>Sensitive Directional residual over current and power protection</td>
<td>SDEPSDE</td>
</tr>
<tr>
<td>Phase selection, quadrilateral characteristic with fixed angle</td>
<td>FDPSPDIS</td>
<td>Synchocheck, energizing check, and synchronizing</td>
<td>SESRSYN</td>
</tr>
</tbody>
</table>

Table continues on next page
<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 Identification</th>
<th>Function description</th>
<th>IEC 61850 Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faulty phase identification with load encroachment</td>
<td>FMSPDIS</td>
<td>Circuit breaker condition monitoring</td>
<td>SSCBR</td>
</tr>
<tr>
<td>Phase selection, quadrilateral characteristic with settable angle</td>
<td>FRPSPDIS</td>
<td>Insulation gas monitoring</td>
<td>SSIMG</td>
</tr>
<tr>
<td>Frequency time accumulation protection</td>
<td>FTAQFVR</td>
<td>Insulation liquid monitoring</td>
<td>SSIML</td>
</tr>
<tr>
<td>Fuse failure supervision</td>
<td>FUFSVPVC</td>
<td>Stub protection</td>
<td>STBPPTOC</td>
</tr>
<tr>
<td>Generator differential protection</td>
<td>GENPDIF</td>
<td>Transformer differential protection, two winding</td>
<td>T2WPDIF</td>
</tr>
<tr>
<td>Directional Overpower protection</td>
<td>GOPPDOP</td>
<td>Transformer differential protection, three winding</td>
<td>T3WPDIF</td>
</tr>
<tr>
<td>Generator rotor overload protection</td>
<td>GRPTTR</td>
<td>Automatic voltage control for tapchanger, single control</td>
<td>TR1ATCC</td>
</tr>
<tr>
<td>Generator stator overload protection</td>
<td>GSPTTR</td>
<td>Automatic voltage control for tapchanger, parallel control</td>
<td>TR8ATCC</td>
</tr>
<tr>
<td>Directional Underpower protection</td>
<td>GUPPDUP</td>
<td>Thermal overload protection, two time constants</td>
<td>TRPTTR</td>
</tr>
<tr>
<td>1Ph High impedance differential protection</td>
<td>HZPDIF</td>
<td>Two step undervoltage protection</td>
<td>UV2PTUV</td>
</tr>
<tr>
<td>Line differential protection, 3 CT sets, 2-3 line ends</td>
<td>L3CPDIF</td>
<td>Voltage differential protection</td>
<td>VDCPTOV</td>
</tr>
<tr>
<td>Line differential protection, 6 CT sets, 3-5 line ends</td>
<td>L6CPDIF</td>
<td>Fuse failure supervision</td>
<td>VDRFUF</td>
</tr>
<tr>
<td>Low active power and power factor protection</td>
<td>LAPPGAPC</td>
<td>Voltage-restrained time overcurrent protection</td>
<td>VRPVOC</td>
</tr>
<tr>
<td>Negative sequence overcurrent protection</td>
<td>LCNSPTOC</td>
<td>Local acceleration logic</td>
<td>ZCLCPSCCH</td>
</tr>
<tr>
<td>Negative sequence overvoltage protection</td>
<td>LCNSPTOV</td>
<td>Scheme communication logic for distance or overcurrent protection</td>
<td>ZCPSCCH</td>
</tr>
<tr>
<td>Three phase overcurrent</td>
<td>LCP3PTOC</td>
<td>Current reversal and weak-end infeed logic for distance protection</td>
<td>ZCRWPSCH</td>
</tr>
<tr>
<td>Three phase undercurrent</td>
<td>LCP3PTUC</td>
<td>Automatic switch onto fault logic, voltage and current based</td>
<td>ZCVPSCOF</td>
</tr>
<tr>
<td>Thermal overload protection, one time constant</td>
<td>LCPTTR</td>
<td>Under impedance protection for generator</td>
<td>ZGVPDIS</td>
</tr>
<tr>
<td>Zero sequence overcurrent protection</td>
<td>LCZSPTOC</td>
<td>Fast distance protection</td>
<td>ZMFCPDIS</td>
</tr>
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</table>

Table continues on next page
<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>Function description</th>
<th>IEC 61850 identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero sequence overvoltage protection</td>
<td>LCZSPTOV</td>
<td>High speed distance protection</td>
<td>ZMFDPDIS</td>
</tr>
<tr>
<td>Line differential coordination</td>
<td>LDLPSCH</td>
<td>Distance measuring zone, quadrilateral characteristic for series compensated lines</td>
<td>ZMCAPDIS</td>
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<tr>
<td>Additional security logic for differential protection</td>
<td>LDRGFC</td>
<td>Distance measuring zone, quadrilateral characteristic for series compensated lines</td>
<td>ZMCPDIS</td>
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<td>Loss of excitation</td>
<td>LEXPDIS</td>
<td>Fullscheme distance protection, mho characteristic</td>
<td>ZMHDPDIS</td>
</tr>
<tr>
<td>Thermal overload protection, one time constant</td>
<td>LFPTTR</td>
<td>Fullscheme distance protection, quadrilateral for earth faults</td>
<td>ZMMAPDIS</td>
</tr>
<tr>
<td>Loss of voltage check</td>
<td>LOVPTUV</td>
<td>Fullscheme distance protection, quadrilateral for earth faults</td>
<td>ZMPDIS</td>
</tr>
<tr>
<td>Line differential protection 3 CT sets, with inzone transformers, 2-3 line ends</td>
<td>LT3CPDIF</td>
<td>Distance protection zone, quadrilateral characteristic</td>
<td>ZMQAPDIS</td>
</tr>
<tr>
<td>Line differential protection 6 CT sets, with inzone transformers, 3-5 line ends</td>
<td>LT6CPDIF</td>
<td>Distance protection zone, quadrilateral characteristic</td>
<td>ZMQPDIS</td>
</tr>
<tr>
<td>Negativ sequence time overcurrent protection for machines</td>
<td>NS2PTOC</td>
<td>Distance protection zone, quadrilateral characteristic, separate settings</td>
<td>ZMRAPDIS</td>
</tr>
<tr>
<td>Four step directional negative phase sequence overcurrent protection</td>
<td>NS4PTOC</td>
<td>Distance protection zone, quadrilateral characteristic, separate settings</td>
<td>ZMRPDIS</td>
</tr>
<tr>
<td>Four step phase overcurrent protection</td>
<td>OC4PTOC</td>
<td>Power swing detection</td>
<td>ZMRPSB</td>
</tr>
<tr>
<td>Overexcitation protection</td>
<td>OEXPVPH</td>
<td>Mho Impedance supervision logic</td>
<td>ZSMGAPC</td>
</tr>
<tr>
<td>Out-of-step protection</td>
<td>OOSPPAM</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 18.3.2.3 Setting examples for IEC 61850-9-2LE and time synchronization

It is important that the IED and the merging units (MU) uses the same time reference. This is especially true if analog data is used from several sources, for example an internal TRM and a MU. Or if several physical MU is used. The same time reference is important to correlate data so that channels from different sources refer to correct phase angle.
When only one MU is used as analog source it is theoretically possible to do without time-synchronization. However, this would mean that timestamps for analog and binary data/events would be uncorrelated. Disturbance recordings will appear incorrect since analog data will be timestamped by MU and binary events will use internal IED time. For this reason it is recommended to use time synchronization also when analog data emanate from only one MU.

An external time-source can be used to synchronize both the IED and the MU. It is also possible to use the MU as clock-master to synchronize the IED from the MU. When using an external clock, it is possible to set the IED to be synchronized via PPS or IRIG-B. It is also possible to use an internal GPS-receiver in the IED (if the external clock is using GPS).

**Using the MU as time source for synchronization**

![Diagram](IEC10000061-1-en.vsd)

**Figure 98:** Setting example when MU is the synchronizing source

Settings in local HMI under **Settings/Time/Synchronization/TIMESYNCHGEN/IEC 61850-9-2:**

- *HwSyncSrc*: set to *PPS* since this is what is generated by the MU (ABB MU)
- *AppSynch*: set to *Synch*, since protection functions should be blocked in case of loss of timesynchronization
- *SyncAccLevel*: could be set to 4us since this corresponds to a maximum phase-angle error of 0.072 degrees at 50Hz
- *fineSyncSource* could still be set to something different in order to correlate events and data to other IED’s in the station

Settings in PST in PCM600 under: **Hardware/Analog modules/Merging units/MU01**
• **SyncMode** : set to Operation. This means that the IED will be blocked if the MU loose time synchronization. Since the MU is set as Time-master, this is unlikely to happen so the setting of **SyncMode** is not important in this case.

There are 3 signals that monitors state related to time synchronization:

• TSYNCERR signal on the TIMEERR function block. This signal will go high whenever internal `timeQuality` goes above the setting `SyncAccLevel` (4μs in this case) and this will block the protection functions. This will happen max 4 seconds after an interruption of the PPS fiber from the MU (or if the `fineSyncSource` is lost).

• SYNCH signal on the MU1_4I_4U function block indicates when protection functions are blocked due to loss of internal time synchronization to the IED (that is loss of the hardware `synchSrc`)

• MUSYNCH signal on the MU_4I_4U function block monitor the synchronization from the MU (in the datastream). When the MU indicates loss of time synchronization this signal will go high. In this case the MU is set to master so it can not loose time synchronization.

The SMPLLOSTsignal will of course also be interesting since this indicate blocking due to missing analog data (interruption of IEC 61850-9-2LE fiber), although this has nothing to do with time synchronization.

**Using an external clock for time synchronization**

![Diagram](image)

*Figure 99: Setting example with external synchronization*

Settings in local HMI under **Settings/Time/Synchronization/TIMESYNCHGEN/IEC 61850-9-2:**
• **HwSyncSrc**: set to PPS/IRIG-B depending on available outputs on the clock
• **AppSynch**: set to Synch, for blocking protection functions in case of loss of time synchronization
• **SyncAccLevel**: could be set to 4us since this correspond to a maximum phase-angle error of 0.072 degrees at 50Hz
• **fineSyncSource**: should be set to IRIG-B if this is available from the clock. If using PPS for HwSyncSrc, “full-time” has to be acquired from another source. If the station clock is on the local area network (LAN) and has a sntp-server this is one option.

Settings in PST in PCM600 under: **Hardware/Analog modules/Merging units/MU01**

• **SyncMode**: set to Operation. This means that the IED will block if the MU loose time synchronization.

There are 3 signals that monitors state related to time synchronization:

• TSYNCERR signal on the TIMEERR function block will go high whenever internal *timeQuality* goes above the setting *SyncAccLevel* (4us in this case). This will block the protection functions after maximum 4 seconds after an interruption in the PPS fiber communication from the MU.
• SYNCH signal on the MU_4I_4U function block indicate that protection functions are blocked by loss of internal time synchronization to the IED (that is loss of the *HW-synchSrc*).
• MUSYNCH signal on the MU_4I_4U function block monitors the synchronization flag from the MU (in the datastream). When the MU indicates loss of time synchronization, this signal is set.

A “blockedByTimeSynch” signal could be made by connecting the MUSYNCH and the SYNCH through an OR gate. If also the SMPLLOST signal is connected to the same OR gate, it will be more of a “BlockedByProblemsWith9-2” signal.

**No synchronization**
It is possible to use IEC 61850-9-2LE communication without time synchronization. Settings in this case under **Settings/Time/Synchronization/TIMESYNCHGEN/IEC 61850-9-2** are:

- *HwSyncSrc*: set to *Off*
- *AppSynch*: set to *NoSynch*. This means that protection functions will not be blocked
- *SyncAccLevel*: set to *unspecified*

Settings in PST in PCM600 under: **Hardware/Analog modules/Merging units/MU01**

- *SyncMode*: set to *NoSynch*. This means that the IED do not care if the MU indicates loss of time synchronization.
- TSYNCERR signal will not be set since there is no configured time synchronization source
- SYNCH signal on the MU_4I_4U function block indicates when protection functions are blocked due to loss of internal time synchronization to the IED. Since *AppSynch* is set to *NoSynch* this signal will not be set.
- MUSYNCH signal on the MU_4I_4U function block will be set if the datastream indicates time synchronization is lost. However, protection functions will not be blocked.

To get higher availability in the protection functions, it is possible to avoid blocking if time synchronization is lost when there is a single source of analog data. This means that if there is only one physical MU and no TRM, parameter *AppSynch* can be set to *NoSynch* but parameter *HwSyncSrc* can still be set to *PPS*. This will keep analog and
binary data correlated in disturbance recordings while not blocking the protection functions if PPS is lost.

18.4 IEC 60870-5-103 communication protocol

18.4.1 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 fibres 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 fibres, glass/plastic
- Opto/electrical converter for the PC/RTU
- PC/RTU

Commands
The commands defined in the IEC 60870-5-103 protocol are represented in 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 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, over-current 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/IEC6870-5-103/

- <config-selector>
- SlaveAddress
- BaudRate
- RevPolarity (optical channel only)
- CycMeasRepTime
- MasterTimeDomain
- TimeSyncMode
- EvalTimeAccuracy
- EventRepMode
- CmdMode

<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 102: 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 **SeqOfEvent** is selected, 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 **HiPriSpont** is selected, 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.

The settings for communication parameters slave number and baud rate can be found on the local HMI under: **Main menu/Configuration/Communication /Station configuration /SPA/SPA:1** and then select a protocol.

### 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 ONCHANGE. 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 26.

Table 26: Channels on disturbance recorder sent with a given ACC

<table>
<thead>
<tr>
<th>#</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>
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<td>5</td>
<td>5</td>
<td>UL1</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>UL2</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>UL3</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>UN</td>
</tr>
<tr>
<td>9</td>
<td>64</td>
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<td>10</td>
<td>65</td>
<td>Private range</td>
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</tr>
<tr>
<td>33</td>
<td>88</td>
<td>Private range</td>
</tr>
</tbody>
</table>

Table continues on next page
### 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
- REG 150 Private range
- REQ 245 Private range
- RES 118 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.
18.5  DNP3 Communication protocol

18.5.1  Application

For more information on the application and setting guidelines for the DNP3 communication protocol refer to the DNP3 Communication protocol manual.
Section 19  Basic IED functions

19.1  Authority status ATHSTAT

19.1.1  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.

19.2  Change lock CHNGLCK

19.2.1  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.

### 19.3 Denial of service DOS

**19.3.1 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

**19.3.2 Setting guidelines**

The function does not have any parameters available in the local HMI or PCM600.
19.4 IED identifiers TERMINALID

19.4.1 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.

19.5 Product information PRODINF

19.5.1 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).

19.5.2 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 (like REL, REC or RET). Example: REL670

- ProductDef
  
  Describes the release number, from the production. Example: 1.2.2.0

- ProductVer
  
  Describes the product version. Example: 1.2.3

  | 1 | is the Major version of the manufactured product this means, new platform of the product |
  | 2 | is the Minor version of the manufactured product this means, new functions or new hardware added to the product |
  | 3 | 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

19.6 Measured value expander block RANGE_XP

19.6.1 Identification

<table>
<thead>
<tr>
<th>Function description</th>
<th>IEC 61850 identification</th>
<th>IEC 80617 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>

19.6.2 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.
19.6.3 Setting guidelines

There are no settable parameters for the measured value expander block function.

19.7 Parameter setting groups

19.7.1 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 (PST) for activation with the ActiveGroup function block.

19.7.2 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.

19.8 Rated system frequency PRIMVAL
19.8.1 **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>Primary system values</td>
<td>PRIMVAL</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

19.8.2 **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.

19.8.3 **Setting guidelines**

Set the system rated frequency. Refer to section "Signal matrix for analog inputs SMAI" for description on frequency tracking.

19.9 **Summation block 3 phase 3PHSUM**

19.9.1 **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.

19.9.2 **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).

*FreqMeasMinVal*: The minimum value of the voltage for which the frequency is calculated, expressed as percent of *UBase* voltage setting (for each instance x).

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

19.10.1 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>Global base values</td>
<td>GBASVAL</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

19.10.2 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.

19.10.3 Setting guidelines

*U*Base: Phase-to-phase voltage value to be used as a base value for applicable functions throughout the IED.

*I*Base: Phase current value to be used as a base value for applicable functions throughout the IED.

*S*Base: Standard apparent power value to be used as a base value for applicable functions throughout the IED, typically SBase=√3·UBase·IBase.

19.11 Signal matrix for binary inputs SMBI

19.11.1 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.
19.11.2 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.

19.12 Signal matrix for binary outputs SMBO

19.12.1 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.

19.12.2 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.

19.13 Signal matrix for mA inputs SMMI

19.13.1 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.

19.13.2 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.

19.14 Signal matrix for analog inputs SMAI
19.14.1 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).

19.14.2 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 $U_{Base}/\sqrt{3}$

If SMAI setting $ConnectionType$ is $Ph-Ph$, at least two of the inputs $GRPxL1$, $GRPxL2$ and $GRPxL3$, where $1 \leq x \leq 12$, 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 103 to make SMAI calculate a positive sequence voltage.

Figure 103: Connection example

The above described scenario does not work if SMAI setting $ConnectionType$ is $Ph-N$. If only one phase-earth voltage is available, the same type of connection can be used but the SMAI $ConnectionType$ setting must still be $Ph-Ph$ and this has to be accounted for when setting $MinValFreqMeas$. If SMAI setting $ConnectionType$ is $Ph-N$ and the same voltage is connected to all three
SMAI inputs, the positive sequence voltage will be zero and the frequency functions will not work properly.

The outputs from the above configured SMAI block shall only be used for Overfrequency protection (SAPTOF), Underfrequency protection (SAPTUF) and Rate-of-change frequency protection (SAPFRC) due to that all other information except frequency and positive sequence voltage might be wrongly calculated.

19.14.3 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 ($\text{IBase}$), ($\text{UBase}$) and ($\text{SBase}$).

**MinValFreqMeas**: The minimum value of the voltage for which the frequency is calculated, expressed as percent of $\text{UBase}$ (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 ($\text{CVMMXN}$, $\text{CMMXU}$, $\text{VMMXU}$, 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 $\text{GOPPDOP}$), it is of outmost importance that parameter setting $\text{DFTReference}$ has the same set value for all of the preprocessing blocks involved
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 105: 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 104 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 105) SMAI2:2 – SMAI12:12: \( DFTReference = DFTRefGrp7 \) for SMAI2:2 – SMAI12:12 to use SMAI7:7 as reference.

For task time group 2 this gives the following settings:

SMAI1:13 – SMAI12:24: \( DFTReference = ExternalDFTRef \) to use DFTSPFC input of SMAI1:13 as reference (SMAI7:7)

For task time group 3 this gives the following settings:

SMAI1:25 – SMAI12:36: \( DFTReference = ExternalDFTRef \) to use DFTSPFC input as reference (SMAI7:7)

Example 2
Figure 106: Configuration for using an instance in task time group 2 as DFT reference.

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 104 for numbering):

SMAI1:1 – SMAI12:12: \textit{DFTReference} = \textit{ExternalDFTRef} to use DFTSPFC input as reference (SMAI4:16)

For task time group 2 this gives the following settings:

SMAI11:13: \textit{DFTRefExtOut} = \textit{DFTRefGrp4} to route SMAI4:16 reference to the SPFCOUT output, \textit{DFTReference} = \textit{DFTRefGrp4} for SMAI11:13 to use SMAI4:16 as reference (see Figure 106) SMAI12:14 – SMAI12:24: \textit{DFTReference} = \textit{DFTRefGrp4} to use SMAI4:16 as reference.

For task time group 3 this gives the following settings:

SMAI12:25 – SMAI12:36: \textit{DFTReference} = \textit{ExternalDFTRef} to use DFTSPFC input as reference (SMAI4:16)
19.15 Test mode functionality TESTMODE

19.16 Self supervision with internal event list INTERRSIG

19.16.1 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 software 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 only be retrieved with the aid of PCM600 Event Monitoring Tool. The PC can either be connected to the front port, or to the port at the back of the IED.
19.17  Time synchronization TIMESYNCHGEN

19.17.1  Application

Use time synchronization to achieve a common time base for the IEDs in a protection and control system. This makes it possible to compare events and disturbance data between all IEDs in the system.

Time-tagging of internal events and disturbances are an excellent help when evaluating faults. Without time synchronization, only the events within one IED can be compared with each other. With time synchronization, events and disturbances within the whole network, can be compared and evaluated.

In the IED, the internal time can be synchronized from the following sources:

- IRIG-B

The selection of the time source is done via the corresponding setting.

19.17.2  Setting guidelines

All the parameters related to time are divided into two categories: System time and Synchronization.

19.17.2.1  System time

The system time can be set manually via the local HMI under Main menu/Configuration/Time/System time. The time is set with years, month, day, hour, minute, second and millisecond. In addition, there are also settings for Day-Light-Saving and adjustment of Time-Zones.

19.17.2.2  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.

**Time Synchronization**

The time synchronization (TIMESYNCHGEN) parameters are divided in two categories, "general" and "IEC61850-9-2" parameters.

The general parameters are as follows:

- *FineSynchSource*
- *SynchMaster*
**FineSynchSource**: This parameter is used to select the time synchronization source. The options are "Off", "GPS", "IRIG-B", or "GPS+IRIG-B". In case that both GPS and IRIG-B are used (GPS+IRIG-B) for redundant time synchronization, the PMU will automatically select the most accurate time synchronization source.

**SynchMaster**: This parameter defines if the IED shall be used as a master clock (SNTP Server) for time synchronization within a Substation Automation System for IEDs connected on a communication network (IEC61850-8-1). The options are "Off" or "SNTP-Server".

The IEC61850-9-2 parameters are as follows:

- *AppSynch*
- *SynchAccLevel*

**AppSynch**: This parameter defines the time synchronization mode when using process bus applications (IEC61850-9-2). The options are "Synch", and "NoSynch". If the parameter is set to "Synch", then if the time quality is worse than the limit set by SynchAccLevel, some functions will be blocked in the IED.

**SynchAccLevel**: This parameter is to define the required time synchronization accuracy for process bus applications. The options are "Class T5 (1µs)", "Class T4 (4µs)", or "Unspecified". If it is set to "Unspecified", the time quality will be always accepted and application functions will not be blocked due to the time quality.

**IRIG-B**

The IRIG-B parameters have to be set according to the external clock providing the IRIG-B signal to the IED. The IRIG-B parameters (IRIG-B:1) are as follows:

- *SynchType*
- *TimeDomain*
- *Encoding*
- *TimeZoneAs1344*

**SynchType**: This parameter is used to select the type of IRIG-B synchronization. The options are "BNC" or "Opto". The IRIG-B module has two inputs. One input is for the electrical IRIG-B (BNC connector) that can handle both a pulse-width modulated signal (also called unmodulated) and an amplitude modulated signal (also called sine wave modulated). The other is an optical input type ST for optical pulse-width modulated signal (IRIG-B 00X). The recommended IRIG-B signal for PMU time synchronization is IRIG-B optical (IRIG-B 00X) with IEEE1344 support. If the optical IRIG-B signal is used, this parameter shall be set as "Opto", and If electrical IRIG-B signal is used (not recommended) this shall be set as "BNC". More information regarding IRIG-B module is available in Technical Manual under section IED Hardware.

**TimeDomain**: This parameter shall be also set according to the external clock used. The options are "LocalTime" or "UTC".
Encoding: This parameter shall be set according to the type of encoding on the IRIG-B signal provided by the external clock. The options are "IRIG-B", "1344", or "1344TZ". The IRIG-B signal used for synchrophasor application has to support IEEE 1344. IEEE 1344 can provide Time Zone offset (TZ) as an additional information. Encoded IRIG-B time plus TZ (Time Zone) offset always equals to UTC.

TimeZoneAs1344: This parameter is used to specify the sign of Time Zone (TZ) offset as defined in IEEE 1344 and according to the external clock. The options are "Plus TZ" or "Minus TZ". Encoded IRIG-B time plus Time Zone offset always equals to UTC.

19.17.2.3 Process bus IEC 61850-9-2LE synchronization

When process bus communication (IEC 61850-9-2LE protocol) is used, it is essential that the merging units are using the same time source as the IED. To achieve this, a satellite-controlled clock shall provide time synchronization to the IED (either internal GPS or via IRIG-B 00x with IEEE1344 support) and to the merging units (via for instance PPS). For the time synchronization of the process bus communication, GPS Time Module (GTM) and/or IRIG-B module can be used. If the IED contains a GTM, the merging unit can be synchronized from the PPS output of the GTM.
20.1 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.

20.1.1 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 small a 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.

20.1.2 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 ($0^\circ$). 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.

20.1.3 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.

### 20.1.4 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.

### 20.1.5 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.

20.1.6 **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.

20.1.7 **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.

20.1.7.1 **Current transformers according to IEC 61869-2, class P, PR**

A CT according to IEC 61869-2 is specified by the secondary limiting e.m.f. $E_{alf}$. The value of the $E_{alf}$ is approximately equal to the corresponding $E_{al}$. Therefore, the CTs according to class P and PR must have a secondary limiting e.m.f. $E_{alf}$ that fulfills the following:

$$E_{2\,\text{max}} > \max E_{alreq}$$

(*Equation 104)*

20.1.7.2 **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:

$$E_{knee} \approx E_k \approx E_{kneeBS} \approx U_{al} > 0.8 \left( \text{maximum of } E_{alreq} \right)$$

(Equation 105)

### 20.1.7.3 Current transformers according to ANSI/IEEE

Current transformers according to ANSI/IEEE are partly specified in different ways. A rated secondary terminal voltage $U_{ANSI}$ is specified for a CT of class C. $U_{ANSI}$ 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 $U_{ANSI}$ values for example, $U_{ANSI}$ is 400 V for a C400 CT. A corresponding rated equivalent limiting secondary e.m.f. $E_{alANSI}$ can be estimated as follows:

$$E_{alANSI} = \left| 20 \cdot I_{sr} \cdot R_{ct} + U_{ANSI} \right| = \left| 20 \cdot I_{sr} \cdot R_{ct} + 20 \cdot I_{sr} \cdot Z_{bANSI} \right|$$

(Equation 106)

where:

- $Z_{bANSI}$ The impedance (that is, with a complex quantity) of the standard ANSI burden for the specific C class ($\Omega$)
- $U_{ANSI}$ 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. $E_{alANSI}$ that fulfills the following:

$$E_{alANSI} > \text{maximum of } E_{alreq}$$

(Equation 107)

A CT according to ANSI/IEEE is also specified by the knee point voltage $U_{kneeANSI}$ that is graphically defined from an excitation curve. The knee point voltage $U_{kneeANSI}$ normally has a lower value than the knee-point e.m.f. according to IEC and BS. $U_{kneeANSI}$ can approximately be estimated to 75% of the corresponding $E_{al}$ according to IEC 61869-2. Therefore, the CTs according to ANSI/EEE must have a knee point voltage $U_{kneeANSI}$ that fulfills the following:

$$V_{kneeANSI} > 0.75 \cdot \left( \text{maximum of } E_{alreq} \right)$$

(Equation 108)
20.2 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.

20.3 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.

20.4 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 >100ms. (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 $\leq 50$ ppm nominal, $\leq 100$ ppm operational
- Jitter and Wander according to ITU-T G.823 and G.825
- Buffer memory $<250$ μs, $<100$ μs 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 $\leq 50$ ppm nominal, $\leq 100$ 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).

**20.5 IEC 61850-9-2LE Merging unit requirements**

The merging units that supply the IED with measured values via the process bus must fulfill the IEC61850-9-2LE standard.

This part of the IEC61850 is specifying “Communication Service Mapping (SCSM) – Sampled values over ISO/IEC 8802”, in other words – sampled data over Ethernet. The 9-2 part of the IEC61850 protocol uses also definitions from 7-2, “Basic communication structure for substation and feeder equipment – Abstract
communication service interface (ACSI)”. The set of functionality implemented in the IED (IEC61850-9-2LE) is a subset of the IEC61850-9-2. For example the IED covers the client part of the standard, not the server part.

The standard does not define the sample rate for data, but in the UCA users group recommendations there are indicated sample rates that are adopted, by consensus, in the industry.

There are two sample rates defined: 80 samples/cycle (4000 samples/sec. at 50Hz or 4800 samples/sec. at 60 Hz) for a merging unit “type1” and 256 samples/cycle for a merging unit “type2”. The IED can receive data rates of 80 samples/cycle.

Note that the IEC 61850-9-2 LE standard does not specify the quality of the sampled values, only the transportation. Thus, the accuracy of the current and voltage inputs to the merging unit and the inaccuracy added by the merging unit must be coordinated with the requirement for actual type of protection function.

Factors influencing the accuracy of the sampled values from the merging unit are for example anti aliasing filters, frequency range, step response, truncating, A/D conversion inaccuracy, time tagging accuracy etc.

In principle the accuracy of the current and voltage transformers, together with the merging unit, shall have the same quality as direct input of currents and voltages.
## Section 21 Glossary

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>AC</td>
<td>Alternating current</td>
</tr>
<tr>
<td>ACC</td>
<td>Actual channel</td>
</tr>
<tr>
<td>ACT</td>
<td>Application configuration tool within PCM600</td>
</tr>
<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>
<tr>
<td>AR</td>
<td>Autoreclosing</td>
</tr>
<tr>
<td>ASCT</td>
<td>Auxiliary summation current transformer</td>
</tr>
<tr>
<td>ASD</td>
<td>Adaptive signal detection</td>
</tr>
<tr>
<td>ASDU</td>
<td>Application service data unit</td>
</tr>
<tr>
<td>AWG</td>
<td>American Wire Gauge standard</td>
</tr>
<tr>
<td>BBP</td>
<td>Busbar protection</td>
</tr>
<tr>
<td>BFOC/2,5</td>
<td>Bayonet fibre optic connector</td>
</tr>
<tr>
<td>BFP</td>
<td>Breaker failure protection</td>
</tr>
<tr>
<td>BI</td>
<td>Binary input</td>
</tr>
<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>
</tr>
<tr>
<td>BR</td>
<td>External bistable relay</td>
</tr>
<tr>
<td>BS</td>
<td>British Standards</td>
</tr>
<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>
</tr>
<tr>
<td>CAN</td>
<td>Controller Area Network. ISO standard (ISO 11898) for serial communication</td>
</tr>
<tr>
<td>CB</td>
<td>Circuit breaker</td>
</tr>
<tr>
<td>CBM</td>
<td>Combined backplane module</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>CCM</td>
<td>CAN carrier module</td>
</tr>
<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>
</tr>
<tr>
<td>CMPPS</td>
<td>Combined megapulses per second</td>
</tr>
<tr>
<td>CMT</td>
<td>Communication Management tool in PCM600</td>
</tr>
<tr>
<td>CO cycle</td>
<td>Close-open cycle</td>
</tr>
<tr>
<td>Codirectional</td>
<td>Way of transmitting G.703 over a balanced line. Involves two twisted pairs making it possible to transmit information in both directions</td>
</tr>
<tr>
<td>COM</td>
<td>Command</td>
</tr>
<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>
</tr>
<tr>
<td>Contra-directional</td>
<td>Way of transmitting G.703 over a balanced line. Involves four twisted pairs, two of which are used for transmitting data in both directions and two for transmitting clock signals</td>
</tr>
<tr>
<td>COT</td>
<td>Cause of transmission</td>
</tr>
<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>
</tr>
<tr>
<td>CROB</td>
<td>Control relay output block</td>
</tr>
<tr>
<td>CS</td>
<td>Carrier send</td>
</tr>
<tr>
<td>CT</td>
<td>Current transformer</td>
</tr>
<tr>
<td>CU</td>
<td>Communication unit</td>
</tr>
<tr>
<td>CVT or CCVT</td>
<td>Capacitive voltage transformer</td>
</tr>
<tr>
<td>DAR</td>
<td>Delayed autoreclosing</td>
</tr>
<tr>
<td>DARPA</td>
<td>Defense Advanced Research Projects Agency (The US developer of the TCP/IP protocol etc.)</td>
</tr>
<tr>
<td>DBDL</td>
<td>Dead bus dead line</td>
</tr>
<tr>
<td>DBLL</td>
<td>Dead bus live line</td>
</tr>
<tr>
<td>DC</td>
<td>Direct current</td>
</tr>
<tr>
<td>DFC</td>
<td>Data flow control</td>
</tr>
<tr>
<td>DFT</td>
<td>Discrete Fourier transform</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>DHCP</td>
<td>Dynamic Host Configuration Protocol</td>
</tr>
<tr>
<td>DIP-switch</td>
<td>Small switch mounted on a printed circuit board</td>
</tr>
<tr>
<td>DI</td>
<td>Digital input</td>
</tr>
<tr>
<td>DLLB</td>
<td>Dead line live bus</td>
</tr>
<tr>
<td>DNP</td>
<td>Distributed Network Protocol as per IEEE Std 1815-2012</td>
</tr>
<tr>
<td>DR</td>
<td>Disturbance recorder</td>
</tr>
<tr>
<td>DRAM</td>
<td>Dynamic random access memory</td>
</tr>
<tr>
<td>DRH</td>
<td>Disturbance report handler</td>
</tr>
<tr>
<td>DSP</td>
<td>Digital signal processor</td>
</tr>
<tr>
<td>DTT</td>
<td>Direct transfer trip scheme</td>
</tr>
<tr>
<td>EHV network</td>
<td>Extra high voltage network</td>
</tr>
<tr>
<td>EIA</td>
<td>Electronic Industries Association</td>
</tr>
<tr>
<td>EMC</td>
<td>Electromagnetic compatibility</td>
</tr>
<tr>
<td>EMF</td>
<td>Electromotive force</td>
</tr>
<tr>
<td>EMI</td>
<td>Electromagnetic interference</td>
</tr>
<tr>
<td>EnFP</td>
<td>End fault protection</td>
</tr>
<tr>
<td>EPA</td>
<td>Enhanced performance architecture</td>
</tr>
<tr>
<td>ESD</td>
<td>Electrostatic discharge</td>
</tr>
<tr>
<td>F-SMA</td>
<td>Type of optical fibre connector</td>
</tr>
<tr>
<td>FAN</td>
<td>Fault number</td>
</tr>
<tr>
<td>FCB</td>
<td>Flow control bit; Frame count bit</td>
</tr>
<tr>
<td>FOX 20</td>
<td>Modular 20 channel telecommunication system for speech, data and protection signals</td>
</tr>
<tr>
<td>FOX 512/515</td>
<td>Access multiplexer</td>
</tr>
<tr>
<td>FOX 6Plus</td>
<td>Compact time-division multiplexer for the transmission of up to seven duplex channels of digital data over optical fibers</td>
</tr>
<tr>
<td>FTP</td>
<td>File Transfer Protocol</td>
</tr>
<tr>
<td>FUN</td>
<td>Function type</td>
</tr>
<tr>
<td>G.703</td>
<td>Electrical and functional description for digital lines used by local telephone companies. Can be transported over balanced and unbalanced lines</td>
</tr>
<tr>
<td>GCM</td>
<td>Communication interface module with carrier of GPS receiver module</td>
</tr>
<tr>
<td>GDE</td>
<td>Graphical display editor within PCM600</td>
</tr>
<tr>
<td>GI</td>
<td>General interrogation command</td>
</tr>
</tbody>
</table>
GIS  Gas-insulated switchgear
GOOSE  Generic object-oriented substation event
GPS  Global positioning system
GSAL  Generic security application
GSE  Generic substation event
HDLC protocol  High-level data link control, protocol based on the HDLC standard
HFBR connector type  Plastic fiber connector
HMI  Human-machine interface
HSAR  High speed autoreclosing
HV  High-voltage
HVDC  High-voltage direct current
IDBS  Integrating deadband supervision
IEC  International Electrical Committee
IEC 60044-6  IEC Standard, Instrument transformers – Part 6: Requirements for protective current transformers for transient performance
IEC 60870-5-103  Communication standard for protection equipment. A serial master/slave protocol for point-to-point communication
IEC 61850  Substation automation communication standard
IEC 61850–8–1  Communication protocol standard
IEEE  Institute of Electrical and Electronics Engineers
IEEE 802.12  A network technology standard that provides 100 Mbits/s on twisted-pair or optical fiber cable
IEEE P1386.1  PCI Mezzanine Card (PMC) standard for local bus modules. References the CMC (IEEE P1386, also known as Common Mezzanine Card) standard for the mechanics and the PCI specifications from the PCI SIG (Special Interest Group) for the electrical EMF (Electromotive force).
IEEE 1686  Standard for Substation Intelligent Electronic Devices (IEDs) Cyber Security Capabilities
IED  Intelligent electronic device
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

**MIM**
Milli-ampere 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
<table>
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<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>OLTC</td>
<td>On-load tap changer</td>
</tr>
<tr>
<td>OTEV</td>
<td>Disturbance data recording initiated by other event than start/pick-up</td>
</tr>
<tr>
<td>OV</td>
<td>Overvoltage</td>
</tr>
<tr>
<td>Overreach</td>
<td>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.</td>
</tr>
<tr>
<td>PCI</td>
<td>Peripheral component interconnect, a local data bus</td>
</tr>
<tr>
<td>PCM</td>
<td>Pulse code modulation</td>
</tr>
<tr>
<td>PCM600</td>
<td>Protection and control IED manager</td>
</tr>
<tr>
<td>PC-MIP</td>
<td>Mezzanine card standard</td>
</tr>
<tr>
<td>PMC</td>
<td>PCI Mezzanine card</td>
</tr>
<tr>
<td>POR</td>
<td>Permissive overreach</td>
</tr>
<tr>
<td>POTT</td>
<td>Permissive overreach transfer trip</td>
</tr>
<tr>
<td>Process bus</td>
<td>Bus or LAN used at the process level, that is, in near proximity to the measured and/or controlled components</td>
</tr>
<tr>
<td>PSM</td>
<td>Power supply module</td>
</tr>
<tr>
<td>PST</td>
<td>Parameter setting tool within PCM600</td>
</tr>
<tr>
<td>PT ratio</td>
<td>Potential transformer or voltage transformer ratio</td>
</tr>
<tr>
<td>PUTT</td>
<td>Permissive underreach transfer trip</td>
</tr>
<tr>
<td>RASC</td>
<td>Synchrocheck relay, COMBIFLEX</td>
</tr>
<tr>
<td>RCA</td>
<td>Relay characteristic angle</td>
</tr>
<tr>
<td>RISC</td>
<td>Reduced instruction set computer</td>
</tr>
<tr>
<td>RMS value</td>
<td>Root mean square value</td>
</tr>
<tr>
<td>RS422</td>
<td>A balanced serial interface for the transmission of digital data in point-to-point connections</td>
</tr>
<tr>
<td>RS485</td>
<td>Serial link according to EIA standard RS485</td>
</tr>
<tr>
<td>RTC</td>
<td>Real-time clock</td>
</tr>
<tr>
<td>RTU</td>
<td>Remote terminal unit</td>
</tr>
<tr>
<td>SA</td>
<td>Substation Automation</td>
</tr>
<tr>
<td>SBO</td>
<td>Select-before-operate</td>
</tr>
<tr>
<td>SC</td>
<td>Switch or push button to close</td>
</tr>
<tr>
<td>SCL</td>
<td>Short circuit location</td>
</tr>
<tr>
<td>SCS</td>
<td>Station control system</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>---------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>SCADA</td>
<td>Supervision, control and data acquisition</td>
</tr>
<tr>
<td>SCT</td>
<td>System configuration tool according to standard IEC 61850</td>
</tr>
<tr>
<td>SDU</td>
<td>Service data unit</td>
</tr>
<tr>
<td>SLM</td>
<td>Serial communication module.</td>
</tr>
<tr>
<td>SMA connector</td>
<td>Subminiature version A, A threaded connector with constant impedance.</td>
</tr>
<tr>
<td>SMT</td>
<td>Signal matrix tool within PCM600</td>
</tr>
<tr>
<td>SMS</td>
<td>Station monitoring system</td>
</tr>
<tr>
<td>SNTP</td>
<td>Simple network time protocol – is used to synchronize computer clocks on local area networks. This reduces the requirement to have accurate hardware clocks in every embedded system in a network. Each embedded node can instead synchronize with a remote clock, providing the required accuracy.</td>
</tr>
<tr>
<td>SOF</td>
<td>Status of fault</td>
</tr>
<tr>
<td>SPA</td>
<td>Strömberg Protection Acquisition (SPA), a serial master/slave protocol for point-to-point and ring communication.</td>
</tr>
<tr>
<td>SRY</td>
<td>Switch for CB ready condition</td>
</tr>
<tr>
<td>ST</td>
<td>Switch or push button to trip</td>
</tr>
<tr>
<td>Starpoint</td>
<td>Neutral point of transformer or generator</td>
</tr>
<tr>
<td>SVC</td>
<td>Static VAr compensation</td>
</tr>
<tr>
<td>TC</td>
<td>Trip coil</td>
</tr>
<tr>
<td>TCS</td>
<td>Trip circuit supervision</td>
</tr>
<tr>
<td>TCP</td>
<td>Transmission control protocol. The most common transport layer protocol used on Ethernet and the Internet.</td>
</tr>
<tr>
<td>TCP/IP</td>
<td>Transmission control protocol over Internet Protocol. The de facto standard Ethernet protocols incorporated into 4.2BSD Unix. TCP/IP was developed by DARPA for Internet working and encompasses both network layer and transport layer protocols. While TCP and IP specify two protocols at specific protocol layers, TCP/IP is often used to refer to the entire US Department of Defense protocol suite based upon these, including Telnet, FTP, UDP and RDP.</td>
</tr>
<tr>
<td>TEF</td>
<td>Time delayed earth-fault protection function</td>
</tr>
<tr>
<td>TLS</td>
<td>Transport Layer Security</td>
</tr>
<tr>
<td>TM</td>
<td>Transmit (disturbance data)</td>
</tr>
<tr>
<td>TNC connector</td>
<td>Threaded Neill-Concelman, a threaded constant impedance version of a BNC connector</td>
</tr>
<tr>
<td>TP</td>
<td>Trip (recorded fault)</td>
</tr>
<tr>
<td><strong>TPZ, TPY, TPX, TPS</strong></td>
<td>Current transformer class according to IEC</td>
</tr>
<tr>
<td>-------------------------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td><strong>TRM</strong></td>
<td>Transformer Module. This module transforms currents and voltages taken from the process into levels suitable for further signal processing.</td>
</tr>
<tr>
<td><strong>TYP</strong></td>
<td>Type identification</td>
</tr>
<tr>
<td><strong>UMT</strong></td>
<td>User management tool</td>
</tr>
<tr>
<td><strong>Underreach</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>UTC</strong></td>
<td>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, &quot;Zulu time.&quot; &quot;Zulu&quot; in the phonetic alphabet stands for &quot;Z&quot;, which stands for longitude zero.</td>
</tr>
<tr>
<td><strong>UV</strong></td>
<td>Undervoltage</td>
</tr>
<tr>
<td><strong>WEI</strong></td>
<td>Weak end infeed logic</td>
</tr>
<tr>
<td><strong>VT</strong></td>
<td>Voltage transformer</td>
</tr>
<tr>
<td><strong>X.21</strong></td>
<td>A digital signalling interface primarily used for telecom equipment</td>
</tr>
<tr>
<td><strong>3I₀</strong></td>
<td>Three times zero-sequence current. Often referred to as the residual or the earth-fault current</td>
</tr>
<tr>
<td><strong>3U₀</strong></td>
<td>Three times the zero sequence voltage. Often referred to as the residual voltage or the neutral point voltage</td>
</tr>
</tbody>
</table>