Relion® 670 series

Phasor measurement unit RES670 2.0 ANSI
Commissioning Manual
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Conformity

This product complies with the directive of the Council of the European Communities on the approximation of the laws of the Member States relating to electromagnetic compatibility (EMC Directive 2004/108/EC) and concerning electrical equipment for use within specified voltage limits (Low-voltage directive 2006/95/EC). This conformity is the result of tests conducted by ABB in accordance with the product standard EN 60255-26 for the EMC directive, and with the product standards EN 60255-1 and EN 60255-27 for the low voltage directive. The product is designed in accordance with the international standards of the IEC 60255 series and ANSI C37.90.
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Section 1  Introduction

1.1  This manual

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.

1.2  Intended audience

This manual addresses the personnel responsible for commissioning, maintenance and taking the IED in and out of normal service.

The commissioning personnel must have a basic knowledge of handling electronic equipment. The commissioning and maintenance personnel must be well experienced in using protection equipment, test equipment, protection functions and the configured functional logics in the IED.
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 Document revision history

<table>
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<td>-/October 2014</td>
<td>First release</td>
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1.3.3 Related documents

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<td>Technical manual</td>
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<td>Type test certificate</td>
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<td>Point list manual, DNP3</td>
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<td>Accessories guide</td>
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<td>Test system, COMBITEST</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 [OK].
- 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/output 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."

• Dimensions are provided both in inches and mm. If it is not specifically mentioned then the dimension is in mm.

### 1.4.3 IEC61850 edition 1 / edition 2 mapping

<table>
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<td>ZSMGAPC</td>
<td>ZSMGAPC</td>
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</table>
Section 2  Safety information

2.1  Symbols on the product

- All warnings must be observed.

- Read the entire manual before doing installation or any maintenance work on the product. All warnings must be observed.

- Do not touch the unit in operation. The installation shall take into account the worst case temperature.

2.2  Warnings

Observe the warnings during all types of work related to the product.

- Only electrically skilled persons with the proper authorization and knowledge of any safety hazards are allowed to carry out the electrical installation.

- National and local electrical safety regulations must always be followed. Working in a high voltage environment requires serious approach to avoid human injuries and damage to equipment.

- Do not touch circuitry during operation. Potentially lethal voltages and currents are present.
Always use suitable isolated test pins when measuring signals in open circuitry. Potentially lethal voltages and currents are present.

Never connect or disconnect a wire and/or a connector to or from a IED during normal operation. Hazardous voltages and currents are present that may be lethal. Operation may be disrupted and IED and measuring circuitry may be damaged.

Dangerous voltages can occur on the connectors, even though the auxiliary voltage has been disconnected.

Always connect the IED to protective ground, regardless of the operating conditions. This also applies to special occasions such as bench testing, demonstrations and off-site configuration. This is class 1 equipment that shall be grounded.

Never disconnect the secondary connection of current transformer circuit without short-circuiting the transformer’s secondary winding. Operating a current transformer with the secondary winding open will cause a massive potential build-up that may damage the transformer and may cause injuries to humans.

Never remove any screw from a powered IED or from a IED connected to powered circuitry. Potentially lethal voltages and currents are present.

Take adequate measures to protect the eyes. Never look into the laser beam.

The IED with accessories should be mounted in a cubicle in a restricted access area within a power station, substation or industrial or retail environment.
Whenever changes are made in the IED, measures should be taken to avoid inadvertent tripping.

The IED contains components which are sensitive to electrostatic discharge. ESD precautions shall always be observed prior to touching components.

Always transport PCBs (modules) using certified conductive bags.

Do not connect live wires to the IED. Internal circuitry may be damaged.

Always use a conductive wrist strap connected to protective ground when replacing modules. Electrostatic discharge (ESD) may damage the module and IED circuitry.

Take care to avoid electrical shock during installation and commissioning.

Changing the active setting group will inevitably change the IEDs operation. Be careful and check regulations before making the change.

2.3 Note signs

Observe the maximum allowed continuous current for the different current transformer inputs of the IED. See technical data.
**Section 3**  
**Available functions**

### 3.1 Wide area measurement functions

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<td>Protocol reporting via IEEE1344 and C37.118</td>
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<td>Protocol reporting of phasor data via IEEE 1344 and C37.118, phasors 1-8</td>
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<td>PHASORREPORT2</td>
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<td>LFPTTR 26</td>
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1) 67 requires voltage  
2) 67N requires voltage

### 3.3 Control and monitoring functions

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<td>Handling of LRswitch positions</td>
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<td>LHMI control of PSTO</td>
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<td>Logic rotating switch for function selection and LHMI presentation</td>
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<td>Generic communication function for Double Point indication</td>
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<td>SPC8GAPC</td>
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<td>Single point generic control 8 signals</td>
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<td>SINGLECMD</td>
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<td>Single command, 16 signals</td>
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<td>VCTRSEND</td>
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<td>Horizontal communication via GOOSE for VCTR</td>
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<td>GOOSEVCTRRCV</td>
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**Secondary system supervision**

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**Logic**

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<td>Logic for group warning</td>
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<tr>
<td>INDCALH</td>
<td>Logic for group indication</td>
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</table>

AND, OR, INV, PULSETIMER, GATE, TIMERSET, XOR, LLD, SRMEMORY, RSMEMORY

Configurable logic blocks 40-280

ANDQT, ORQT, INVERTERQT, XORQT, SRMEMORYQT, RSMEMORYQT, TIMERSETQT, PULSETIMERQT, INVALIDQT, INDECOMBSPQT, INDEXTSPQT

Configurable logic blocks Q/T 0–1

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### Available functions

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<td>IBTIGAPC</td>
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<td>GOOSEINTRCV</td>
<td></td>
<td>GOOSE function block to receive an integer value</td>
<td>32</td>
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<tr>
<td>GOOSEMVRCV</td>
<td></td>
<td>GOOSE function block to receive a measurand value</td>
<td>60</td>
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<tr>
<td>GOOSESPRCV</td>
<td></td>
<td>GOOSE function block to receive a single point value</td>
<td>64</td>
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<tr>
<td>MULTICMDRCV, MULTICMDSND</td>
<td></td>
<td>Multiple command and transmit</td>
<td>60/10</td>
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<tr>
<td>FRONT, LANABI, LANAB, LANCDI, LANCD</td>
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<td>Ethernet configuration of links</td>
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<tr>
<td>GATEWAY</td>
<td></td>
<td>Ethernet configuration of link one</td>
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<tr>
<td>OPTICAL103</td>
<td></td>
<td>IEC 60870-5-103 Optical serial communication</td>
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<td>RS485103</td>
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<td>IEC 60870-5-103 serial communication for RS485</td>
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<tr>
<td>AGSAL</td>
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<td>Generic security application component</td>
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<tr>
<td>LD0LLN0</td>
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<td>IEC 61850 LD0 LLN0</td>
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<tr>
<td>SYSLLN0</td>
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<td>IEC 61850 SYS LLN0</td>
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<td>LPHD</td>
<td></td>
<td>Physical device information</td>
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<tr>
<td>PCMACCS</td>
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<td>IED Configuration Protocol</td>
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</tr>
<tr>
<td>SECALARM</td>
<td></td>
<td>Component for mapping security events on protocols such as DNP3 and IEC103</td>
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<tr>
<td>FSTACCS</td>
<td></td>
<td>Field service tool access via SPA protocol over ethernet communication</td>
<td>1</td>
</tr>
<tr>
<td>ACTIVLOG</td>
<td></td>
<td>Activity logging parameters</td>
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<tr>
<td>ALTRK</td>
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<td>Service Tracking</td>
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<tr>
<td>SINGLELCCH</td>
<td></td>
<td>Single ethernet port link status</td>
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<tr>
<td>PRPSTATUS</td>
<td></td>
<td>Dual ethernet port link status</td>
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</table>

1) Only included for 9-2LE products
### 3.5 Basic IED functions

<table>
<thead>
<tr>
<th>IEC 61850 or function name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTERRSIG</td>
<td>Self supervision with internal event list</td>
</tr>
<tr>
<td>SELFSUPEVLST</td>
<td>Self supervision with internal event list</td>
</tr>
<tr>
<td>TIMESYNCHGEN</td>
<td>Time synchronization module</td>
</tr>
<tr>
<td>SYNHCHAN, SYNCHCMPPS, SYNCHCPPS, SYNCHSNTP, SYNCHCMPPS</td>
<td>Time synchronization</td>
</tr>
<tr>
<td>TIMEZONE</td>
<td>Time synchronization</td>
</tr>
<tr>
<td>DSTBEGIN, DSTENABLE, DSTEND</td>
<td>GPS time synchronization module</td>
</tr>
<tr>
<td>IRIG-B</td>
<td>Time synchronization</td>
</tr>
<tr>
<td>SETGRPS</td>
<td>Number of setting groups</td>
</tr>
<tr>
<td>ACTVGRP</td>
<td>Parameter setting groups</td>
</tr>
<tr>
<td>TESTMODE</td>
<td>Test mode functionality</td>
</tr>
<tr>
<td>CHNGLCK</td>
<td>Change lock function</td>
</tr>
<tr>
<td>SMBI</td>
<td>Signal matrix for binary inputs</td>
</tr>
<tr>
<td>SMBO</td>
<td>Signal matrix for binary outputs</td>
</tr>
<tr>
<td>SMMI</td>
<td>Signal matrix for mA inputs</td>
</tr>
<tr>
<td>SMAI1 - SMAI20</td>
<td>Signal matrix for analog inputs</td>
</tr>
<tr>
<td>3PHSUM</td>
<td>Summation block 3 phase</td>
</tr>
<tr>
<td>ATHSTAT</td>
<td>Authority status</td>
</tr>
<tr>
<td>ATHCHCK</td>
<td>Authority check</td>
</tr>
<tr>
<td>AUTHMAN</td>
<td>Authority management</td>
</tr>
<tr>
<td>FTPACCS</td>
<td>FTP access with password</td>
</tr>
<tr>
<td>SPACOMMMAP</td>
<td>SPA communication mapping</td>
</tr>
<tr>
<td>SPATD</td>
<td>Date and time via SPA protocol</td>
</tr>
<tr>
<td>DOSFRNT</td>
<td>Denial of service, frame rate control for front port</td>
</tr>
<tr>
<td>DOSLANAB</td>
<td>Denial of service, frame rate control for OEM port AB</td>
</tr>
<tr>
<td>DOSLANCD</td>
<td>Denial of service, frame rate control for OEM port CD</td>
</tr>
<tr>
<td>DOSSSCKT</td>
<td>Denial of service, socket flow control</td>
</tr>
<tr>
<td>GBASVAL</td>
<td>Global base values for settings</td>
</tr>
<tr>
<td>PRIMVAL</td>
<td>Primary system values</td>
</tr>
<tr>
<td>ALTMS</td>
<td>Time master supervision</td>
</tr>
</tbody>
</table>

Table continues on next page
### Available functions

<table>
<thead>
<tr>
<th>IEC 61850 or function name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALTIM</td>
<td>Time management</td>
</tr>
<tr>
<td>ALTRK</td>
<td>Service tracking</td>
</tr>
<tr>
<td>ACTIVLOG</td>
<td>Activity logging parameters</td>
</tr>
<tr>
<td>FSTACCS</td>
<td>Field service tool access via SPA protocol over ethernet communication</td>
</tr>
<tr>
<td>PCMACCS</td>
<td>IED Configuration Protocol</td>
</tr>
<tr>
<td>SECALARM</td>
<td>Component for mapping security events on protocols such as DNP3 and IEC103</td>
</tr>
<tr>
<td>DNPGEN</td>
<td>DNP3.0 communication general protocol</td>
</tr>
<tr>
<td>DNPGENTCP</td>
<td>DNP3.0 communication general TCP protocol</td>
</tr>
<tr>
<td>CHSEROPT</td>
<td>DNP3.0 for TCP/IP and EIA-485 communication protocol</td>
</tr>
<tr>
<td>MSTSER</td>
<td>DNP3.0 for serial communication protocol</td>
</tr>
<tr>
<td>OPTICAL103</td>
<td>IEC 60870-5-103 Optical serial communication</td>
</tr>
<tr>
<td>RS485103</td>
<td>IEC 60870-5-103 serial communication for RS485</td>
</tr>
<tr>
<td>IEC61850-8-1</td>
<td>Parameter setting function for IEC 61850</td>
</tr>
<tr>
<td>HORZCOMM</td>
<td>Network variables via LON</td>
</tr>
<tr>
<td>LONSPA</td>
<td>SPA communication protocol</td>
</tr>
<tr>
<td>LEDGEN</td>
<td>General LED indication part for LHMI</td>
</tr>
</tbody>
</table>
4.1 Factory and site acceptance testing

Testing the proper IED operation is carried out at different occasions, for example:

• Acceptance testing
• Commissioning testing
• Maintenance testing

This manual describes the workflow and the steps to carry out the commissioning testing.

Factory acceptance testing (FAT) is typically done to verify that the IED and its corresponding configuration meet the requirements of the utility or industry. This test is the most complex and in depth, as it is done to familiarize the user with a new product or to verify a new configuration. The complexity of this testing depends on several factors, such as:

• New IED type
• New configuration
• Modified configuration

Site acceptance testing (SAT or commissioning testing) is typically done to verify that the installed IED is correctly set and connected to the power system. SAT requires that the acceptance testing has been performed and that the application configuration is verified.

Maintenance testing is a periodic verification that the IED is healthy and has correct settings, depending on changes in the power system. There are also other types of maintenance testing.

4.2 Commissioning checklist

Before starting up commissioning at site, check that the following items are available.

• Single line diagram
• Protection block diagram
• Circuit diagram
• Setting list and configuration
4.3 Checking the power supply

Check that the auxiliary supply voltage remains within the permissible input voltage range under all operating conditions. Check that the polarity is correct before energizing the IED.

4.4 Energizing the IED

4.4.1 Checking the IED operation

Check all connections to external circuitry to ensure correct installation, before energizing the IED and carrying out the commissioning procedures.

The user could also check the software version, the IED's serial number and the installed modules and their ordering number to ensure that the IED is according to delivery and ordering specifications.

Energize the power supply of the IED to pickup. This could be done in a number of ways, from energizing a whole cubicle to energizing a single IED. The user should reconfigure the IED to activate the hardware modules in order to enable the self supervision function to detect possible hardware errors. Set the IED time if no time synchronization source is configured. Check also the self-supervision function in Main menu/Diagnostics/Monitoring menu in local HMI to verify that the IED operates properly.

4.4.2 IED start-up sequence

When the IED is energized, the green LED starts flashing instantly. After approximately 55 seconds the window lights up and the window displays ‘IED Startup’. The main menu is displayed and the upper row should indicate ‘Available’ after about 90 seconds. A steady green light indicates a successful startup.
Figure 2: Typical IED start-up sequence

1. IED energized. Green LED instantly starts flashing
2. LCD lights up and "IED startup" is displayed
3. The main menu is displayed. A steady green light indicates a successful startup.

If the upper row in the window indicates ‘Fail’ instead of ‘Available’ and the green LED flashes, an internal failure in the IED has been detected. See section "Checking the self supervision function" to investigate the fault.

4.5 Setting up communication between PCM600 and the IED

The communication between the IED and PCM600 is independent of the communication protocol used within the substation or to the NCC.

The communication media is always Ethernet and the used protocol is TCP/IP.

Each IED has an RJ-45 Ethernet interface connector on the front. The front Ethernet connector shall be used for communication with PCM600.

When an Ethernet-based station protocol is used, PCM600 communication can use the same Ethernet port and IP address.

To connect PCM600 to the IED, two basic variants must be considered.

- Direct point-to-point link between PCM600 and the IED front port. The front port can be seen as a service port.
- Indirect link via a station LAN or from remote via a network.

The physical connection and the IP address must be configured in both cases to enable communication.

The communication procedures are the same in both cases.
1. If needed, set the IP address for the IEDs.
2. Set up the PC or workstation for a direct link (point-to-point), or
3. Connect the PC or workstation to the LAN/WAN network.
4. Configure the IED IP addresses in the PCM600 project for each IED to match the IP addresses of the physical IEDs.

Setting up IP addresses

The IP address and the corresponding mask must be set via the LHMI for each available Ethernet interface in the IED. Each Ethernet interface has a default factory IP address when the IED is delivered. This is not given when an additional Ethernet interface is installed or an interface is replaced.

- The default IP address for the IED front port is 10.1.150.3 and the corresponding subnetwork mask is 255.255.255.0, which can be set via the local HMI path Main menu/Configuration/Communication/Ethernet configuration/FRONT:1.

Setting up the PC or workstation for point-to-point access to IEDs front port

A special cable is needed to connect two physical Ethernet interfaces together without a hub, router, bridge or switch in between. The Tx and Rx signal wires must be crossed in the cable to connect Tx with Rx on the other side and vice versa. These cables are known as cross over cables. The maximum length is 2 m. The connector type is RJ-45.

Figure 3: Point-to-point link between IED and PCM600 using a null-modem cable

The following description is an example valid for standard PCs using Microsoft Windows operating system. The example is taken from a Laptop with one Ethernet interface.

Administrator rights are required to change the PC communication setup. Some PCs have the feature to automatically detect that Tx signals from the IED are received on the Tx pin on the PC. Thus, a straight (standard) Ethernet cable can be used.
1. Select **Search programs and files** in the **Start menu** in Windows.

   ![Search programs and files in Windows](image)

   **Figure 4:** Select: Search programs and files

2. Type **View network connections** and click on the **View network connections** icon.
3. Right-click and select **Properties**.

4. Select the TCP/IPv4 protocol from the list of configured components using this connection and click **Properties**.
Figure 7: Select the TCP/IPv4 protocol and open Properties

5. Select **Use the following IP address** and define **IP address** and **Subnet mask** if the front port is used and if the **IP address** is not set to be obtained automatically by the IED, see **Figure 8**. The IP address must be different from the IP address chosen for the IED.
4.6 Writing an application configuration to the IED

When writing a configuration to the IED with the application configuration tool, the IED is automatically set in configuration mode. When the IED is set in configuration mode, all functions are blocked. The red LED on the IED flashes, and the green LED is lit while the IED is in the configuration mode.

When the configuration is written and completed, the IED is automatically set into normal mode. For further instructions please refer to the users manuals for PCM600.
4.7 Checking CT circuits

Check that the wiring is in strict accordance with the supplied connection diagram.

The CTs must be connected in accordance with the circuit diagram provided with the IED, both with regards to phases and polarity. The following tests shall be performed on every primary CT connected to the IED:

- Primary injection test to verify the current ratio of the CT, the correct wiring up to the protection IED and correct phase sequence connection (that is A, B, C.)
- Polarity check to prove that the predicted direction of secondary current flow is correct for a given direction of primary current flow. This is an essential test for the proper operation of the differential function and directional protection functions.
- CT secondary loop resistance measurement to confirm that the current transformer secondary loop DC resistance is within the specification for the connected protection functions. When the measured loop resistance is near the calculated value for maximum DC resistance, perform a complete burden test.
- CT excitation test in order to confirm that the current transformer is of the correct accuracy rating and that there are no shorted turns in the current transformer windings. Manufacturer's design curves must be available for the current transformer to compare the actual results.
- Grounding check of the individual CT secondary circuits to verify that each three-phase set of main CTs is properly connected to the station ground and only at one electrical point.
- Insulation resistance check.

While the CT primary is energized, the secondary circuit shall never be open circuited because extremely dangerous high voltages may arise.

Both the primary and the secondary sides must be disconnected from the line and the IED when plotting the excitation characteristics.

If the CT secondary circuit ground connection is removed without the current transformer primary being de-energized, dangerous voltages may result in the secondary CT circuits.
4.8 Checking VT circuits

Check that the wiring is in strict accordance with the supplied connection diagram.

Correct possible errors before continuing to test the circuitry.

Test the circuitry.

- Polarity check when applicable; this test is often omitted for CVTs
- VT circuit voltage measurement (primary injection test)
- Grounding check
- Phase relationship
- Insulation resistance check

The primary injection test verifies the VT ratio and the wiring all the way from the primary system to the IED. Injection must be performed for each phase-to-neutral circuit.

While testing VT secondary circuit and associated secondary equipment, care shall be exercised to isolate the VT from the circuit being tested to avoid backcharging the VT from the secondary side.

4.9 Using the RTXP test switch

The RTXP test switch is designed to provide the means of safe testing of the IED. This is achieved by the electromechanical design of the test switch and test plug handle. When the test plug handle is inserted, it first blocks the trip and alarm circuits then it short circuits the CT secondary circuit and opens the VT secondary circuits making the IED available for secondary injection.

When pulled out, the test handle is mechanically stopped in half withdrawn position. In this position, the current and voltage enter the protection, but the alarm and trip circuits are still isolated and the IED is in test mode. Before removing the test handle, check the measured values in the IED.

Not until the test handle is completely removed, the trip and alarm circuits are restored for operation.
Verify that the contact sockets have been crimped correctly and that they are fully inserted by tugging on the wires. Never do this with current circuits in service.

Current circuit

1. Verify that the contacts are of current circuit type.
2. Verify that the short circuit jumpers are located in the correct slots.

Voltage circuit

1. Verify that the contacts are of voltage circuit type.
2. Check that no short circuit jumpers are located in the slots dedicated for voltage.

Trip and alarm circuits

1. Check that the correct types of contacts are used.

4.10 Checking the binary I/O circuits

4.10.1 Binary input circuits

Preferably, disconnect the binary input connector from the binary input cards. Check all connected signals so that both input level and polarity are in accordance with the IED specifications.

4.10.2 Binary output circuits

Preferably, disconnect the binary output connector from the binary output cards. Check all connected signals so that both load and polarity are in accordance with IED specifications.

4.11 Checking optical connections

Check that the Tx and Rx optical connections are correct.

An IED equipped with optical connections requires a minimum depth of 180 mm (7.2 inches) for plastic fiber cables and 275 mm (10.9
inches) for glass fiber cables. Check the allowed minimum bending radius from the optical cable manufacturer.
Section 5 Configuring the IED and changing settings

5.1 Overview

The customer specific values for each setting parameter and a configuration file have to be available before the IED can be set and configured, if the IED is not delivered with a configuration.

Use the configuration tools in PCM600 to verify that the IED has the expected configuration. A new configuration is done with the application configuration tool. The binary outputs can be selected from a signal list where the signals are grouped under their function names. It is also possible to specify a user-defined name for each input and output signal.

Each function included in the IED has several setting parameters, which have to be set in order to make the IED behave as intended. A factory default value is provided for each parameter. A setting file can be prepared using the Parameter Setting tool, which is available in PCM600.

All settings can be

- Entered manually through the local HMI.
- Written from a PC, either locally or remotely using PCM600. Front or rear port communication has to be established before the settings can be written to the IED.

It takes a minimum of three minutes for the IED to save the new settings, during this time the DC supply must not be turned off.

The IED uses a FLASH disk for storing configuration data and process data like counters, object states, Local/Remote switch position etc. Since FLASH memory is used, measures have been taken in software to make sure that the FLASH disk is not worn out by too intensive storing of data. These mechanisms make it necessary to think about a couple of issues in order to not loose configuration data, especially at commissioning time.

After the commissioning is complete, the configuration data is always stored to FLASH, so that is not an issue. But other things, like objects states and the Local/Remote switch position is stored in a slightly different way, where the save of data to FLASH is performed more and more seldom to eliminate the risk of wearing out the
FLASH disk. In worst case, the time between saves of this kind of data is around one hour.

This means, that to be absolutely sure that all data have been saved to FLASH, it is necessary to leave the IED with auxiliary power connected after all the commissioning is done (including setting the Local/Remote switch to the desired position) for at least one hour after the last commissioning action performed on the IED.

After that time has elapsed, it will be safe to turn the IED off, no data will be lost.

5.2 Configuring analog CT inputs

The analog input channels must be configured to get correct measurement results as well as correct protection functionality. Because all protection algorithms in the IED utilize the primary system quantities, it is extremely important to make sure that connected current transformer settings are done properly. These data are calculated by the system engineer and normally set by the commissioning personnel from the local HMI or from PCM600.

The analog inputs on the transformer input module are dimensioned for either 1A or 5A. Each transformer input module has a unique combination of current and voltage inputs. Make sure the input current rating is correct and that it matches the order documentation.

The primary CT data are entered via the HMI menu under Main menu/Settings/General Settings/Analog modules/AnalogInputs

The following parameter shall be set for every current transformer connected to the IED:

<table>
<thead>
<tr>
<th>Parameter description</th>
<th>Parameter name</th>
<th>Range</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated CT primary current in A</td>
<td>CT Prim Input</td>
<td>from 0 to 99999</td>
<td>3000</td>
</tr>
</tbody>
</table>

This parameter defines the primary rated current of the CT. For two set of CTs with ratio 1000/1 and 1000/5 this parameter is set to the same value of 1000 for both CT inputs. The parameter CTStarPoint can be used in order to reverse the direction of the CT.

For main CTs with 2A rated secondary current, it is recommended to connect the secondary wiring to the 1A input.
Take the rated permissive overload values for the current inputs into consideration.

5.3 Reconfiguring the IED

I/O modules configured as logical I/O modules (BIM, BOM or IOM) are supervised. I/O modules that are not configured are not supervised.

Each logical I/O module has an error flag that indicates signal or module failure. The error flag is also set when the physical I/O module of the correct type is not detected in the connected slot.
Section 6  Establishing connection and verifying the SPA/IEC communication

6.1 Entering settings

If the IED is connected to a monitoring or control system via the rear SPA/IEC port, the SPA/IEC port has to be set either for SPA or IEC use.

6.1.1 Entering SPA settings

The SPA/IEC port is located on the rear side of the IED. Two types of interfaces can be used:

- for plastic fibres with connector type HFBR
- for glass fibres with connectors type ST

When using the SPA protocol, the rear SPA/IEC port must be set for SPA use.

Procedure

1. Set the operation of the rear optical SPA/IEC port to “SPA”.
   The operation of the rear SPA port can be found on the local HMI under Main menu/Configuration/Communication/Station communication/Port configuration/SLM optical serial port/PROTOCOL:1
   When the setting is entered the IED restarts automatically. After the restart the SPA/IEC port operates as a SPA port.
2. Set the slave number and baud rate for the rear SPA port
   The slave number and baud rate can be found on the local HMI under Main menu/Configuration/Communication/Station communication/SPA/SPA:1
   Set the same slave number and baud rate as set in the SMS system for the IED.

6.1.2 Entering IEC settings

When using the IEC protocol, the rear SPA/IEC port must be set for IEC use.

Two types of interfaces can be used:
• for plastic fibres with connector type HFBR
• for glass fibres with connectors type ST

Procedure

1. Set the operation of the rear SPA/IEC port to “IEC”.
   The operation of the rear SPA/IEC port can be found on the local HMI under Main menu/Configuration/Communication/SLM configuration/Rear optical SPA-IEC-DNP port/PROTOCOL:1
   When the setting is entered the IED restarts automatically. After the restart the selected IEC port operates as an IEC port.

2. Set the slave number and baud rate for the rear IEC port.
   The slave number and baud rate can be found on the local HMI under Main menu/Configuration/Communication/SLM configuration/Rear optical SPA-IEC-DNP port/IEC60870–5–103
   Set the same slave number and baud rate as set in the IEC master system for the IED.

6.2 Verifying the communication

To verify that the rear communication with the SMS/SCS system is working, there are some different methods. Choose one of the following.

6.2.1 Verifying SPA communication

Procedure

1. Use a SPA-emulator and send “RF” to the IED. The answer from the IED should be the type and version of it, for example, “”.

2. Generate one binary event by activating a function, which is configured to an event block where the used input is set to generate events on SPA. The configuration must be made with the PCM600 software. Verify that the event is presented in the SMS/SCS system.

   During the following tests of the different functions in the IED, verify that the events and indications in the SMS/SCS system are as expected.
6.2.2 Verifying IEC communication

To verify that the IEC communication with the IEC master system is working, there are some different methods. Choose one of the following.

Procedure

1. Check that the master system time-out for response from the IED, for example after a setting change, is > 40 seconds.
2. Use a protocol analyzer and record the communication between the IED and the IEC master. Check in the protocol analyzer’s log that the IED answers the master messages.
3. Generate one binary event by activating a function that is configured to an event block where the used input is set to generate events on IEC. The configuration must be made with the PCM600 software. Verify that the event is presented in the IEC master system.

During the following tests of the different functions in the IED, verify that the events and indications in the IEC master system are as expected.

6.3 Fibre optic loop

The SPA communication is mainly used for SMS. It can include different numerical IEDs with remote communication possibilities. The fibre optic loop can contain < 20-30 IEDs depending on requirements on response time. Connection to a personal computer (PC) can be made directly (if the PC is located in the substation) or by telephone modem through a telephone network with ITU (CCITT) characteristics.

<table>
<thead>
<tr>
<th>Table 4: Max distances between IEDs/nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>glass</td>
</tr>
<tr>
<td>plastic</td>
</tr>
</tbody>
</table>
6.4 Optical budget calculation for serial communication with SPA/IEC

Table 5: Example

<table>
<thead>
<tr>
<th>Distance 1 km Glass</th>
<th>Distance 25 m Plastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum attenuation</td>
<td>- 11 dB</td>
</tr>
<tr>
<td>4 dB/km multi mode: 820 nm - 62.5/125 um</td>
<td>4 dB</td>
</tr>
<tr>
<td>0.16 dB/m plastic: 620 nm - 1mm</td>
<td>-</td>
</tr>
<tr>
<td>Margins for installation, aging, and so on</td>
<td>5 dB</td>
</tr>
<tr>
<td>Losses in connection box, two contacts (0.5 dB/contact)</td>
<td>1 dB</td>
</tr>
<tr>
<td>Losses in connection box, two contacts (1 dB/contact)</td>
<td>-</td>
</tr>
<tr>
<td>Margin for 2 repair splices (0.5 dB/splice)</td>
<td>1 dB</td>
</tr>
<tr>
<td>Maximum total attenuation</td>
<td>11 dB</td>
</tr>
</tbody>
</table>
Section 7 Establishing connection and verifying the IEC 61850 communication

7.1 Overview

The rear OEM ports are used for substation bus (IEC 61850-8-1) communication, process bus (IEC 61850-9-2LE) communication, and IEEE C37.118/1344 communication where applicable.

For IEC 61850-8-1 redundant communication, both rear OEM ports are utilized. In this case IEC 61850-9-2LE communication can not be used.

7.2 Setting the station communication

To enable IEC 61850 communication the corresponding OEM ports must be activated. The rear OEM port AB and CD is used for IEC 61850-8-1 communication. The rear OEM port CD is used for IEC 61850-9-2LE communication. For IEC 61850-8-1 redundant communication, both OEM port AB and CD are used exclusively.

IEC 61850-9-2LE communication can only be used on OEM rear port X311:C, D.

To enable IEC 61850 station communication:

1. Enable IEC 61850-8-1 (substation bus) communication for port AB.

   1.1. Set values for the rear ports AB and CD.
   
   Navigate to: Main menu/Configuration/Communication/Ethernet configuration/LANAB:1
   
   Set values for Mode, IPAddress and IPMask. Mode must be set to Normal.
   
   Check that the correct IP address is assigned to the port.

1.2. Enable IEC 61850-8-1 communication.

   Navigate to: Main menu/Configuration/Communication/Station communication/IEC61850-8-1/IEC61850–8–1:1
Set Operation to Enabled and PortSelGOOSE to the port used (for example LANAB).

2. Enable redundant IEC 61850-8-1 communication for port AB and CD
   2.1. Enable redundant communication.
   Navigate to: Main menu/Configuration/Communication/Ethernet configuration/PRP:1
   Set values for Operation, IPAddress and IPMask. Operation must be set to Enabled.
   The IED will restart after confirmation. Menu items LANAB:1 and LANCD:1 are hidden in local HMI after restart but are visible in PST where the values for parameter Mode is set to Duo.

3. Enable IEC 61850-9-2LE (process bus) communication for port CD.
   3.1. Set values for the rear port CD.
   Navigate to: Main menu/Configuration/Communication/Ethernet configuration/LANCD:1
   Set values for Mode, IPAddress and IPMask. Mode must be set to IEC9-2.

There are no settings needed for the IEC 61850-9-2LE communication in the local HMI branch Station communication. Make sure that the optical fibres are connected correctly. Communication is enabled whenever the merging unit starts sending data.

7.3 Verifying the communication

Connect your PC to the substation network and ping the connected IED and the Substation Master PC, to verify that the communication is working (up to the transport layer).

The best way to verify the communication up to the application layer is to use protocol analyzer connected to the substation or process bus, and monitor the communication.

Verifying redundant IEC 61850-8-1 communication

Ensure that the IED receives IEC 61850-8-1 data on both port AB and CD. Browse in the local HMI to Main menu/Diagnostics/Communication/Redundant PRP and check that both signals LAN-A-STATUS and LAN-B-STATUS are shown as Ok. Remove the optical connection to one of the ports AB or CD. Verify that either signal LAN-A-STATUS or LAN-B-STATUS (depending on which connection that was removed) are shown as Error and the that other signal is shown as Ok. Be sure to re-connect the removed connection after completed verification.
8.1 Overview

The IED can support synchrophasor data communication via IEEE C37.118 and/or IEEE1344 with maximum 8 TCP clients and 6 UDP client groups, simultaneously.

The rear OEM ports are used for IEEE C37.118/1344 communication. The same ports can also be used for substation bus (IEC 61850-8-1) communication and process bus (IEC 61850-9-2LE) communication where applicable.

In order to establish a connection between PMU and a TCP/UDP client (PDC client), an Ethernet communication link (e.g. optical fiber) shall be available and the required parameters on both PMU and the TCP/UDP client shall be set. For the purpose of this section, an Open PDC tool (PMU Connection Tester) installed on a PC is used as the TCP/UDP client.

8.2 Setting the PMU station communication (PMU Report)

1. Check the settings for the PMU Report parameters by navigating to: **Main menu/Configuration/Communication/Station communication/phasor measurement/PMU Report/PMUREPORT:1**
   1.1. Make sure that the operation of at least one PMU instance (e.g. PMU1) is **Enabled**.
   1.2. Enable sending the frequency data by setting the parameter **SendFreqInfo** to **Enabled**.
2. Check the operation of the required phasor channels (PHASORREPORT) by navigating to: **Main menu/Configuration/Communication/Station communication/phasor measurement/PMU Report/PHASORREPORT:x**.
8.3 Setting the PMU station communication (PMU configuration)

To enable IEEE C37.118/1344 communication, the corresponding OEM ports must be activated. The galvanic Ethernet front port and both rear OEM port AB and CD can be used for IEEE C37.118/1344 communication.

To enable IEEE C37.118/1344 synchrophasor communication on OEM port AB:

1. Enable communication for port AB by navigating to: Main menu/Configuration/Communication/Ethernet configuration/LANAB:1.
   1.1. Set values for Mode, IPAddress and IPMask. Mode must be set to Normal.
   1.2. Check that the correct IP address is assigned to the port. In this section, the default IP address for port AB (192.168.1.10) is used.

2. Set the TCP communication parameters by navigating to: Main menu/Configuration/Communication/Station communication/phasor measurement/PMU Configuration/PMUCONF. The first three parameters are related to TCP communication. The default TCP parameters setting can be used. More information regarding TCP communication is available in RES670 Application Manual under section Short guidance for use of TCP.

3. Set the UDP communication parameters by navigating to: Main menu/Configuration/Communication/Station communication/phasor measurement/PMU Configuration/PMUCONF. The first three parameters are related to TCP communication and the rest of parameters are related to setting of six independent UDP client groups. Each UDP group has eight parameters. More information regarding UDP communication is available in RES670 Application Manual under section Short guidance for use of UDP. The following steps describes setting parameters for the first UDP group:

   3.1. Enable the first UDP group by setting the parameter SendDataUDP1 to Enabled.
   3.2. Set the UDP client IP address by setting the parameter UDPDestAddress1 to 192.168.1.99. For the purpose of the communication set-up in this section the LAN IP address of the PC is used, where the PDC client tool is installed.
   3.3. The default parameter settings can be used for the rest of parameters for the first UDP group.
8.4 Setting the TCP/UDP client communication

As an example of a TCP/UDP client, the openPDC tool (PMU Connection Tester Ver. 4.2.12) from Grid Protection Alliance is used in this section. Install PMU Connection Tester tool on a PC with Ethernet network adaptor available. The same PC used for PCM600 can be used to install the PMU Connection Tester tool.

The following steps explain how to set the PMU Connection Tester parameters in order to establish an IEEE C37.118 connection with the PMU:

1. Set the IP stack on PMU Connection Tester to IPv4. Note that the default IP stack on PMU Connection Tester tool is IPv6.

Figure 9: PMU Connection Tester tool

IEC140000133-1-en.vsd

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1.1. Navigate to the **Settings** tab.

1.2. Force the IP stack to IPv4 by setting the parameter **ForceIPv4** to **True**.

2. Set the Connection Parameters on PMU Connection Tester for TCP communication according to the PMU configuration.
2.1. Set *Host IP* to the PMU IP address configured for the port in use. Here the LANAB:1 IPAddress (192.168.1.10) is set.

2.2. Set *Port* to RES670 TCP port set in the PMU under parameter C37.118TCPport (4712 is default). Alternatively, in order to make an IEEE1344 communication, the 1344TCPport parameter setting can be used (4713 is default).

2.3. Set the **Protocol** as IEEE C37.118.2-2011.

2.4. Set the *Device ID Code* in PMU Connection Tester per PMU Data Stream ID Number (IDCODE). The PMU Data Stream ID Number is a user assigned ID number (1-65534) for each data stream sent out from the PMU and it is defined under parameter PMUdataStreamIDCODE. *(Main menu/Configuration/Communication/Station communication/phasor measurement/PMU Report/PMUREPORT:1)*

2.5. Make sure that the **Configure Alternate Command Channel** is set as *Not Defined*. The Configure Alternate Command Channel is used to configure a TCP channel to control the UDP data communication and transfer the header, configuration and command frames.

2.6. Continue to the section **Verifying the IEEE C37.118/1344 TCP communication**.

3. Set the Connection Parameters on PMU Connection Tester for UDP communication according to the PMU configuration.

3.1. Set the *Local Port* to UDP destination port defined in the PMU under the parameter UDPDestPort1 (Default value: 8910).

3.2. Click the **Configure Alternate Command Channel** to configure the TCP channel. A new window will pop up. A TCP channel needs to be configured in order to control the UDP data communication and transfer the header, configuration and command frames.
3.3. Set the *Host IP* as the PMU IP address configured for the port in use. Here the LANAB:1 IPAddress (192.168.1.10) is set.

3.4. Set the *Port* as the TCP port defined in the PMU for control of data sent over UDP client group 1 (Default value: 4713). This can be found under the parameter *TCPportUDPdataCtrl1* as one of the UDP communication parameters.

3.5. **Save** the *Alternate Command Channel Configuration* settings.

3.6. Continue to the section [Verifying the IEEE C37.118/1344 UDP communication](#).

### 8.5 Verifying the communication

Connect your PC to the substation network and ping the connected IED and the Substation Master PC, to verify that the communication is working (up to the transport layer). Make sure that the optical fibers are connected correctly.

After checking the communication, it is time to verify the IEEE C37.118/1344 communication over both TCP and UDP protocols.

One way to verify the communication up to the application layer is to use a protocol analyzer connected to the substation bus, and monitor the communication. Alternatively, the PMU Connection Tester tool can be used to verify the IEEE C37.118/1344 communication. The section [Setting the TCP/UDP client](#)
8.5.1 Verifying the IEEE C37.118/1344 TCP communication

After setting both PMU configuration and the TCP client configuration (As explained in sections Setting the PMU station communication (PMU Report), Setting the PMU station communication (PMU configuration) and Setting the TCP/UDP client communication) and making sure that the Ethernet communication is set up, click Connect on the PMU Connection Tester tool.

Figure 10: Verifying the TCP communication using PMU Connection Tester

- Now it should be possible to see the streaming synchrophasor data. In the Graph tab, observe the Frequency, data Reporting Rate, Phasor names, and Phase angles of the reported synchrophasors. Observe the real-time frame details of the Data Frame in the bottom of the window.
• Open the drop-down menu in the Command field. There is a list of commands that can be sent from the client (PMU Connection Tester) to the PMU. Try different commands and make sure that the PMU is receiving and responding to them.

Figure 11: Graphic view over streaming synchrophasor data
Figure 12: Drop-down menu with commands for testing the PMU

- Switch to the **Protocol Specific** tab. Here, all the IEEE C37.118 message types can be seen. If the **HeaderFrame** is not included, ask the PMU to send the header frame via the **Send Header Frame** command (Previous stage). Open each message type and observe the content of each message.
Figure 13: All the IEEE C37.118 message types

- It is also possible to capture the IEEE C37.118 synchrophasor data in an Excel file. This is done by navigating to File/Capture/Start Stream Debug Capture...
The tool will ask to Set Stream Debug Capture File Name and path to save the capture file.
Figure 14: Start capturing the IEEE C37.118 synchrophasor data

- The synchrophasor data capturing process can be stopped at any point of time by navigating to File/Capture/Stop Stream Debug Capture...
Open the capture file and observe the captured synchrophasor data. In order to get the Phasor names on top of each column (See figure 16), the capture process should start before connecting the PMU Connection Tester to the PMU, i.e. first start the capturing and then click Connect.
After setting both PMU configuration and the UDP client configuration (As explained in sections Setting the PMU station communication (PMU Report), Setting the PMU station communication (PMU configuration), and Setting the TCP/UDP client communication) and making sure that the Ethernet communication is set up, click Connect on the PMU Connection Tester tool.
Figure 17: Verifying the UDP communication using PMU Connection Tester

- Now it should be possible to see the streaming synchrophasor data.
- Verify the communication by following the same steps as in section Verifying the IEEE C37.118/1344 TCP communication.

8.6 Optical budget calculation for RES670 - PDC communication

Most of the times, the RES670 IEDs are located in the substations. A local PDC might be located in the substation. For communications within the substation or between the RES670 and the WAN/LAN access point, it is important to know what is the optical budget available. The graph in Figure 18 shows the dynamic range available for a PMU – PDC configuration using typical OEMs.
Figure 18: Optical power budget for fiber optic cable lengths

As shown in the graph, if one uses a 62.5/125 μm fiber, the value under the 62.5/125 μm curve represents the remaining optical budget at any link length, which is available for overcoming non-fiber cable related losses.

Losses in the connectors and splices are typically 0.3dB/connection. The user must reserve 3dB spare for the uncertainty of the measurements.
Section 9 Testing IED operation

9.1 Preparing for test

9.1.1 Requirements

IED test requirements:

- Calculated settings
- Application configuration diagram
- Signal matrix (SMT) configuration
- Terminal connection diagram
- Technical manual
- Three-phase test equipment
- Process bus, IEC61850-9-2LE, MU test simulator, if IEC 61850-9-2LE process bus communication is used.
- PCM600

The setting and configuration of the IED must be completed before the testing can start.

The terminal diagram, available in the technical reference manual, is a general diagram of the IED.

Note that the same diagram is not always applicable to each specific delivery (especially for the configuration of all the binary inputs and outputs).

Therefore, before testing, check that the available terminal diagram corresponds to the IED.

The technical manual contains application and functionality summaries, function blocks, logic diagrams, input and output signals, setting parameters and technical data sorted per function.

The test equipment should be able to provide a three-phase supply of voltages and currents. The magnitude of voltage and current as well as the phase angle between voltage and current must be variable. The voltages and currents from the test equipment must be obtained from the same source and they must have minimal
harmonic content. If the test equipment cannot indicate the phase angle, a separate phase-angle measuring instrument is necessary.

Prepare the IED for test before testing a particular function. Consider the logic diagram of the tested protection function when performing the test. All included functions in the IED are tested according to the corresponding test instructions in this chapter. The functions can be tested in any order according to user preferences. Only the functions that are used (Operation is set to Enabled) should be tested.

The response from a test can be viewed in different ways:

• Binary outputs signals
• Service values on the local HMI (logical signals or phasors)
• A PC with PCM600 application configuration software in debug mode

All setting groups that are used should be tested.

This IED is designed for a maximum continuous current of four times the rated current.

All references to CT and VT must be interpreted as analog values received from merging units (MU) via IEC 61850-9-2LE communication protocol, analog values received from the transformer input module, or analog values received from the LDCM.

When using a MU test simulator, make sure it is set to the correct SVID and that the system frequency is set to the same as in the IED.

Please observe the measuring accuracy of the IED, the test equipment and the angular accuracy for both of them.

Please consider the configured logic from the function block to the output contacts when measuring the operate time.

After intense testing, it is important that the IED is not immediately restarted, which might cause a faulty trip due to flash memory restrictions. Some time must pass before the IED is restarted. For more
information about the flash memory, refer to section “Configuring the IED and changing settings”.

9.1.2 Preparing the IED to verify settings

If a test switch is included, start preparation by making the necessary connections to the test switch. This means connecting the test equipment according to a specific and designated IED terminal diagram.

Put the IED into the test mode to facilitate the test of individual functions and prevent unwanted operation caused by other functions. The busbar differential protection is not included in the test mode and is not prevented to operate during the test operations. The test switch should then be connected to the IED.

Verify that analog input signals from the analog input module are measured and recorded correctly by injecting currents and voltages required by the specific IED.

To make testing even more effective, use PCM600. PCM600 includes the Signal monitoring tool, which is useful in reading the individual currents and voltages, their amplitudes and phase angles. In addition, PCM600 contains the Disturbance handling tool. The content of reports generated by the Disturbance handling tool can be configured which makes the work more efficient. For example, the tool may be configured to only show time tagged events and to exclude analog information and so on.

Check the disturbance report settings to ensure that the indications are correct.

For information about the functions to test, for example signal or parameter names, see the technical manual. The correct initiation of the disturbance recorder is made on pickup and/or release or trip from a function. Also check that the wanted recordings of analog (real and calculated) and binary signals are achieved.

Parameters can be entered into different setting groups. Make sure to test functions for the same parameter setting group. If needed, repeat the tests for all different setting groups used. The difference between testing the first parameter setting group and the remaining is that there is no need for testing the connections.

During testing, observe that the right testing method, that corresponds to the actual parameters set in the activated parameter setting group, is used.

Set and configure the function(s) before testing. Most functions are highly flexible and permit a choice of functional and tripping modes. The various modes are checked at the factory as part of the design verification. In certain cases, only modes with a high
probability of coming into operation need to be checked when commissioned to verify the configuration and settings.

9.2 Activating the test mode

Put the IED into the test mode before testing. The test mode blocks all protection functions and some of the control functions in the IED, and the individual functions to be tested can be unblocked to prevent unwanted operation caused by other functions. In this way, it is possible to test slower back-up measuring functions without the interference from faster measuring functions. The busbar differential protection is not included in the test mode and is not prevented to operate during the test operations. The test switch should then be connected to the IED. Test mode is indicated when the yellow PickupLED flashes.

It is important that the IED function to be tested is put into test mode, even if the MU is sending data marked as "test". The IED will interpret these data as valid if it is not in test mode.

1. Browse to the TestMode menu and press E. The TestMode menu is found on the local HMI under Main menu/Test/IED test mode/TestMode.
2. Use the up and down arrows to choose Enabled and press E.
3. Press the left arrow to exit the menu. The dialog box Save changes appears.
4. Choose Yes, press E and exit the menu. The yellow pickupLED above the LCD will start flashing when the IED is in test mode.

9.3 Preparing the connection to the test equipment

The IED can be equipped with a test switch of type RTXP8, RTXP18 or RTXP24 or FT. The test switch and its associated test plug handles are a part of the COMBITEST or FT system of ABB, which provides secure and convenient testing of the IED.

When using the COMBITEST, preparations for testing are automatically carried out in the proper sequence, that is, for example, blocking of tripping circuits, short circuiting of CTs, opening of voltage circuits, making IED terminals available for secondary injection. Terminals 1 and 8, 1 and 18 as well as 1 and 12 of the test switches RTXP8, RTXP18 and RTXP24 respectively are not disconnected as they supply DC power to the protection IED. When FT switch is used for testing, care shall be exercised to open the tripping circuit, ahead of manipulating the CT fingers.
The RTXH test-plug handle leads may be connected to any type of test equipment or instrument. When a number of protection IEDs of the same type are tested, the test-plug handle only needs to be moved from the test switch of one protection IED to the test switch of the other, without altering the previous connections.

Use COMBITEST test system to prevent unwanted tripping when the handle is withdrawn, since latches on the handle secure it in the half withdrawn position. In this position, all voltages and currents are restored and any re-energizing transients are given a chance to decay before the trip circuits are restored. When the latches are released, the handle can be completely withdrawn from the test switch, restoring the trip circuits to the protection IED.

If a test switch is not used, perform measurement according to the provided circuit diagrams.

Never disconnect the secondary connection of a current transformer circuit without first short-circuiting the transformer's secondary winding. Operating a current transformer with the secondary winding open will cause a massive potential build up that may damage the transformer and cause personal injury.

9.4 Connecting the test equipment to the IED

Connect the test equipment according to the IED specific connection diagram and the needed input and output signals for the function under test. An example of a connection is shown in figure 19.

Connect the current and voltage terminals. Pay attention to the current polarity. Make sure that the connection of input and output current terminals and the connection of the residual current conductor is correct. Check that the input and output logical signals in the logic diagram for the function under test are connected to the corresponding binary inputs and outputs of the IED under test.

The MU test equipment must be connected to the CD port on the OEM module when process bus IEC61850-9-2LE communication is used.

To ensure correct results, make sure that the IED as well as the test equipment are properly grounded before testing.
Releasing the function to be tested

Release or unblock the function to be tested. This is done to ensure that only the function or the chain of functions to be tested are in operation and that other functions are prevented from operating. Release the tested function(s) by setting the corresponding `Blocked` parameter under Function test modes to `No` in the local HMI.

When testing a function in this blocking feature, remember that not only the actual function must be activated, but the whole sequence of interconnected functions (from measuring inputs to binary output contacts), including logic must be activated. Before starting a new test mode session, scroll through every function to ensure that only the function to be tested (and the interconnected ones) have the parameters `Blocked` and eventually `EvDisable` set to `No` and `Yes` respectively. Remember that a function is also blocked if the BLOCK input signal on the corresponding function block is active, which depends on the configuration. Ensure that the logical status of the BLOCK input signal is equal to 0 for the function to be tested. Event function blocks can also be individually blocked to ensure that no events are reported to a remote station during the test. This is done by setting the parameter `EvDisable` to `Yes`. 
Any function is blocked if the corresponding setting in the local HMI under Main menu/Test/Function test modes menu remains Enabled, that is, the parameter Blocked is set to Yes and the parameter TestMode under Main menu/Test/IED test mode remains active. All functions that were blocked or released in a previous test mode session, that is, the parameter Test mode is set to Enabled, are reset when a new test mode session is started.

Procedure

1. Click the Function test modes menu.
   The Function test modes menu is located in the local HMI under Main menu/Test/Function test modes.
2. Browse to the function instance that needs to be released.
3. Set parameter Blocked for the selected function to No.

9.6 Verifying analog primary and secondary measurement

Verify that the connections are correct and that measuring and scaling is done correctly. This is done by injecting current and voltage to the IED.

Besides verifying analog input values from the merging unit via the IEC 61850-9-2-LE process bus, analog values from the transformer input module can be verified as follows.

Apply input signals as needed according to the actual hardware and the application configuration.

1. Inject a symmetrical three-phase voltage and current at rated value.
2. Compare the injected value with the measured values.
   The voltage and current phasor menu in the local HMI is located under Main menu/Measurements/Analog primary values and Main menu/Measurements/Analog secondary values.
3. Compare the frequency reading with the set frequency and the direction of the power.
   The frequency and active power are located under Main menu/Measurements/Monitoring/ServiceValues(MMXN)/CVMMXN:x. Then navigate to the bottom of the list to find the frequency.
4. Inject an unsymmetrical three-phase voltage and current, to verify that phases are correctly connected.
If some setting deviates, check the analog input settings under

**Main menu/Settings/General settings/Analog modules**

If the IEC61850-9-2LE communication is interrupted during current injection, the report tool in PCM600 will display the current that was injected before the interruption.

*Figure 20: PCM600 report tool display after communication interruption*

### 9.7 Testing the protection functionality

Each protection function must be tested individually by secondary injection.
• Verify operating levels (trip) and timers.
• Verify alarm and blocking signals.
• Use the disturbance handling tool in PCM600 to evaluate that the protection function has received the correct data and responded correctly (signaling and timing).
• Use the event viewer tool in PCM600 to check that only expected events have occurred.
Section 10 Testing functionality by secondary injection

10.1 Testing disturbance report

10.1.1 Introduction

The following sub-functions are included in the disturbance report function:

- Disturbance recorder
- Event list
- Event recorder
- Trip value recorder
- Indications

If the disturbance report is enabled, then its sub-functions are also set up and so it is not possible to only disable these sub-functions. The disturbance report function is disabled (parameter Operation = Disabled) in PCM600 or the local HMI under Main menu/Settings/IED Settings/Monitoring/Disturbance report/DRPRDRE:1.

10.1.2 Disturbance report settings

When the IED is in test mode, the disturbance report can be made active or inactive. If the disturbance recorder is turned on during test mode, recordings will be made. When test mode is switched off all recordings made during the test session are cleared.

Setting OpModeTest for the control of the disturbance recorder during test mode are located on the local HMI under Main menu/Settings/IED Settings/Monitoring/Disturbance report/DRPRDRE:1.

10.1.3 Disturbance recorder (DR)

A Manual Trig can be started at any time. This results in a recording of the actual values from all recorded channels.

The Manual Trig can be started in two ways:

1. From the local HMI under Main menu/Disturbance records.
   1.1. Enter on the row at the bottom of the HMI called Manual trig.
A new recording begins. The view is updated if you leave the menu and return.

1.2. Navigate to **General information** or to **Trip values** to obtain more detailed information.

2. Open the Disturbance handling tool for the IED in the plant structure in PCM600.
   
   2.1. Right-click and select **Execute manual Trig** in the window **Available recordings in IED**.
   
   2.2. Read the required recordings from the IED.
   
   2.3. Refresh the window **Recordings** and select a recording.
   
   2.4. Right-click and select **Create Report** or **Open With** to export the recordings to any disturbance analyzing tool that can handle Comtrade formatted files.

Evaluation of the results from the disturbance recording function requires access to a PC either permanently connected to the IED or temporarily connected to the Ethernet port (RJ-45) on the front. The PCM600 software package must be installed in the PC.

Disturbance upload can be performed by the use of PCM600 or by any third party tool with IEC 61850 protocol. Reports can automatically be generated from PCM600. Disturbance files can be analyzed by any tool reading Comtrade formatted disturbance files.

It could be useful to have a printer for hard copies. The correct start criteria and behavior of the disturbance recording function can be checked when IED protective functions are tested.

When the IED is brought into normal service it is recommended to delete all recordings, made during commissioning to avoid confusion in future fault analysis.

All recordings in the IED can be deleted in two ways:

1. in the local HMI under **Main menu/Clear/Reset disturbances**, or
2. in the Disturbance handling tool in PCM600 by selecting **Delete all recordings in the IED**... in the window **Available Recordings in IED**.

### 10.1.4 Event recorder (ER) and Event list (EL)

The result from the event recorder and event list can be viewed on the local HMI or, after upload, in PCM600 as follows:

1. on the local HMI under **Main menu/Events**, or in more details via
2. the **Event Viewer** in PCM600.

   The internal FIFO register of all events will appear when the event viewer is launched.
When the IED is brought into normal service it is recommended to delete all events resulting from commissioning tests to avoid confusion in future fault analysis. All events in the IED can be cleared in the local HMI under Main Menu/Clear/ Clear internal event list or Main menu/Clear/Clear process event list. It is not possible to clear the event lists from PCM600.

When testing binary inputs, the event list (EL) might be used instead. No uploading or analyzing of registrations is then needed since the event list keeps running, independent of start of disturbance registration.

10.2 Identifying the function to test in the technical reference manual

Use the technical manual to identify function blocks, logic diagrams, input and output signals, setting parameters and technical data.

10.3 Differential protection

10.3.1 Line differential protection L3CPDIF (87L) and L6CPDIF (87L)

Prepare the IED for verification of settings as outlined in section "Requirements" and section "Preparing for test" in this chapter.

The test of the line differential protection is done with the different IEDs geographically separated from each other. It is important to note that local actions, in one IED, may cause operation in remotely located IEDs. In the test of the line differential function actions must be done in all involved IEDs.

When the protection at one end is activated to Test mode, this information is automatically sent to remote end IEDs through the LineDiffLogic function block and the remote functions are then also blocked automatically.

Before test the trip signal to the circuit breaker must be blocked, for example by applying the COMBITEST test switch or opening the trip link through FT switch.

Line differential protection must be set in test mode. This involves switching the IED to Test mode and the functions involved in the test. For the Differential protection there are settings to Test mode and also the activation of the local function with setting "Release local". Remember also for example the trip function block deblocking to be
able to measure trip times. In the test mode the injected current is communicated to the remote IEDs and sent back to the IED under test. The echoed current is switched in phase so that current in phase A is returned in phase B, current in phase B is returned in phase C and current in phase C is returned in phase A. The magnitude of the returned current can be set separately as a ratio of the injected current.

Take a line with three IEDs, for example, set the return current from each remote IED to be 50% of the injected current. Inject a current I in phase A to get the following differential and bias currents:

**Phase A:**

\[ IDiff_A = IBias_A = I_{injected,A} \]

**Phase B:**

\[ IDiff_B = IBias_B = I_{injected,A} \cdot 1\angle 240^\circ \]

**Phase C:**

\[ IDiff_C = IBias_C = 0 \]

### 10.3.1.1 Verifying the settings

**Procedure**

1. Block the trip signal from all involved IEDs with local operation released. See below.
2. Set *Test mode* to *Enabled* for the Line differential function for test.
3. Release the local function with setting *ReleaseLocal* in local HMI under: **Main menu/Test/Line differential test/LineDiffLogic**
4. Set the factor of the return currents to \(1/(\text{number of current IEDs} = 1)\).
5. Inject a current in phase A and increase the current until the function operates for phases A and B.
   The injected trip current must correspond to the set *IdMin*. The service values for *IDiff_A*, *IBias_A*, *IDiff_B* and *IBias_B* must be equal to the injected current.
6. Repeat step 4 by current injection in phases B and C.
7. Inject a symmetrical three-phase current, and increase the current until operation is achieved in all three phases.
The injected trip current must correspond to the set \( \text{IdMin} \). The service values for \( \text{IDiff}_A, \text{IBias}_A, \text{IDiff}_B, \text{IBias}_C, \text{IDiff}_C \) and \( \text{IBias}_C \) must be equal to the injected current.

8. Read the transmission delay.
9. Measure the operating time by injection of a single-phase current in phase A. The injected current must be 4 times the operating current. The time measurement is stopped by the trip output.

Note that tripping times at this loop test includes sending the local currents to remote side and with a factor sending them back. This means that tripping times are virtually double to the times achieved at a real fault or at bench testing.

10. Check the negative sequence fault discriminator by injecting a three-phase current with changed phase sequence: switch phases A and B. The injected current will now be seen as a pure negative-sequence current where the phase angle between the local negative-sequence current and the remote negative-sequence currents will be 120°.

With the current above \( \text{IMinNegSeq} \), the signal external fault (EXTFAULT) must apply. No trip must be generated.

11. Disconnect the test equipment and reconnect the current transformers.
12. Read and check the service values of the three-phase current.
13. Switch off the test mode and the release local.
14. With a through load current (maximum current of line ends) of minimum 20% of \( \text{IBase} \) the current \( \text{IDiff} \) and \( \text{IBias} \) are read in all phases.

\( \text{IDiff} \) must be less than 10% of the maximum line end current and \( \text{IBias} \) must be equal to the largest line end current.

### 10.3.1.2 Completing the test

Continue to test another function or end the test by changing the \textit{TestMode} setting to \textit{Disabled}. Restore connections and settings to their original values, if they were changed for testing purposes.

After finishing a loop test with line in service and before leaving test mode, the setting \textit{ReleaseLocal} in local HMI under: Main menu/Test/Line differential test/LineDiffLogic must be set to \textit{BlockAll}. If not, the load current might cause incorrect operation of the differential function at restarts of the line differential protection IED.
10.4 Impedance protection

10.4.1 Power swing detection ZMRPSB (68)

The aim is to verify that the settings of the Power swing detection function ZMRPSB (68) is according to the setting table and to verify that ZMRPSB (68) operates as expected.

Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".

Before starting this process, all impedance measuring zones shall be set and in operation. Test the outer resistive boarder in forward and reverse direction, $RLdOutFw$ and $RLdOutRv$ and the inner reactive boarder in forward and reverse direction $X1InFw$ and $X1InRv$. See figure 21.

The corresponding resistive border for the inner resistive boundary and outer resistive boundary is calculated automatically from the setting of $kLdRFw$ and $kLdRRv$.

The inner zone of ZMRPSB (68) must cover all zones by at least 10% margin.

The test is mainly divided into two parts, one which aim is to verify that the settings are in accordance to the selectivity plan and a second part to verify the operation of ZMRPSB (68). The proposed test points for validation of the settings are numbered according to figure 21.

Test of the interactions or combinations that are not configured are not considered in this instruction.
Figure 21: Operating principle and characteristic of the power swing detection function (settings parameters in italic)

Where:

\[ RLdInFw = RLdOutFw \cdot kLdRFw \]
\[ RLdInRv = RLdOutRv \cdot kLdRRv \]
\[ X1OutFw = X1InFw + (RLdOutFw - RLdInFw) \]
\[ X1OutRv = X1InRv + (RLdOutFw - RLdInFw) \]

10.4.1.1 Verifying the settings

Preconditions

The following output signal shall be configured to binary output available: ZOUT, measured impedance within outer impedance boundary.
1. Keep the measured current as close as possible to its rated value or lower. Keep it constant during the test, but ensure that it is higher than the set minimum operating current.
2. Ensure that the maximum continuous current to the IED does not exceed four times its rated value, if the measurement of the operating characteristics runs under constant voltage conditions.
3. Make the necessary connections and settings of the test equipment for test of point 1 according to figure 21.
4. Decrease the measured three-phase impedance slowly and observe the operation value for the signal ZOUT.
5. Compare the operation value with the set value.
6. Do the necessary change of the setting of the test equipment and repeat step 4 and step 5 for point 2, 3 and 4 according to figure 21.

10.4.1.2 Testing the power swing detection function ZMRPSB (68)

Preconditions

The following output signals shall be configured to binary outputs: ZOUT, measured impedance within outer impedance boundary, ZIN, measured impedance within inner impedance boundary and PICKUP, power swing detection.

1. Slowly decrease the measured impedance in all three phases until the PICKUP signal gets activated.
2. Increase the measured voltages to their rated values.
3. Decrease instantaneously voltages in all three phases to the values, which are approximately 20% lower than the voltage that gives the set value RILIn at the predefined test current.
4. The PICKUP signal must not appear.
5. Increase the measured voltages to their rated values.

10.4.1.3 Testing the tR1 timer

Preconditions

- The input I0CHECK, residual current (3I0) detection used to inhibit the pickup output must be configured to the output signal PHG_FLT on the FDPSPDIS (21) or FRSPDIS (21) function.
- The input BLK_SS, block inhibit of the pickup output for subsequent residual current detection is connected to FALSE.
1. Program the test equipment for a single-phase to ground fault and energize FDPSPDIS (21) or FRPSPDIS (21) and check that the input BLOCK on the power swing detection function ZMRPSB (68) is activated.

2. Make a test sequence so that a single-phase to ground fault occurs after that the trajectory of the impedance has passed the outer and inner boundary of ZMRPSB (68) during power swing. Use the result from test of ZMRPSB (68) above to determine when the fault shall be applied. The ground-fault must be activated before $t_{R1}$ has elapsed.

3. Start the sequence and observe that the PICKUP signal will not be activated.

### 10.4.1.4 Testing the block input, interaction between FDPSPDIS (21) or FRPSPDIS (21) and ZMRPSB (78)

**Precondition**

The BLOCK input is configured and connected to PHG_FLT output on the FDPSPDIS (21) or FRPSPDIS (21) function.

1. Make a test sequence so that a single phase-to-ground-fault occurs after that the trajectory of the impedance has passed the outer boundary but not the inner boundary of the power swing detection function ZMRPSB (68). Use the result from test of ZMRPSB (68) above to instance when the fault shall be applied.

2. Start the test sequence by continuously reducing the voltage and observe that the output signal ZOUT may come, but not PICKUP.

   If the input I0CHECK is configured (connected to output signal PHG_FLT on FDPSPDIS (21) or FRPSPDIS (21), the test of inhibit of ZMRPSB (68) at ground-fault during power swing can be done in the same way as for test of $t_{R1}$. The inhibit of ZMRPSB (68) shall be instantaneous if the input TRSP is activated at the same time as the input I0CHECK during power swing.

### 10.4.1.5 Completing the test

Continue to test another function or end the test by changing the TestMode setting to Disabled. Restore connections and settings to their original values, if they were changed for testing purposes.

### 10.4.2 Out-of-step protection OOSPPAM

The out-of-step protection OOSPPAM (78) function in the IED can be used for both generator protection and as well for line protection applications.

The main purpose of the OOSPPAM (78) function is to detect, evaluate, and take the required action during pole slipping occurrences in the power system.
The OOSPPAM (78) function detects pole slip conditions and trips the generator as fast as possible, after the first pole-slip if the center of oscillation is found to be in zone 1, which normally includes the generator and its step-up power transformer. If the center of oscillation is found to be further out in the power system, in zone 2, more than one pole-slip is usually allowed before the generator-transformer unit is disconnected. A parameter setting is available to take into account the circuit breaker opening time. If there are several out-of-step relays in the power system, then the one which finds the center of oscillation in its zone 1 should operate first.

Two current channels I3P1 and I3P2 are available in OOSPPAM function to allow the direct connection of two groups of three-phase currents; that may be needed for very powerful generators, with stator windings split into two groups per phase, when each group is equipped with current transformers. The protection function performs a simple summation of the currents of the two channels I3P1 and I3P2.

10.4.3 Verifying the settings

The test of the out-of-step protection function is made to verify that the trip is issued if the following events happen.

- the impedance, seen by the function, enters the lens characteristic from one side and leaves it from the opposite side
- the trip is issued according to the settings TripAngle and tBreaker

The tripping zone needs to be detected and confirmed. The test may be performed by taking into account the following key points that are shown in Figure 22:

- the point RE (RE = Receiving End)
- the intersection between the line segment SE-RE and the X-line, which is defined through the setting ReachZ1
- the point SE (SE = Sending End)
The test of the out-of-step protection function requires the injection of the analog quantities for a quite long time. The rating of the analogue channels is considered in order to avoid any hardware damage. The test current is lower than the continuous permissive overload current $I_{ovrl}$ of the protection current channels of the transformer module.

If the rated secondary current $I_{rs}$ of the analog channel is 1 A, then the maximum current test $I_{ts}$ is

$$I_{ts} \leq I_{ovrl} = 4 \times I_{rs} = 4A$$

(Equation 1)

If the CT of the generator has ratio 9000/1 A, then in primary values

$$I_{p} \leq I_{ovrl,p} = I_{ovrl} \times \frac{I_{p}}{I_{rs}} = 4 \times \frac{9000}{1} = 36000A$$

(Equation 2)

Reference is made to the numerical values of the example, explained in the “Setting guidelines” of the Application Manual. A test current equal to 2.5 time the base current of the generator is chosen; this choice is related to the selected test voltage that is applied while testing the point SE and RE.

$$I_{t} = 2.5 \times I_{bus} = 2.5 \times 8367 = 20918A$$

(Equation 3)
The parameter \( \text{ReachZ1} \) defines the boundary between zone 1 and zone 2; it is expressed in percent of the parameter \( \text{ForwardX} \). If the setting of \( \text{ReachZ1} = 12\% \), then the corresponding primary value of the reactance is

\[
X_{\text{RZ1}} = \frac{\text{ReachZ1}}{100} \times \frac{\text{ForwardX}}{100} \times Z_{\text{Base}} = \frac{12}{100} \times \frac{59.33}{100} \times 0.9522 = 0.068\Omega
\]

(Equation 4)

The calculation of the test voltage, that is related to \( \text{ReachZ1} \), is based on the impedance \( Z_{\text{RZ1}} \) that has imaginary part \( X_{\text{RZ1}} \) and real part \( R_{\text{RZ1}} \):

\[
R_{\text{RZ1}} = \frac{\text{ReachZ1}}{100} \times \frac{\text{ForwardR}}{100} \times Z_{\text{Base}} = \frac{12}{100} \times \frac{8.19}{100} \times 0.9522 = 0.009\Omega
\]

(Equation 5)

The magnitude of the impedance \( Z_{\text{RZ1}} \) is:

\[
Z_{\text{RZ1}} = \sqrt{R_{\text{RZ1}}^2 + X_{\text{RZ1}}^2} = \sqrt{0.009^2 + 0.068^2} = 0.069\Omega
\]

(Equation 6)

Hence the reference voltage of the test of the boundary between zone 1 and zone 2 is

\[
V_{t,\text{RZ1}} = Z_{\text{RZ1}} \times I_c = 0.069 \times 20918 = 1435V
\]

(Equation 7)

If the test voltage is lower than \( V_{t,\text{RZ1}} \) (or in opposition), then the test is related to the zone 1; if the test voltage is higher than \( V_{t,\text{RZ1}} \), then the test is related to the zone 2.

Considering the resistances and reactances which are related to the settings \( \langle \text{ForwardR}, \text{ForwardX} \rangle \) and \( \langle \text{ReverseR}, \text{ReverseX} \rangle \):

\[
R_{\text{Fwd}} = \frac{\text{ForwardR}}{100} \times Z_{\text{Base}} = \frac{8.19}{100} \times 0.9522 = 0.078\Omega
\]

(Equation 8)

\[
X_{\text{Fwd}} = \frac{\text{ForwardX}}{100} \times Z_{\text{Base}} = \frac{59.33}{100} \times 0.9522 = 0.565\Omega
\]

(Equation 9)

\[
R_{\text{Rvs}} = \frac{\text{ReverseR}}{100} \times Z_{\text{Base}} = \frac{0.29}{100} \times 0.9522 = 0.003\Omega
\]

(Equation 10)

\[
X_{\text{Rvs}} = \frac{\text{ReverseX}}{100} \times Z_{\text{Base}} = \frac{29.6}{100} \times 0.9522 = 0.282\Omega
\]

(Equation 11)

and the voltages that are related to them:
The previous calculations are in primary values. They are transferred to secondary values to perform injections by a test set. Primary values are transferred to secondary values by taking into account the CT ratio and the VT ratio (respectively 9000/1 A and 13.8/0.1 kV in the example).

The magnitude of the secondary voltages, that are related to the points RE and SE of the R-X plane, needs to be checked.

RE ($R_{FwdR}$, $X_{FwdX}$):

$$V_{r,FwdZ} = V_{r,FwdZ} \times I_{r} = \sqrt{R_{FwdR}^2 + X_{FwdX}^2} \times I_{r} = \sqrt{0.078^2 + 0.565^2} \times 20918 = 0.570 \times 20918 = 11931V$$

(Equation 12)

$$V_{r,RvsZ} = V_{r,RvsZ} \times I_{r} = \sqrt{R_{RvsR}^2 + X_{RvsX}^2} \times I_{r} = \sqrt{0.003^2 + 0.282^2} \times 20918 = 0.282 \times 20918 = 5899V$$

(Equation 13)

The tests, which are described in this section, may require voltages that have magnitude equal to 110% of the previous values. The continuous permissive overload voltage of the protection voltage channels of the TRM module is 420 V; so the previous voltages may be applied to the analog channels of the IED continuously. Limitations may be related to the available test set; the current $I_t$ was calculated by using a factor 2.5 (instead of the maximum value 4) in order to reduce the magnitude of the test voltage for the points RE and SE.

Test sets usually do not have a feature to simulate a real network during a power swing and apply the related analog quantities at the terminal of the generator. The scope of the present test is not a simulation of a real network. Voltages and currents are supplied in order to measure an impedance that changes in the time and traverses the plane R-X and, in particular, the area inside the lens characteristic. The test may be performed by applying:

- Symmetric three-phase voltage at 50 Hz. The magnitude depends on the point of the characteristic that needs to be verified. The following three main points of the line segment SE-RE need to be checked:
The phase angle of the test voltages is equal to:

- \( \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) \) for tests in the quadrant 1 and 2 of the R-X plane
- \( \arctan \left( \frac{\text{ReverseX}}{\text{ReverseR}} \right) - 180^\circ \) for tests in the quadrant 3 and 4 of the R-X plane

Symmetric three-phase current, where the current is the summation of two currents that have the same magnitude, but different frequencies.

\[
I_{50} = I_q = \frac{I}{2} = \frac{20918}{2} = 10459 \text{A}
\]

(Equation 16)

The first current \( I_{50} \) has frequency 50 Hz, magnitude 10459 A (that is, 1.162 A secondary) and phase angle 0°.

The second current \( I_q \) has magnitude 10459 A (that is, 1.162 A secondary), phase angle 180° (at the starting time of the test) and frequency:

- 49.5 Hz for the test as generator in the quadrant 1 and 2 of the R-X plane
- 50.5 Hz for the test as generator in the quadrant 3 and 4 of the R-X plane

When the trajectory of the impedance, that is seen by the protection function, traverses the lens characteristic then a pole slipping is detected. The present procedure avoids tests of points of the line SE-RE that are too close to the R-axis because in that case the voltage is close to zero and, therefore, the impedance may approach a not defined quantity 0/0.

The accuracy of the impedance reach is ±2% of the base impedance; that is considered while evaluating the test results.

For the test as motor the frequency current may have 50.5 Hz in the quadrant 1 and 2 of the R-X plane and 49.5 Hz in the quadrant 3 and 4.
10.4.3.1 Verifying the settings by secondary injection

It is advised to connect the analog output channels of the function block OOSPPAM to the internal disturbance recorder (and in particular to the function block A4RADR) in order to perform a better analysis of the tests.

If the device is in test mode, the recording of the disturbances are enabled by the setting in Main menu/Settings/IED Settings/Monitoring/Disturbance report/ DisturbanceReport/DRPRDRE:1: set the parameter OpModeTest to On.

1. Check the Application Configuration: verify that hardware voltage and current channels of the IED are properly connected to SMAI function blocks, and that the proper analog outputs of SMAI’s are connected to the analog inputs of the function block OOSPPAM.
2. Connect three-phase voltage channels of the test set to the appropriate IED terminals.
3. Connect in parallel two groups of three-phase currents of the test set to the appropriate IED terminals.
4. Connect the appropriate trip output of the IED to the input channel of the test set that monitors the trip.
5. Go to Main menu/Settings/IED Settings/Impedance protection/ OutOfStep(78,Ucos)/OOSPPAM(78,Ucos):1, and make sure that the function is enabled, that is, Operation is set to On.

10.4.4 Test of point RE (R_{FwdR}, X_{FwdX})

10.4.4.1 The trajectory of the impedance does not enter the lens characteristic.

Preliminary steady state test at 50 Hz

- Go to Main menu/Test/Function status/Impedance protection/ OutOfStep(78,Ucos)/OOSPPAM(78,Ucos):1/Outputs to check the available service values of the function block OOSPPAM.
- Apply the following three-phase symmetrical quantities (the phase angle is related to phase L1):

\[ V_u = 1.1 \times V_{\text{FwdR}} \times \frac{V_{\text{FwdX}}}{V_{\text{FwdR}}} = 1.1 \times 11931 \times \frac{0.1}{13.8} = 95.1V \]

(Equation 17)

\[ \angle V_u = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]

(Equation 18)

frequency of \( V_{ls} = 50 \) Hz
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Testing functionality by secondary injection

\[ I_{ns} = I_{s0} \times \frac{I_{c0}}{I_{cp}} = 10459 \times \frac{1}{9000} = 1.162 \, A \]  
\hspace{10cm} (Equation 19)

\[ \angle I_{s0} = 0^\circ \]  
frequency of \( I_{s0} = 50 \, Hz \)

\[ I_{ts} = I_{t0} \times \frac{I_{c0}}{I_{cp}} = 10459 \times \frac{1}{9000} = 1.162 \, A \]  
\hspace{10cm} (Equation 20)

\[ \angle I_{t0} = 0^\circ \]  
frequency of \( I_{t0} = 50 \, Hz \)

- Check that the service values (VOLTAGE, CURRENT, R(%), X(%)) are according to the injected quantities and that ROTORANG is close to 0 rad. For this particular injection the service values are:
  - VOLTAGE = 13.12 kV
  - CURRENT = 20918 A
  - R = 9.01%
  - X = 65.27%
  - ROTORANG = 0.04 rad

Note that these values identify a point outside the lens characteristic, even if it is close to the point RE. Neither START nor TRIP is issued.

**Execution of the dynamic test**

The test may be performed by using two states of a sequence tool that is a basic feature of test sets.

- State 1: pre-test condition.
  Steady voltage and current are applied in order to get a steady high impedance. This is a point in the plane R-X that is far away from the lens characteristic. Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

  \[ V_n = 1.1 \times V_{n, rad} \times \frac{V_{y.d}}{V_{y.r}} = 1.1 \times 11931 \times \frac{0.1}{13.8} = 95.1 \, V \]  
  \hspace{10cm} (Equation 21)

  \[ \angle V_n = \arctan \left( \frac{ForwardX}{ForwardR} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]  
  \hspace{10cm} (Equation 22)

frequency of \( V_{ts} = 50 \, Hz \)
I_{50s}=0 \text{ A}
I_{fs}=0 \text{ A}

- State 2: main test step.

Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

\[ V_u = 1.1 \times V_{r,f,\text{sym}} \times \frac{V_{\text{tr,s}}}{V_{\text{tr,f}}}, \quad \frac{0.1}{13.8} = 95.1 \text{V} \]  
\[ \angle V_u = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]  

(Equation 23)

\[ \angle I_{50s} = 0^\circ \]  

frequency of \( V_{fs} = 50 \text{ Hz} \)

\[ I_{so} = I_{so} \times \frac{I_{ct,s}}{I_{ct,f}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \]  

(Equation 24)

\[ \angle I_{50s} = 0^\circ \]  

frequency of \( I_{50s} = 50 \text{ Hz} \)

\[ I_{to} = I_{to} \times \frac{I_{ct,o}}{I_{ct,f}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \]  

(Equation 25)

\[ \angle I_{fs} = 180^\circ \]  

frequency of \( I_{fs} = 49.5 \text{ Hz} \)

Expected result: the protection function does not issue either start or trip.

10.4.4.2 The trajectory of the impedance traverses the lens characteristic in zone 2

Preliminary steady state test at 50 Hz

- Go to Main menu/Test/Function status/Impedance protection/OutOfStep(78,Ucos)/OOSPPAM(78,Ucos):1/Outputs to check the available service values of the function block OOSPPAM.

- Apply the following three-phase symmetrical quantities (the phase angle is related to phase L1):
\[ V_v = 0.9 \times V_{\text{r,s}} \times \frac{V_{\text{r},p}}{V_{\text{r},p}} = 0.9 \times 11931 \times \frac{0.1}{13.8} = 77.81 \text{V} \]  

(Equation 27)

\[ \angle V_v = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]  

(Equation 28)

frequency of \( V_{\text{ts}} = 50 \text{ Hz} \)

\[ I_{\text{t}50s} = I_{50} \times \frac{I_{\text{cp}}}{I_{\text{cp}}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \]  

(Equation 29)

\[ \angle I_{\text{t}50s} = 0^\circ \]

frequency of \( I_{50s} = 50 \text{ Hz} \)

\[ I_{\text{t}0} = I_{0} \times \frac{I_{\text{cp}}}{I_{\text{cp}}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \]  

(Equation 30)

\[ \angle I_{\text{t}0} = 0^\circ \]

frequency of \( I_{0} = 50 \text{ Hz} \)

- Check that the service values (VOLTAGE, CURRENT, R(\%), X(\%)) are according to the injected quantities and that ROTORANG is close to 3.14 rad. For this particular injection the service values are:
  - VOLTAGE = 10.74 kV
  - CURRENT = 20918 A
  - R = 7.37\%
  - X = 53.40\%
  - ROTORANG = -3.09 rad

Note that these values identify a point inside the lens characteristic, in the zone 2, that is close to the point RE. The START is issued, but no TRIP is performed.

**Execution of the dynamic test**
The test may be performed by using two states of a sequence tool that is a basic feature of test sets.

- State 1: pre-test condition.
  Steady voltage and current are applied in order to get a steady high impedance, that is, a point in the plane R-X which is far away from the lens characteristic.
  Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):
\[ V_u = 0.9 \times V_{Fw,ad} \times \frac{V_{VT,s}}{V_{VT,p}} = 0.9 \times 11931 \times \frac{0.1}{13.8} = 77.81V \]  
(Equation 31)

\[ \angle V_u = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]  
(Equation 32)

frequency of \( V_{fs} = 50 \text{ Hz} \)
\( I_{50s} = 0 \text{ A} \)
\( I_{tfs} = 0 \text{ A} \)

- State 2: main test step.
Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

\[ V_u = 0.9 \times V_{Fw,ad} \times \frac{V_{VT,s}}{V_{VT,p}} = 0.9 \times 11931 \times \frac{0.1}{13.8} = 77.81V \]  
(Equation 33)

\[ \angle V_u = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]  
(Equation 34)

frequency of \( V_{fs} = 50 \text{ Hz} \)

\[ I_{50s} = I_0 \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \]  
(Equation 35)

\[ \angle I_{50s} = 0^\circ \]
frequency of \( I_{50s} = 50 \text{ Hz} \)

\[ I_{tfs} = I_0 \times \frac{I_{CTs}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \]  
(Equation 36)

\[ \angle I_{tfs} = 180^\circ \]
frequency of \( I_{tfs} = 49.5 \text{ Hz} \)

Expected result: start of the protection function and trip in zone 2, when trip conditions are fulfilled.
10.4.5 Test of the boundary between zone 1 and zone 2, which is defined by the parameter ReachZ1

10.4.5.1 The trajectory of the impedance traverses the lens characteristic in zone 2

Preliminary steady state test at 50 Hz

- Go to Main menu/Test/Function status/Impedance protection/OutOfStep(78,Ucos)/OOSPPAM(78,Ucos):1/Outputs to check the available service values of the function block OOSPPAM.
- Apply the following three-phase symmetrical quantities (the phase angle is related to phase L1):

\[
V_a = 1.1 \times V_{s,22} \times \frac{V_{v,t}}{V_{v,r}} = 1.1 \times 1435 \times \frac{0.1}{13.8} = 11.44V
\]  
\text{(Equation 37)}

\[
\angle V_a = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ
\]  
\text{(Equation 38)}

Frequency of \( V_{ts} = 50 \text{ Hz} \)

\[
I_{ms} = I_{ms} \times \frac{I_{ct}}{I_{ct}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A}
\]  
\text{(Equation 39)}

\[
\angle I_{50s} = 0^\circ
\]
Frequency of \( I_{50s} = 50 \text{ Hz} \)

\[
I_{ts} = I_{ts} \times \frac{I_{ct}}{I_{ct}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A}
\]
\text{(Equation 40)}

\[
\angle I_{tfs} = 0^\circ
\]
Frequency of \( I_{tfs} = 50 \text{ Hz} \)

- Check that the service values (VOLTAGE, CURRENT, R(%), X(%)) are according to the injected quantities and that ROTORANG is close to 3.14 rad. For this particular injection the service values are:
VOLTAGE = 1.58 kV
CURRENT = 20918 A
R = 1.08%
X = 7.85%
ROTORANG = -3.04 rad

Note that these values identify a point inside the lens characteristic, in the Zone 2, that is close to the boundary between zone 1 and zone 2. The START is issued, but no TRIP is performed.

Execution of the dynamic test
The test may be performed by using two states of a sequence tool that is a basic feature of test sets.

• State 1: pre-test condition.
Steady voltage and current are applied in order to get a steady high impedance, that is a point in the plane R-X that is far away from the lens characteristic. Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

\[ V_u = 1.1 \times V_{r,2} \times \frac{V_{V_1}}{V_{V_2}} = 1.1 \times 1435 \times \frac{0.1}{13.8} = 11.44V \]

(Equation 41)

\[ \angle V_u = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]

(Equation 42)

frequency of \( V_t = 50 \) Hz.
\( I_{50s} = 0 \) A
\( I_{f5s} = 0 \) A

• State 2: main test step.
Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

\[ V_u = 1.1 \times V_{r,2} \times \frac{V_{V_1}}{V_{V_2}} = 1.1 \times 1435 \times \frac{0.1}{13.8} = 11.44V \]

(Equation 43)

\[ \angle V_u = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]

(Equation 44)

frequency of \( V_t = 50 \) Hz
\[ I_{s0} = I_{s0} \times \frac{I_{CT}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162 \text{A} \]  
\hspace{1cm} \text{(Equation 45)}

\[ \angle I_{50s} = 0^\circ \]
frequency of \( I_{50s} = 50 \text{ Hz} \)

\[ I_{f} = I_{f} \times \frac{I_{CT}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162 \text{A} \]  
\hspace{1cm} \text{(Equation 46)}

\[ \angle I_{f5s} = 180^\circ \]
frequency of \( I_{f5s} = 49.5 \text{ Hz} \)

Expected result: start of the protection function and trip in zone 2 when trip conditions are fulfilled.

10.4.5.2 The trajectory of the impedance traverses the lens characteristic in zone 1

Preliminary steady state test at 50 Hz

• Go to Main menu/Test/Function status/Impedance protection/OutOfStep(78, Ucos)/OOSPPAM(78, Ucos):1/Outputs to check the available service values of the function block OOSPPAM.
• Apply the following three-phase symmetrical quantities (the phase angle is related to phase L1):

\[ V_{ts} = 0.9 \times V_{LRZ} \times \frac{V_{V,s}}{V_{V,R}} = 0.9 \times 1435 \times \frac{0.1}{13.8} = 9.36 \text{V} \]  
\hspace{1cm} \text{(Equation 47)}

\[ \angle V_{ts} = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]  
\hspace{1cm} \text{(Equation 48)}

frequency of \( V_{ts} = 50 \text{ Hz} \)

\[ I_{s0} = I_{s0} \times \frac{I_{CT}}{I_{CTp}} = 10459 \times \frac{1}{9000} = 1.162 \text{A} \]  
\hspace{1cm} \text{(Equation 49)}

\[ \angle I_{50s} = 0^\circ \]
frequency of \( I_{50s} = 50 \text{ Hz} \)
It is observed that:

\[ \mathbb{I}_{fs} = 0^\circ \]

frequency of \( I_{fs} = 50 \) Hz

- Check that the service values (VOLTAGE, CURRENT, R(%), X(%)) are according to the injected quantities and that ROTORANG is close to 3.14 rad. For this particular injection the service values are:
  - VOLTAGE = 1.29 kV
  - CURRENT = 20918 A
  - R = 0.89%
  - X = 6.42%
  - ROTORANG = -3.04 rad

Note that these values identify a point inside the lens characteristic in zone 1, that is close to the boundary between zone 1 and zone 2. The START is issued, but no TRIP is performed.

**Execution of the dynamic test**

The test may be performed by using two states of a sequence tool that is a basic feature of test sets.

- State 1: pre-test condition.
  Steady voltage and current are applied in order to get a steady high impedance, that is a point in the plane R-X which is far away from the lens characteristic. Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

\[
V_u = 0.9 \times V_{XZL} \times \frac{V_{V,L}}{V_{T,P}} = 0.9 \times 1435 \times \frac{0.1}{13.8} = 9.36 V
\]

(Equation 51)

\[
\angle V_u = \arctan \left( \frac{ForwardX}{ForwardR} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ
\]

(Equation 52)

frequency of \( V_{fs} = 50 \) Hz

\( I_{50s} = 0 \) A

\( I_{fs} = 0 \) A

- State 2: main test step.
  Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):
\[ V_v = 0.9 \times V_{\text{el},i} \times \frac{V_{\text{vf},i}}{V_{\text{vf},p}} = 0.9 \times 1435 \times \frac{0.1}{13.8} = 9.36V \]  
(Equation 53)

\[ \angle V_v = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]  
(Equation 54)

frequency of \( V_{\text{ts}} \) = 50 Hz

\[ I_{\text{su}} = I_s \times \frac{I_{\text{cp}}}{I_{\text{cp}}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \]  
(Equation 55)

\( \angle I_{50s} = 0^\circ \)

frequency of \( I_{50s} \) = 50 Hz

\[ I_{\text{fp}} = I_f \times \frac{I_{\text{cp}}}{I_{\text{cp}}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \]  
(Equation 56)

\( \angle I_{\text{tf5}} = 180^\circ \)

frequency of \( I_{\text{tf5}} \) = 49.5 Hz

Expected result: start of the protection function and trip in zone 1 when trip conditions are fulfilled.

10.4.6 Test of the point SE \((R_{\text{rvsR}}, X_{\text{rvsX}})\)

10.4.6.1 The trajectory of the impedance traverses the lens characteristic in zone 1

Preliminary steady state test at 50 Hz

- Go to Main menu/Test/Function status/Impedance protection/OutOfStep(78,Ucos)/OOSPPAM(78,Ucos):1/Outputs to check the available service values of the function block OOSPPAM.
- Apply the following three-phase symmetrical quantities (the phase angle is related to phase L1):

\[ V_v = 0.9 \times V_{\text{el},i} \times \frac{V_{\text{vf},i}}{V_{\text{vf},p}} = 0.9 \times 5899 \times \frac{0.1}{13.8} = 38.47V \]  
(Equation 57)
\[ \angle V_o = \arctan \left( \frac{\text{Reverse}V}{\text{Reverse}R} \right) - 180^\circ = \arctan \left( \frac{29.60}{0.29} \right) - 180^\circ = -90.56^\circ \]  

(Equation 58)

frequency of \( V_{ts} = 50 \text{ Hz} \)

\[ I_{s,t} = I_{s} \times \frac{I_{ct,s}}{I_{ct,p}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \]  

(Equation 59)

\( \angle I_{50s} = 0^\circ \)

frequency of \( I_{50s} = 50 \text{ Hz} \)

\[ I_{50s} = I_{50} \times \frac{I_{ct,s}}{I_{ct,p}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \]  

(Equation 60)

\( \angle I_{ts} = 0^\circ \)

frequency of \( I_{ts} = 50 \text{ Hz} \)

• Check that the service values (VOLTAGE, CURRENT, R(%), X(%)) are according to the injected quantities and that ROTORANG is close to \( 3.14 \text{ rad} \). For this particular injection the service values are:
  • VOLTAGE = 5.31 kV
  • CURRENT = 20918 A
  • R = -0.26%
  • X = -26.65%
  • ROTORANG = -3.06 rad

Note that these values identify a point inside the lens characteristic in zone 1 that is close to the point SE. The START is issued, but no TRIP is performed.

**Execution of the dynamic test**
The test may be performed by using two states of a sequence tool that is a basic feature of test sets.

• State 1: pre-test condition.
Steady voltage and current are applied in order to get a steady high impedance, that is a point in the plane R-X which is far away from the lens characteristic. Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

\[ V_u = 0.9 \times V_{v,\text{rad}} \times \frac{V_{V,I}}{V_{V,I,p}} = 0.9 \times 5899 \times \frac{0.1}{13.8} = 38.47 \text{ V} \]  

(Equation 61)
\[-90.56^\circ = \arctan \left( \frac{\text{ReverseX}}{\text{ReverseR}} \right) - 180^\circ = \arctan \left( \frac{29.60}{0.29} \right) - 180^\circ = -90.56^\circ \]

(Equation 62)

- State 2: main test step.
  Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

\[ V_s = 0.9 \times V_{L,\text{bus}} \times \frac{V_{V,s}}{V_{V,p}} = 0.9 \times 5899 \times \frac{0.1}{13.8} = 38.47V \]

(Equation 63)

\[-90.56^\circ = \arctan \left( \frac{\text{ReverseX}}{\text{ReverseR}} \right) - 180^\circ = \arctan \left( \frac{29.60}{0.29} \right) - 180^\circ = -90.56^\circ \]

(Equation 64)

frequency of \( V_{ts} = 50 \) Hz
\( I_{50s} = 0 \) A
\( I_{tfs} = 0 \) A

- Expected result: start of the protection function and trip in zone 1 when trip conditions are fulfilled.
10.4.6.2 The trajectory of the impedance does not enter the lens characteristic

**Preliminary steady state test at 50 Hz**

- Go to `Main menu/Test/Function status/Impedance protection/OutOfStep(78,Ucos)/OOSPPAM(78,Ucos):1/Outputs` to check the available service values of the function block OOSPPAM.
- Apply the following three-phase symmetrical quantities (the phase angle is related to phase L1):

  \[ V_u = 1.1 \times V_{r,rad} \times \frac{V_{ef}}{V_{ef,p}} = 1.1 \times 5899 \times \frac{0.1}{13.8} = 47.02 \text{V} \]

  (Equation 67)

  \[ \angle V_u = \arctan \left( \frac{\text{Reverse}X}{\text{Reverse}R} \right) - 180^\circ = \arctan \left( \frac{29.60}{0.29} \right) - 180^\circ = -90.56^\circ \]

  (Equation 68)

  frequency of \( V_{ts} = 50 \text{ Hz} \)

  \[ I_{so} = I_5 \times \frac{I_{cto}}{I_{ctp}} = 10459 \times \frac{1}{9000} = 1.162 \text{A} \]

  (Equation 69)

  \[ \angle I_{50s} = 0^\circ \]

  frequency of \( I_{50s} = 50 \text{ Hz} \)

  \[ I_{ts} = I_5 \times \frac{I_{cto}}{I_{ctp}} = 10459 \times \frac{1}{9000} = 1.162 \text{A} \]

  (Equation 70)

  \[ \angle I_{ts} = 0^\circ \]

  frequency of \( I_{ts} = 50 \text{ Hz} \)

- Check that the service values (VOLTAGE, CURRENT, R(%), X(%) ) are according to the injected quantities and that ROTORANG is close to 0 rad. For this particular injection the service values are:
  - VOLTAGE = 6.49 kV
  - CURRENT = 20918 A
  - R = -0.32%
  - X = -32.57%
  - ROTORANG = 0.08 rad

Note that these values identify a point outside the lens characteristic, even if it is close to the point SE. Neither START nor TRIP is issued.
Execution of the dynamic test

The test may be performed by using two states of a sequence tool that is a basic feature of test sets.

- State 1: pre-test condition.

  Steady voltage and current are applied in order to get a steady high impedance, that is, a point in the plane R-X which is far away from the lens characteristic. Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

  \[ V_n = 1.1 \times V_{r,\text{ref}} \times \frac{V_{VT}}{V_{VT,p}} = 1.1 \times 5899 \times \frac{0.1}{13.8} = 47.02V \]

  \[ \angle V_n = \arctan \left( \frac{ReverseX}{ReverseR} \right) - 180^\circ = \arctan \left( \frac{29.60}{0.29} \right) - 180^\circ = -90.56^\circ \]

  frequency of \( V_{Is} = 50 \text{ Hz} \)

  \( I_{50s} = 0 \text{ A} \)

  \( I_{tIs} = 0 \text{ A} \)

- State 2: main test step.

  Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

  \[ V_n = 1.1 \times V_{r,\text{ref}} \times \frac{V_{VT}}{V_{VT,p}} = 1.1 \times 5899 \times \frac{0.1}{13.8} = 47.02V \]

  \[ \angle V_n = \arctan \left( \frac{ReverseX}{ReverseR} \right) - 180^\circ = \arctan \left( \frac{29.60}{0.29} \right) - 180^\circ = -90.56^\circ \]

  frequency of \( V_{Is} = 50 \text{ Hz} \)

  \( I_{50s} = 0 \text{ A} \)

  \[ I_{50s} = I_{S0} \times \frac{I_{CT}}{I_{CTP}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \]

  \[ \angle I_{50s} = 0^\circ \]

  frequency of \( I_{50s} = 50 \text{ Hz} \)

  \[ I_{f} = I_{f} \times \frac{I_{CT}}{I_{CTP}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \]
$I_{fs} = 180^\circ$

frequency of $I_{fs} = 50.5$ Hz

Expected result: the protection function does not issue either start or trip.

After each test it is possible to download and study the related disturbance recording.

![Diagram of Boolean output signals for the injected current with two components: a 50 Hz current component and a 49.5 Hz current component](IEC10000142-1-en.vsd)

**Figure 23:** Boolean output signals for the injected current with two components: a 50 Hz current component and a 49.5 Hz current component

### 10.5 Current protection

#### 10.5.1 Four step phase overcurrent protection 3-phase output OC4PTOC (51_67)

Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".
10.5.1.1 Verifying the settings

1. Connect the test set for current injection to the appropriate IED phases. If there is any configuration logic that is used to enable or block any of the four available overcurrent steps, make sure that the step under test is enabled (for example, end fault protection). If 1 out of 3 currents for operation is chosen: Connect the injection current to phases A and neutral. If 2 out of 3 currents for operation is chosen: Connect the injection current into phase A and out from phase B. If 3 out of 3 currents for operation is chosen: Connect the symmetrical three-phase injection current into phases A, B and C.

2. Connect the test set for the appropriate three-phase voltage injection to the IED phases A, B and C. The protection shall be fed with a symmetrical three-phase voltage.

3. Set the injected polarizing voltage slightly larger than the set minimum polarizing voltage (default is 5% of \( V_{Base} \)) and set the injection current to lag the appropriate voltage by an angle of about 80° if forward directional function is selected. If 1 out of 3 currents for operation is chosen: The voltage angle of phase A is the reference. If 2 out of 3 currents for operation is chosen: The voltage angle of phase A – the voltage angle of B is the reference. If 3 out of 3 currents for operation is chosen: The voltage angle of phase A is the reference. If reverse directional function is selected, set the injection current to lag the polarizing voltage by an angle equal to 260° (equal to 80° + 180°).

4. Increase the injected current and note the trip value of the tested step of the function.

5. Decrease the current slowly and note the reset value.

6. If the test has been performed by injection of current in phase A, repeat the test, injecting current into phases B and C with polarizing voltage connected to phases B, respectively C (1 out of 3 currents for operation).

7. If the test has been performed by injection of current in phases AB, repeat the test, injecting current into phases BC and CA with the appropriate phase angle of injected currents.

8. Block higher set stages when testing lower set stages by following the procedure described below.

9. Connect a trip output contact to a timer.

10. Set the injected current to 200% of the operate level of the tested stage, switch on the current and check the time delay. For inverse time curves, check the trip time at a current equal to 110% of the trip current for \( tx_{Min} \).
11. Check that all trip and pickup contacts operate according to the configuration (signal matrixes)
12. Reverse the direction of the injected current and check that the protection does not operate.
13. If 2 out of 3 or 3 out of 3 currents for operation is chosen: Check that the function will not trip with current in one phase only.
14. Repeat the above described tests for the higher set stages.
15. Finally check that pickup and trip information is stored in the event menu.

Verification of the non-directional phase overcurrent function is done as instructed above, without applying any polarizing voltage.

10.5.1.2 Completing the test

Continue to test another function or end the test by changing the TestMode setting to Disabled. Restore connections and settings to their original values, if they were changed for testing purposes.

10.5.2 Four step residual overcurrent protection, (Zero sequence or negative sequence directionality) EF4PTOC (51N/67N)

Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".

10.5.2.1 Four step directional ground fault protection

1. Connect the test set for single current injection to the appropriate IED terminals. Connect the injection current to terminals A and neutral.
2. Set the injected polarizing voltage slightly larger than the set minimum polarizing voltage (default 5% of Vn) and set the injection current to lag the voltage by an angle equal to the set reference characteristic angle (AngleRCA), if the forward directional function is selected.
   If reverse directional function is selected, set the injection current to lag the polarizing voltage by an angle equal to RCA + 180°.
3. Increase the injected current and note the value at which the studied step of the function operates.
4. Decrease the current slowly and note the reset value.
5. If the test has been performed by injection of current in phase A, repeat the test, injecting current into terminals B and C with a polarizing voltage connected to terminals B, respectively C.
6. Block lower set steps when testing higher set steps according to the instructions that follow.
7. Connect a trip output contact to a timer.
8. Set the injected current to 200% of the operate level of the tested step, switch on the current and check the time delay.
   For inverse time curves, check the operate time at a current equal to 110% of the operate current for \( t_{xMin} \).
9. Check that all trip and trip contacts operate according to the configuration (signal matrixes)
10. Reverse the direction of the injected current and check that the step does not operate.
11. Check that the protection does not operate when the polarizing voltage is zero.
12. Repeat the above described tests for the higher set steps.
13. Finally, check that pickup and trip information is stored in the event menu.

10.5.2.2 Four step non-directional ground fault protection

1. Do as described in "Four step directional ground fault protection", but without applying any polarizing voltage.

10.5.3 Completing the test

Continue to test another function or end the test by changing the TestMode setting to Disabled. Restore connections and settings to their original values, if they were changed for testing purposes.

10.5.3 Four step negative sequence overcurrent protection

NS4PTOC (46I2)

Prepare the IED for verification of settings as outlined in section "Requirements" and section "Preparing for test" in this chapter.

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.
1. Connect the test set for injection of three-phase currents and voltages to the appropriate CT and VT inputs of the IED.

2. Inject pure negative sequence current, that is, phase currents with exactly same magnitude, reversed sequence and exactly 120° phase displaced into the IED with an initial value below negative sequence current pickup level. No output signals should be activated. Check under NS4PTOC function Service Values that correct I2 magnitude is measured by the function.

3. Set the injected negative sequence polarizing voltage slightly larger than the set minimum polarizing voltage (default 5 % of Vn) and set the injection current to lag the voltage by an angle equal to the set reference characteristic angle ($180° - \text{AngleRCA}$) if the forward directional function is selected. If reverse directional function is selected, set the injection current to lag the polarizing voltage by an angle equal to RCA.

4. Increase the injected current and note the value at which the studied step of the function operates.

5. Decrease the current slowly and note the reset value.

6. Block lower set steps when testing higher set steps according to the instructions that follow.

7. Connect a trip output contact to a timer.

8. Set the injected current to 200% of the operate level of the tested step, switch on the current and check the time delay. For inverse time curves, check the operate time at a current equal to 110% of the operate current in order to test parameter $txmin$.

9. Check that all trip and pickup contacts operate according to the configuration (signal matrixes)

10. Reverse the direction of the injected current and check that the step does not operate.

11. Check that the protection does not operate when the polarizing voltage is zero.

12. Repeat the above-described tests for the higher set steps.

13. Finally, check that pickup and trip information is stored in the event menu.

10.5.3.1 Completing the test

Continue to test another function or end the test by changing the TestMode setting to Disabled. Restore connections and settings to their original values, if they were changed for testing purposes.

10.5.4 Sensitive directional residual overcurrent and power protection SDEPSDE (67N)

Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".
Values of the logical signals belonging to the sensitive directional residual overcurrent and power protection are available on the local HMI under **Main menu/Test/Function status/Current protection/SensDirResOvCurr(67N,IN>)/SDEPSDE(67N,IN>):x**

### 10.5.4.1 Measuring the operate and time limit for set values

**Operation mode 3I₀ · cosφ**

**Procedure**

1. Set the polarizing voltage to 1.2 · VNRelPU and set the phase angle between voltage and current to the set characteristic angle (RCADir). Note that the current lagging the voltage. Take setting RCAComp into consideration if not equal to 0.
2. Inject current until the function picks up, and make sure that the operate current of the set directional element is equal to the INcosPhiPU setting. The I Dir (3I₀ · cosφ) function activates the PICKUP and PUNDIN output.
3. Assume that φ’ is the phase angle between injected voltage (3V₀) and current (3I₀) i.e. φ’ = RCADir-φ. Change φ’ to for example 45 degrees. Increase the injected current until the function operates.
4. Compare the result with the set value and make sure that the new injected \(3I_0 \cdot \cos \phi\) is equal to the setting \(IN_{cosPhiPU}\).
   Take the set characteristic into consideration, see Figure 25 and Figure 26.
5. Measure the operate time of the timer by injecting a current two times the set \(IN_{cosPhiPU}\) value and the polarizing voltage \(1.2 \cdot VN_{RelPU}\).
   \[
   T_{inv} = \frac{TDSN \cdot SRef}{3I_0 \cdot 3V_{test} \cdot \cos(\phi)}
   \]
   (Equation 77)
6. Compare the result with the expected value.
   The expected value depends on whether definite or inverse time was selected.
7. Set the polarizing voltage to zero and increase until the boolean output signal UNREL is activated, which is visible in the Application Configuration in PCM600 when the IED is in online mode. Compare the voltage with the set value \(VN_{RelPU}\).
8. Continue to test another function or complete the test by setting the test mode to Disabled.
Figure 25: Characteristic with ROAdir restriction
Operation mode $3I_0 \cdot 3V_0 \cdot \cos \varphi$

1. Set the polarizing voltage to $1.2 \cdot VN_{RelPU}$ and set the phase angle between voltage and current to the set characteristic angle ($RCADir$). Note that the current lagging the voltage.

2. Inject current until the function picks up, and make sure that the operate power is equal to the $SN_{PU}$ setting for the set directional element. Note that for pick-up, both the injected current and voltage must be greater than the set values $IN_{RelPU}$ and $VN_{RelPU}$ respectively. The function activates the PICKUP and PUDIRIN outputs.

3. Assume that $\varphi'$ is the phase angle between injected voltage ($3V_0$) and current ($3I_0$) i.e. $\varphi' = RCADir - \varphi$. Change $\varphi'$ to for example 45 degrees. Increase the injected current until the function operates.
4. Compare the result with the set value and make sure that the new injected $3I_0 \cdot 3V_0 \cdot \cos \phi$ is equal to the setting $SN\_PU$. Take the set characteristic into consideration, see figure 25 and figure 26.

5. Measure the trip time of the timer by injecting $1.2 \cdot VNRelPU$ and a current to get two times the set $SN\_PU$ trip value.

\[
T_{inv} = \frac{TDSN \cdot SRef}{\sqrt{3}} \cdot 3V_{0\text{test}} \cdot \cos(\phi)
\]

(Equation 78)

6. Compare the result with the expected value.
The expected value depends on whether definite or inverse time was selected.

7. Continue to test another function or complete the test by setting the test mode to Disabled.

**Operation mode $3I_0$ and $\phi$**

1. Set the polarizing voltage to $1.2 \cdot VNRelPU$ and set the phase angle between voltage and current to the set characteristic angle ($RCADir$). Note that the current lagging the voltage.

2. Inject current until the function picks up, and make sure that the operate current is equal to the $INRelPU$ setting for the set directional element.

Note that for pickup, both the injected current and voltage must be greater than the set values $INRelPU$ and $VNRelPU$ respectively.

The function activates the PICKUP and PUDIRIN output.

3. Measure with angles $\phi$ around $RCADir \pm ROADir$.

4. Compare the result with the set values, refer to figure 27 for example characteristic.

5. Measure the trip time of the timer by injecting a current to get two times the set $SN\_PU$ trip value.

\[
T_{inv} = \frac{TDSN \cdot SRef}{3I_{0\text{test}}} \cdot 3V_{0\text{test}} \cdot \cos(\phi)
\]

(Equation 79)

6. Compare the result with the expected value.
The expected value depends on whether definite or inverse time was selected.

7. Continue to test another function or complete the test by setting the test mode to Disabled.
Non-directional ground fault current protection
Procedure

1. Measure that the operate current is equal to the $IN_{NonDirPU}$ setting.
   The function activates the PICKUP and PUDIRIN output.
2. Measure the trip time of the timer by injecting a current of 200% of the trip value.
3. Compare the result with the expected value.
   The expected value depends on whether definite time $t_{IN_{NonDir}}$ or inverse time was selected.
4. Continue to test another function or complete the test by setting the test mode to Disabled.

Residual overvoltage release and protection
Procedure

1. Measure that the trip voltage is equal to the $VN_{PU}$ setting.
   The function activates the PICKUP and PUVN signals.
2. Measure the operate time by injecting a voltage 1.2 times set $VN_{PU}$ trip value.
3. Compare the result with the set $t_{VN}$ trip value.
4. Inject a voltage $0.8 \cdot VNRelPU$ and a current high enough to trip the directional function at the chosen angle.
5. Increase the voltage until the directional function is released.
6. Compare the measured value with the set $VNRelPU$ trip value.

10.5.4.2 Completing the test

Continue to test another function or end the test by changing the TestMode setting to Disabled. Restore connections and settings to their original values, if they were changed for testing purposes.

10.5.5 Thermal overload protection, one time constant, Fahrenheit/ Celsius LFPTTR/LCPTTR (26)

Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".

Check that the input logical signal BLOCK is logical zero and that on the local HMI, the logical signal TRIP, PICKUP and ALARM are equal to logical zero.

10.5.5.1 Measuring the operate and time limit of set values

Testing the protection without external temperature compensation (NonComp)

1. Quickly set the measured current (fault current) in one phase to about 300% of $IRef$ (to minimise the trip time), and switch the current off.
2. Reset the thermal memory on the local HMI under Main menu/Reset/Reset temperature/ThermalOverload1TimeConst(PTRR,26)/LFPTTR:x, Main menu/Reset/Reset temperature/ThermalOverload1TimeConst(PTRR,26)/LCPTTR:x,
3. Switch the fault current on and take note of the temperature, available on the local HMI under Main menu/Test/Function status/Current protection/ThermOverLoad1TimeConst(PTRR,26)/LFPTTR:x/TEMP, Main menu/Test/Function status/Current protection/ThermOverLoad1TimeConst(PTRR,26)/LCPTTR:x/TEMP,
4. Check the time until the actual temperature TEMP has reached the AlarmTemp level during injection.
Monitor the signal ALARM until it appears on the corresponding binary output or on the local HMI.
5. Measure the LFPTTR/LCPTTR (26) protection trip time.
Use the TRIP signal from the configured binary output to stop the timer.
6. Take the TEMP readings.
   Compare with the setting of TripTemp.
7. Activate the BLOCK binary input.
   The signals ALARM, PICKUP and TRIP should disappear.
8. Reset the BLOCK binary input.
9. Check the reset limit (TdReset).
   Monitor the signal PICKUP until it disappears on the corresponding binary output
   or on the local HMI, take the TEMP readings and compare with the setting of
   ReclTemp.
10. Compare the measured trip time with the setting according to the formula.
11. Reset the thermal memory.
12. Continue to test another function or end the test by changing the test mode setting
    to Disabled.

10.5.5.2 Completing the test

Continue to test another function or end the test by changing the TestMode setting to
Disabled. Restore connections and settings to their original values, if they were
changed for testing purposes.

10.5.6 Directional underpower protection GUPPDUP (37)

Prepare the IED for verification of settings outlined in section "Preparing the IED to
verify settings".

10.5.6.1 Verifying the settings

The underpower protection shall be set to values according to the real set values to be
used.

The test is made by means of injection of voltage and current where the amplitude of
both current and voltage and the phase angle between the voltage and current can be
controlled. During the test, the analog outputs of active and reactive power shall be
monitored.

1. Connect the test set for injection of voltage and current corresponding to the
   mode to be used in the application. If a three-phase test set is available this could
   be used for all the modes. If a single-phase current/voltage test set is available the
   test set should be connected to a selected input for one-phase current and voltage.
### Table 6: Calculation modes

<table>
<thead>
<tr>
<th>Set value: Mode</th>
<th>Formula used for complex power calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A, B, C</td>
<td>$S = \overline{V}_A \cdot \overline{I}_A^* + \overline{V}_B \cdot \overline{I}_B^* + \overline{V}_C \cdot \overline{I}_C^*$</td>
</tr>
<tr>
<td>Arone</td>
<td>$S = \overline{V}_{AB} \cdot \overline{I}<em>A^* - \overline{V}</em>{BC} \cdot \overline{I}_C^*$</td>
</tr>
<tr>
<td>PosSeq</td>
<td>$S = 3 \cdot \overline{V}<em>{PosSeq} \cdot \overline{I}</em>{PosSeq}^*$</td>
</tr>
<tr>
<td>AB</td>
<td>$S = \overline{V}_{AB} \cdot (\overline{I}_A^* - \overline{I}_B^*)$</td>
</tr>
<tr>
<td>BC</td>
<td>$S = \overline{V}_{BC} \cdot (\overline{I}_B^* - \overline{I}_C^*)$</td>
</tr>
<tr>
<td>CA</td>
<td>$S = \overline{V}_{CA} \cdot (\overline{I}_C^* - \overline{I}_A^*)$</td>
</tr>
<tr>
<td>A</td>
<td>$S = 3 \cdot \overline{V}_A \cdot \overline{I}_A^*$</td>
</tr>
<tr>
<td>B</td>
<td>$S = 3 \cdot \overline{V}_B \cdot \overline{I}_B^*$</td>
</tr>
<tr>
<td>C</td>
<td>$S = 3 \cdot \overline{V}_C \cdot \overline{I}_C^*$</td>
</tr>
</tbody>
</table>

2. Adjust the injected current and voltage to the set values in % of $IBase$ and $VBase$ (converted to secondary current and voltage). The angle between the injected current and voltage shall be set equal to the set direction $Angle1$, angle for stage 1 (equal to $0^\circ$ for low forward power protection and equal to $180^\circ$ for reverse...
power protection). Check that the monitored active power is equal to 100% of rated power and that the reactive power is equal to 0% of rated power.

3. Change the angle between the injected current and voltage to \(\text{Angle1} + 90^\circ\). Check that the monitored active power is equal to 0% of rated power and that the reactive power is equal to 100% of rated power.

4. Change the angle between the injected current and voltage back to 0°. Decrease the current slowly until the PICKUP1 signal, pickup of stage 1, is activated.

5. Increase the current to 100% of \(IBase\).

6. Switch the current off and measure the time for activation of TRIP1, trip of stage 1.

7. If a second stage is used, repeat steps 2 to 6 for the second stage.

10.5.6.2 Completing the test

Continue to test another function or end the test by changing the \(TestMode\) setting to \(Disabled\). Restore connections and settings to their original values, if they were changed for testing purposes.

10.5.7 Directional overpower protection GOPPDOP (32)

Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".

10.5.7.1 Verifying the settings

The overpower protection shall be set to values according to the real set values to be used. The test is made by means of injection of voltage and current where the amplitude of both current and voltage and the phase angle between the voltage and current can be controlled. During the test the analog outputs of active and reactive power shall be monitored.

1. Connect the test set for injection of voltage and current corresponding to the mode to be used in the application. If a three phase test set is available this could be used for all the modes. If a single phase current/voltage test set is available the test set should be connected to a selected input for one phase current and voltage.

2. Adjust the injected current and voltage to the set rated values in % of \(IBase\) and \(VBase\) (converted to secondary current and voltage). The angle between the injected current and voltage shall be set equal to the set direction \(\text{Angle1}\), angle for stage 1 (equal to 0° for low forward power protection and equal to 180° for
reverse power protection). Check that the monitored active power is equal to 100% of rated power and that the reactive power is equal to 0% of rated power.

3. Change the angle between the injected current and voltage to $\text{Angle1} + 90^\circ$.
Check that the monitored active power is equal to 0% of rated power and that the reactive power is equal to 100% of rated power.

4. Change the angle between the injected current and voltage back to $\text{Angle1}$ value.
Increase the current slowly from 0 until the PICKUP1 signal, pickup of stage 1, is activated. Check the injected power and compare it to the set value $\text{Power1}$, power setting for stage 1 in % of $S_{\text{base}}$.

5. Increase the current to 100% of $I_{\text{base}}$ and switch the current off.

6. Switch the current on and measure the time for activation of TRIP1, trip of stage 1.

7. If a second stage is used, repeat steps 2 to 6 for the second stage.

10.5.7.2 Completing the test

Continue to test another function or end the test by changing the TestMode setting to Disabled. Restore connections and settings to their original values, if they were changed for testing purposes.

10.6 Voltage protection

10.6.1 Two step undervoltage protection UV2PTUV (27)

Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".

10.6.1.1 Verifying the settings

Verification of PICKUP value and time delay to operate for Step 1

1. Check that the IED settings are appropriate, especially the PICKUP value, the definite time delay and the 1 out of 3 operation mode.
2. Supply the IED with three-phase voltages at their rated values.
3. Slowly decrease the voltage in one of the phases, until the PICKUP signal appears.
4. Note the operate value and compare it with the set value.

The operate value in secondary volts is calculated according to the following equations:

For phase-to-ground measurement:
\[
\frac{V_{\text{pickup}}}{100} < \frac{V_{\text{Base}} \times VT_{\text{sec}}}{\sqrt{3} \times VT_{\text{prim}}}
\]

(Equation 89)

For phase-to-phase measurement:

\[
\frac{V_{\text{pickup}}}{100} < \frac{V_{\text{Base}} \times VT_{\text{sec}}}{VT_{\text{prim}}}
\]

(Equation 90)

5. Increase the measured voltage to rated load conditions.
6. Check that the PICKUP signal resets.
7. Instantaneously decrease the voltage in one phase to a value about 20% lower than the measured operate value.
8. Measure the time delay for the TRIP signal, and compare it with the set value.
9. Check the inverse time delay by injecting a voltage corresponding to \(0.8 \times V_{\text{pickup}}\).

For example, if the inverse time curve A is selected, the trip signals TRST1 and TRIP operate after a time corresponding to the equation:

\[
t(s) = \frac{TD1}{\left(1 - \frac{V}{V_{\text{pickup}}<}\right)}
\]

(Equation 91)

where:
- \(t(s)\): Operate time in seconds
- \(TD1\): Settable time multiplier of the function for step 1
- \(V\): Measured voltage
- \(V_{\text{pickup}}<\): Set pickup voltage for step 1

For example, if the measured voltage jumps from the rated value to 0.8 times the set pickup voltage level and time multiplier TD1 is set to 0.05 s (default value), then the TRST1 and TRIP signals operate at a time equal to 0.250 s ± tolerance.

10. The test above can be repeated to check the inverse time characteristic at different voltage levels.
11. Repeat the above-described steps for Step 2 of the function.

**Extended testing**

The tests above can be repeated for 2 out of 3 and for 3 out of 3 operation mode.
10.6.1.2 Completing the test

Continue to test another function or end the test by changing the TestMode setting to Disabled. Restore connections and settings to their original values, if they were changed for testing purposes.

10.6.2 Two step overvoltage protection OV2PTOV (59)

Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".

10.6.2.1 Verifying the settings

Verification of single-phase voltage and time delay to operate for Step 1

1. Apply single-phase voltage below the set value Pickup1.
2. Slowly increase the voltage until the PU_ST1 signal appears.
3. Note the operate value and compare it with the set value.

The operate value in secondary volts is calculated according to the following equations:

For phase-to-ground measurement:

\[
V_{\text{pickup}} > \frac{V_{\text{Base}} \times VT_{\text{sec}}}{\sqrt{3}} \times VT_{\text{prim}}
\]

(Equation 92)

For phase-to-phase measurement:

\[
V_{\text{pickup}} > \frac{V_{\text{Base}} \times VT_{\text{sec}}}{V_{\text{prim}}}
\]

(Equation 93)

4. Decrease the voltage slowly and note the reset value.
5. Set and apply about 20% higher voltage than the measured operate value for one phase.
6. Measure the time delay for the TRST1 signal and compare it with the set value.
7. Check the inverse time delay by injecting a voltage corresponding to 1.2 × V_{\text{pickup}}.
For example, if the inverse time curve A is selected, the trip signals TRST1 and TRIP operate after a time corresponding to the equation:

\[
t(s) = \frac{TD1}{V - V\text{pickup}}
\]

(Equation 94)

where:
- \(t\) (s) Operate time in seconds
- \(TD1\) Settable time multiplier of the function for step 1
- \(V\) Measured voltage
- \(V\text{pickup}\) Set pickup voltage for step 1

For example, if the measured voltage jumps from 0 to 1.2 times the set pickup voltage level and time multiplier \(TD1\) is set to 0.05 s (default value), then the TRST1 and TRIP signals operate at a time equal to 0.250 s ± tolerance.

8. The test above can be repeated to check the inverse time characteristic at different voltage levels.

9. Repeat the above-described steps for Step 2 of the function.

10.6.2.2 Extended testing

1. The tests above can be repeated for 2 out of 3 and for 3 out of 3 operation mode.

10.6.2.3 Completing the test

Continue to test another function or end the test by changing the TestMode setting to Disabled. Restore connections and settings to their original values, if they were changed for testing purposes.
10.7 Frequency protection

10.7.1 Underfrequency protection SAPTUF (81)

Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".

10.7.1.1 Verifying the settings

Verification of PICKUP value and time delay to trip

1. Check that the IED settings are appropriate, for example the PICKUP value and the time delay.
2. Supply the IED with three-phase voltages at their rated values.
3. Slowly decrease the frequency of the applied voltage, until the PICKUP signal appears.
4. Note the trip value and compare it with the set value.
5. Increase the frequency until rated operating levels are reached.
6. Check that the PICKUP signal resets.
7. Instantaneously decrease the frequency of the applied voltage to a value about 1% lower than the trip value (a step change more than 2% will increase the time delay).
8. Measure the time delay of the TRIP signal, and compare it with the set value. Note that the measured time consists of the set value for time delay plus minimum trip time of the pickup start function (80 - 90 ms).

Extended testing

1. The test above can be repeated to check the time to reset.
2. The tests above can be repeated to test the frequency dependent inverse time characteristic.

Verification of the low voltage magnitude blocking

1. Check that the IED settings are appropriate, for example the PUFrequency, VMin, and the tDelay.
2. Supply the IED with three-phase voltages at rated values.
3. Slowly decrease the magnitude of the applied voltage, until the BLKDMAGN signal appears.
4. Note the voltage magnitude value and compare it with the set value VMin.
5. Slowly decrease the frequency of the applied voltage, to a value below \textit{PUFrequency}.
6. Check that the PICKUP signal does not appear.
7. Wait for a time corresponding to \textit{tDelay}, make sure that the TRIP signal does not appear.

\section*{10.7.1.2 Completing the test}

Continue to test another function or end the test by changing the \textit{TestMode} setting to \textit{Disabled}. Restore connections and settings to their original values, if they were changed for testing purposes.

\section*{10.7.2 Overfrequency protection SAPTOF (81)}

Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".

\subsection*{10.7.2.1 Verifying the settings}

\textbf{Verification of PICKUP value and time delay to trip}

1. Check that the settings in the IED are appropriate, for example the PICKUP value and the time delay.
2. Supply the IED with three-phase voltages at their rated values.
3. Slowly increase the frequency of the applied voltage, until the PICKUP signal appears.
4. Note the trip value and compare it with the set value.
5. Decrease the frequency to rated operating conditions.
6. Check that the PICKUP signal resets.
7. Instantaneously increase the frequency of the applied voltage to a value about 1\% lower than the trip value (a step change more than 2\% will increase the time delay).
8. Measure the time delay for the TRIP signal, and compare it with the set value.
   Note that the measured time consists of the set value for time delay plus minimum trip time of the pickup function (80 - 90 ms).

\textbf{Extended testing}

1. The test above can be repeated to check the time to reset.

\textbf{Verification of the low voltage magnitude blocking}
1. Check that the settings in the IED are appropriate, for example the \textit{PUFrequency}, \textit{VMin}, and the \textit{tDelay}.
2. Supply the IED with three-phase voltages at their rated values.
3. Slowly decrease the magnitude of the applied voltage, until the BLKDMAGN signal appears.
4. Note the voltage magnitude value and compare it with the set value, \textit{VMin}.
5. Slowly increase the frequency of the applied voltage, to a value above \textit{PUFrequency}.
6. Check that the PICKUP signal does not appear.
7. Wait for a time corresponding to \textit{tDelay}, make sure that the TRIP signal does not appear.

10.7.2.2 Completing the test

Continue to test another function or end the test by changing the \textit{TestMode} setting to \textit{Disabled}. Restore connections and settings to their original values, if they were changed for testing purposes.

10.7.3 Rate-of-change frequency protection SAPFRC (81)

Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".

10.7.3.1 Verifying the settings

PICKUP value and time delay to operate

1. Check that the settings in the IED are appropriate, especially the PICKUP value and the definite time delay. Set \textit{PickupFreqgrad}, to a rather small negative value.
2. Supply the IED with three-phase voltages at their rated values.
3. Slowly decrease the frequency of the applied voltage, with an increasing rate-of-change that finally exceeds the setting of \textit{PickupFreqgrad}, and check that the PICKUP signal appears.
4. Note the operate value and compare it with the set value.
5. Increase the frequency to rated operating conditions, and zero rate-of-change.
6. Check that the PICKUP signal resets.
7. Instantaneously decrease the frequency of the applied voltage to a value about 20\% lower than the nominal value.
8. Measure the time delay for the TRIP signal, and compare it with the set value.

Extended testing
1. The test above can be repeated to check a positive setting of \textit{PickupFreqGrad}.
2. The tests above can be repeated to check the time to reset.
3. The tests above can be repeated to test the RESTORE signal, when the frequency recovers from a low value.

10.7.3.2 Completing the test

Continue to test another function or end the test by changing the \textit{TestMode} setting to \textit{Disabled}. Restore connections and settings to their original values, if they were changed for testing purposes.

10.7.4 Frequency time accumulation protection function FTAQFVR (81A)

Prepare the IED for verification of settings as outlined in section “Overview” and section “Preparing for test” in this chapter.

10.7.4.1 Verifying the settings

Time measurement and the injection of current and voltage can be done using a common test equipment.

\textbf{Verification of the PICKUP value and time delay to operation}

1. Connect the test set for the injection of three-phase currents and three-phase voltages to the appropriate current and voltage terminals of the IED.
2. Ensure that the settings in the IED are appropriate, especially the \textit{PickupCurrentLevel, FreqHighLimit, FreqLowLimit, VHighLimit} and \textit{VLowLimit} setting.
3. Supply the IED with three-phase currents and voltages at their rated value.
4. Slowly decrease the frequency of the applied voltage until it crosses the frequency high limit and the \textit{BFI_3P} signal appears.
5. Check that the \textit{FREQOK} signal appears.
6. Compare the operate value to the set frequency high limit value.
7. Decrease the frequency of the applied voltage until it crosses the frequency low limit and the \textit{BFI_3P} signal disappears.
8. Check that the \textit{FREQOK} signal disappears.
9. Compare the reset value to the set frequency low limit value.
10. Readjust the frequency of the applied voltage (with steps of 0.001 Hz/s) to a value within the set frequency band limit.
11. Ensure that the BFI_3P signal reappears.
12. Wait for a time corresponding to \( t_{Cont} \) and ensure that the TRIP and TRIPCONT signals are generated.
13. Measure the time delay for the TRIP signal and compare it to the set value.

**Verification of the ACCALARM value and time delay to trip**

1. Connect the test set for the injection of three-phase currents and three-phase voltages to the appropriate current and voltage terminals of the IED.
2. Ensure that the settings in the IED are appropriate for the default settings, especially the PickupCurrentLevel, FreqHighLimit, FreqLowLimit, VHighLimit and VLowLimit setting.
3. Supply the IED with three-phase currents and voltages at their rated value.
4. Slowly decrease the frequency of the applied voltage until it crosses the frequency high limit and the BFI_3P signal appears.
5. Continuously change the frequency of the applied voltage, so that for a certain time the frequency is outside the set band limit and falls gradually within the band limit.
6. Count only the time when the frequency lies within the set frequency band limit. Wait for a time corresponding to \( t_{AccLimit} \) and ensure that the ACCALARM signal appears.
7. Measure the time delay for the ACCALARM signal and compare it to the set value.

**Extended testing**

1. To check the value of TRIPACC, repeat the above test case in such a way that the frequency of the applied voltage is within the set frequency band when time approaches the \( t_{AccLimit} \) setting value.

**Verification of generator start and stop logic**

1. Ensure that the settings in the IED are appropriate to the default settings, especially the PickupCurrentLevel, FreqHighLimit, FreqLowLimit, VHighLimit and VLowLimit.
2. Ensure that the setting CBCheck is enabled.
3. Supply the IED with three-phase currents and voltages at their rated values.
4. Slowly decrease the frequency of the applied voltage until the BFI_3P signal appears.
5. Activate the CBOPEN input signal.
6. Slowly decrease the injected current below the PickupCurrentLevel value until the BFI_3P signal disappears.
7. Compare the current magnitude value to the set value.
Verification of voltage band limit check logic

1. Ensure that the settings in the IED are appropriate to the default settings, especially the *PickupCurrentLevel*, *FreqHighLimit*, *FreqLowLimit*, *VHighLimit* and *VLowLimit* settings.
2. Ensure that the *EnaVoltCheck* is enabled.
3. Supply the IED with three-phase currents and voltages at their rated values.
4. Check that the *VOLTOK* signal appears.
5. Slowly decrease the frequency of the applied voltage until the *BFI_3P* signal appears.
6. Slowly decrease the positive-sequence voltage of the injected voltage below the *VLowLimit* value until the *BFI_3P* signal disappears.
7. Check that the *VOLTOK* signal disappears.
8. Compare the reset value to the set voltage low limit value.
9. Readjust the positive-sequence voltage of the applied voltage to a value within the set voltage band limits.
10. Check that the *BFI_3P* signal reappears.
11. Slowly increase the positive-sequence voltage of the injected voltage above the *VUHighLimit* value until the *BFI_3P* signal disappears.
12. Compare the reset value to the set voltage high limit value.

10.7.4.2 Completing the test

- Continue to test another function or end the test by changing the *Test mode* setting to *Disabled*.
- Restore connections and settings to their original values if they were changed for testing purposes.

10.8 Multipurpose protection

10.8.1 General current and voltage protection CVGAPC

Prepare the IED for verification of settings as outlined in section "Requirements" and section "Preparing for test" in this chapter.

One of the new facilities within the general current and voltage protection function CVGAPC is that the value, which is processed and used for evaluation in the function, can be chosen in many different ways by the setting parameters *CurrentInput* and *VoltageInput*.

These setting parameters decide what kind of preprocessing the connected three-phase CT and VT inputs shall be subjected to. That is, for example, single-phase quantities,
phase-to-phase quantities, positive sequence quantities, negative sequence quantities, maximum quantity from the three-phase group, minimum quantity from the three-phase group, difference between maximum and minimum quantities (unbalance) can be derived and then used in the function.

Due to the versatile possibilities of CVGAPC itself, but also the possibilities of logic combinations in the application configuration of outputs from more than one CVGAPC function block, it is hardly possible to define a fully covering general commissioning test.

10.8.1.1 Built-in overcurrent feature (non-directional)

Procedure

1. Go to Main menu/Test/Function test modes/Multipurpose protection/GeneralCurrentVoltage(GAPC)/CVGAPC:x and make sure that CVGAPC to be tested is unblocked and other functions that might disturb the evaluation of the test are blocked.
2. Connect the test set for injection of three-phase currents to the appropriate current terminals of the IED in the 670 series.
3. Inject current(s) in a way that relevant measured current (according to setting parameter CurrentInput) is created from the test set. Increase the current(s) until the low set stage operates and check against the set operate value.
4. Decrease the current slowly and check the reset value.
5. Block high set stage if the injection current will activate the high set stage when testing the low set stage according to below.
6. Connect a TRIP output contact to the timer.
7. Set the current to 200% of the operate value of low set stage, switch on the current and check the time delay.
   For inverse time curves, check the operate time at a current equal to 110% of the operate current at t_MinTripDelay.
8. Check that TRIP and PICKUP contacts operate according to the configuration logic.
9. Release the blocking of the high set stage and check the operate and reset value and the time delay for the high set stage in the same way as for the low set stage.
10. Finally check that PICKUP and TRIP information is stored in the event menu.

Information on how to use the event menu is found in the operator's manual.
10.8.1.2  **Overcurrent feature with current restraint**

The current restraining value has also to be measured or calculated and the influence on the operation has to be calculated when the testing of the operate value is done.

**Procedure**

1. Operate value measurement
   The current restraining value has also to be measured or calculated and the influence on the operation has to be calculated when the testing of the operate value is done.

10.8.1.3  **Overcurrent feature with voltage restraint**

**Procedure**

1. Connect the test set for injection of three-phase currents and three-phase voltages to the appropriate current and voltage terminals of the IED.
2. Inject current(s) and voltage(s) in a way that relevant measured (according to setting parameter `CurrentInput` and `VoltageInput`) currents and voltages are created from the test set.
   Overall check in principal as above (non-directional overcurrent feature)
3. Operate value measurement
   The relevant voltage restraining value (according to setting parameter `VoltageInput`) has also to be injected from the test set and the influence on the operate value has to be calculated when testing of the operate value is done.
4. Operate time measurement
   Definite times may be tested as above (non-directional overcurrent feature). For inverse time characteristics the PICKUP value (to which the overcurrent ratio has to be calculated) is the actual pickup value as got with actual restraining from the voltage restraining quantity.

10.8.1.4  **Overcurrent feature with directionality**

Please note that the directional characteristic can be set in two different ways either just dependent on the angle between current and polarizing voltage (setting parameter `DirPrinc_OC1` or `DirPrinc_OC2` set to or in a way that the operate value also is dependent on the angle between current and polarizing voltage according to the \( I \cdot \cos(\Phi) \) law (setting parameter `DirPrinc_OC1` or `DirPrinc_OC2` set to \( I \cdot \cos(\Phi) \)). This has to be known if a more detailed measurement of the directional characteristic is made, than the one described below.

**Procedure**
1. Connect the test set for injection of three-phase currents and three-phase voltages to the appropriate current and voltage terminals of the IED.

2. Inject current(s) and voltage(s) in a way that relevant measured (according to setting parameter CurrentInput and VoltageInput) currents and voltages are created from the test set.

3. Set the relevant measuring quantity current to lag or lead (lag for negative RCA angle and lead for positive RCA angle) the relevant polarizing quantity voltage by an angle equal to the set IED characteristic angle (rca-dir) when forward directional feature is selected and the CTWYEpont configuration parameter is set to ToObject.

If reverse directional feature is selected or CTWYEpont configuration parameter is set to FromObject, the angle between current and polarizing voltage shall be set equal to rca-dir+180°.

4. Overall check in principal as above (non-directional overcurrent feature)

5. Reverse the direction of the injection current and check that the protection does not operate.

6. Check with low polarization voltage that the feature becomes non-directional, blocked or with memory according to the setting.

10.8.1.5 Over/Undervoltage feature

Procedure

1. Connect the test set for injection three-phase voltages to the appropriate voltage terminals of the IED.

2. Inject voltage(s) in a way that relevant measured (according to setting parameter VoltageInput) voltages are created from the test set.

3. Overall check in principal as above (non-directional overcurrent feature) and correspondingly for the undervoltage feature.

10.8.1.6 Completing the test

Continue to test another function or end the test by changing the TestMode setting to Disabled. Restore connections and settings to their original values, if they were changed for testing purposes.
10.9 Secondary system supervision

10.9.1 Current circuit supervision CCSSPVC (87)

Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".

The Current circuit supervision function CCSSPVC (87) is conveniently tested with the same three-phase test set as used when testing the measuring functions in the IED.

The condition for this procedure is that the setting of $I_{minOp}$ is lower than the setting of $Pickup\_Block$.

10.9.1.1 Verifying the settings

1. Check the input circuits and the operate value of the $I_{minOp}$ current level detector by injecting current, one phase at a time.
2. Check the phase current blocking function for all three phases by injecting current, one phase at a time. The output signals shall reset with a delay of 1 second when the current exceeds $1.5 \cdot I_{Base}$.
3. Inject a current $0.1 \cdot I_{Base}$ to the reference current input Analogue channel ID current input 5.
4. Increase slowly the current in one of the phases current input and check that FAIL output is obtained when the current is about $0.9 \cdot I_{Base}$.

10.9.1.2 Completing the test

Continue to test another function or end the test by changing the TestMode setting to Disabled. Restore connections and settings to their original values, if they were changed for testing purposes.

10.9.2 Fuse failure supervision FUFSPVC

Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".

The verification is divided in two main parts. The first part is common to all fuse failure supervision options, and checks that binary inputs and outputs operate as expected according to actual configuration. In the second part the relevant set operate values are measured.
10.9.2.1 Checking that the binary inputs and outputs operate as expected

1. Simulate normal operating conditions with the three-phase currents in phase with their corresponding phase voltages and with all of them equal to their rated values.
2. Connect the nominal dc voltage to the 89bS binary input.
   • The signal BLKV should appear with almost no time delay.
   • The signals BLKZ and 3PH should not appear on the IED.
   • Only the distance protection function can operate.
   • Undervoltage-dependent functions must not operate.
3. Disconnect the dc voltage from the 89b binary input terminal.
4. Connect the nominal dc voltage to the MCBOP binary input.
   • The BLKV and BLKZ signals should appear without any time delay.
   • All undervoltage-dependent functions must be blocked.
5. Disconnect the dc voltage from the MCBOP binary input terminal.
6. Disconnect one of the phase voltages and observe the logical output signals on the binary outputs of the IED.
   BLKV and BLKZ signals should appear simultaneously wether the BLKV and BLKZ reset depends on the setting \textit{SealIn} “on” or “off”. If “on” no reset, if “off” reset.
7. After more than 5 seconds disconnect the remaining two-phase voltages and all three currents.
   • There should be no change in the high status of the output signals BLKV and BLKZ.
   • The signal 3PH will appear.
8. Establish normal voltage and current operating conditions simultaneously and observe the corresponding output signals.
   They should change to logical 0 as follows:
   • Signal 3PH after about 25ms
   • Signal BLKV after about 50ms
   • Signal BLKZ after about 200ms

10.9.2.2 Measuring the operate value for the negative sequence function

Measure the operate value for the negative sequence function, if included in the IED.
1. Simulate normal operating conditions with the three-phase currents in phase with their corresponding phase voltages and with all of them equal to their rated values.
2. Slowly decrease the measured voltage in one phase until the BLKV signal appears.
3. Record the measured voltage and calculate the corresponding negative-sequence voltage according to the equation (observe that the voltages in the equation are phasors):

\[ 3 \cdot \overline{V_2} = \overline{V_A} + a^2 \cdot \overline{V_B} + a \cdot \overline{V_C} \]

(Equation 95)

Where:
\[ \overline{V_A}, \overline{V_B} \text{ and } \overline{V_C} \]
are the measured phase voltages

\[ a = 1 \cdot e^{\frac{2\pi}{3}} = -0.5 + j\frac{\sqrt{3}}{2} \]

4. Compare the result with the set value of the negative-sequence operating voltage (consider that the set value \(3V_{2PU}\) is in percentage of the base voltage \(V_{Base}\)).
5. Repeat steps 1 and 2. Then slowly increase the measured current in one phase until the BLKV signal disappears.
6. Record the measured current and calculate the corresponding negative-sequence current according to the equation (observe that the currents in the equation are phasors):

\[ 3 \cdot \overline{I_2} = \overline{I_A} + a^2 \cdot \overline{I_B} + a \cdot \overline{I_C} \]

(Equation 98)

Where:
\[ \overline{I_A}, \overline{I_B} \text{ and } \overline{I_C} \]
are the measured phase currents

\[ a = 1 \cdot e^{\frac{2\pi}{3}} = -0.5 + j\frac{\sqrt{3}}{2} \]

7. Compare the result with the set value of the negative-sequence operating current. Consider that the set value \(3I_{2PU}\) is in percentage of the base current \(I_{Base}\).
10.9.2.3 Measuring the operate value for the zero-sequence function

Measure the operate value for the zero-sequence function, if included in the IED.

1. Simulate normal operating conditions with the three-phase currents in phase with their corresponding phase voltages and with all of them equal to their rated values.
2. Slowly decrease the measured voltage in one phase until the BLKV signal appears.
3. Record the measured voltage and calculate the corresponding zero-sequence voltage according to the equation (observe that the voltages in the equation are phasors):

\[ 3 \cdot V_0 = V_A + V_B + V_C \]

(Equation 101)

Where:

\[ V_A, V_B, \text{ and } V_C \]

are the measured phase voltages

4. Compare the result with the set value of the zero-sequence operating voltage (consider that the set value \( 3V0\text{Pickup} \) is in percentage of the base voltage.)
5. Repeat steps 1 and 2. Then slowly increase the measured current in one phase until the BLKV signal disappears.
6. Record the measured current and calculate the corresponding zero-sequence current according to the equation (observe that the currents in the equation are phasors):

\[ 3 \cdot I_0 = I_A + I_B + I_C \]

(Equation 103)

Where:

\[ I_A, I_B, \text{ and } I_C \]

are the measured phase currents

7. Compare the result with the set value of the zero-sequence operating current. Consider that the set value \( 3I0\text{<} \) is in percentage of the base current \( I_{Base} \).

10.9.2.4 Measuring the operate value for the dead line detection function
1. Apply three-phase voltages with their rated value and zero currents.
2. Decrease the measured voltage in one phase until the DLD1PH signal appears.
3. This is the point at which the dead line condition is detected. Check the value of the decreased voltage with the set value VDLDPU (VDLDPU is in percentage of the base voltage $V_{Base}$).
4. Apply three-phase currents with their rated value and zero voltages.
5. Decrease the measured current in one phase until the DLD1PH signal appears.
6. This is the point at which the dead line condition is detected. Check the value of the decreased current with the set value IDLDPU (IDLDPU is in percentage of the base current $I_{Base}$).

10.9.2.5 Checking the operation of the $dv/dt$ and $di/dt$ based function

Check the operation of the $dv/dt$ and $di/dt$ based function if included in the IED.

1. Simulate normal operating conditions with the three-phase currents in phase with their corresponding phase voltages and with all of them equal to their rated values.
2. Change the voltages and currents in all three phases simultaneously.
   The voltage change must be higher than the set value $DV_{PU}$ and the current change must be lower than the set value $DIP_{PU}$.
   - The BLKV and BLKZ signals appear without any time delay. The BLKZ signal will be activated only if the internal deadline detection is not activated at the same time.
   - 3PH should appear after 5 seconds, if the remaining voltage levels are lower than the set $VDLDPU$ of the dead line detection function.
3. Apply normal conditions as in step 1.
The BLKV, BLKZ and 3PH signals should reset, if activated, see step 1 and 2.
4. Change the voltages and currents in all three phases simultaneously.
The voltage change must be higher than the set value $DV_{PU}$ and the current change must be higher than the set value $DIP_{PU}$.
The BLKV, BLKZ and 3PH signals should not appear.
5. Repeat step 2.
6. Connect the nominal voltages in all three phases and feed a current below the operate level in all three phases.
7. Keep the current constant. Disconnect the voltage in all three phases simultaneously. The BLKV, BLKZ and 3PH signals should not appear.
8. Change the magnitude of the voltage and current for phase 1 to a value higher than the set value $DVPU$ and $DIPU$.

9. Check that the pickup output signals $PU\_DV\_A$ and $PU\_DI\_A$ and the general pickup signals $PU\_DV$ or $PU\_DI$ are activated.

10. Check that the pickup output signals for the current and voltage phases 2 and 3 are activated by changing the magnitude of the voltage and current for phases 2 and 3.

10.9.2.6 Completing the test

Continue to test another function or end the test by changing the $TestMode$ setting to $Disabled$. Restore connections and settings to their original values, if they were changed for testing purposes.

10.10 Logic

10.10.1 Tripping logic, common 3-phase output SMPPTRC (94)

Prepare the IED for verification of settings outlined in section "Preparing the IED to verify settings".

This function is functionality tested together with other protection functions (line differential protection, ground-fault overcurrent protection, and so on) within the IED. It is recommended that the function is tested together with the autorecloser function, when built into the IED or when a separate external unit is used for reclosing purposes. The instances of SMPPTRC (94) are identical except for the name of the function block SMPPTRC (94). The testing is preferably done in conjunction with the protection system and autoreclosing function.

10.10.1.1 Three-phase operating mode

1. Check that $AutoLock$ and $TripLockout$ are both set to $Disabled$.
2. Initiate a three-phase fault.
   An adequate time interval between the faults should be considered, to overcome a reset time caused by the possible activation of the Autorecloser function $SMBRREC$ (79). The function must issue a three-pole trip in all cases, when trip is initiated by any protection or some other built-in or external function. The following functional output signals must always appear simultaneously: TRIP, TR_A, TR_B, TR_C and TR3P.
10.10.1.2 1ph/3ph operating mode

In addition to various other tests, the following tests should be performed. They depend on the complete configuration of an IED:

Procedure

1. Make sure that TripLockout and AutoLock are both set to Disabled.
2. Initiate different single-phase-to-ground faults one at a time.
3. Initiate different phase-to-phase and three-phase faults.
   Consider using an adequate time interval between faults, to overcome a reset time, which is activated by SMBRREC (79). A three-pole trip should occur for each separate fault and all of the trips. Functional outputs TRIP, all TR_A, TR_B, TR_C and TR3P should be active at each fault.
   
   No other outputs should be active.

4. Initiate a single phase-to-ground fault and switch it off immediately when the trip signal is issued for the corresponding phase. Initiate the same fault once again within the reset time of the used SMBRREC (79).
5. Initiate a single phase-to-ground fault and switch it off immediately when the trip signal is issued for the corresponding phase. Initiate the second single phase-to-ground fault in one of the remaining phases within the time interval, shorter than tEvolvingFault (default setting 2.0s) and shorter than the dead-time of SMBRREC (79), when included in the protection scheme.
   Check that the second trip is a three-pole trip and that a three-phase autoreclosing attempt is given after the three-phase dead time. Functional outputs TRIP, TR_A, TR_B, TR_C and TR1P should be active during the first fault. No other outputs should be active. Functional outputs TRIP, all TR_A, TR_B, TR_C and TR3P should be active during second fault.

10.10.1.3 1ph/2ph/3ph operating mode

In addition to other tests, the following tests, which depend on the complete configuration of an IED, should be carried out.

Procedure

1. Make sure that AutoLock and TripLockout are both set to Disabled.
2. Initiate different single-phase-to-ground faults one at a time.
   Take an adequate time interval between faults into consideration, to overcome a reset time, which is activated by the autorecloser function SMBRREC (79). Only
a single-pole trip should occur for each separate fault and only one of the trip outputs (TR_A, TR_B, TR_C) should be activated at a time. Functional outputs TRIP and TR1P should be active at each fault. No other outputs should be active.

3. Initiate different phase-to-phase faults one at a time.
   Take an adequate time interval between faults into consideration, to overcome a reset time which is activated by SMBRREC (79). Only a two-phase trip should occur for each separate fault and only corresponding two trip outputs (TR_A, TR_B, TR_C) should be activated at a time. Functional outputs TRIP and TR2P should be active at each fault. No other outputs should be active.

4. Initiate a three-phase fault.

5. Initiate a single phase-to-ground fault and switch it off immediately when the trip signal is issued for the corresponding phase. Initiate the same fault once again within the reset time of the used SMBRREC (79).
   A single-phase fault shall be given at the first fault. A three-pole trip must be initiated for the second fault. Check that the corresponding trip signals appear after both faults. Functional outputs TRIP, TR_A, TR_B, TR_C and TR1P should be active during first fault. No other outputs should be active. Functional outputs TRIP, all TR_A, TR_B, TR_C and TR3P should be active during second fault.

6. Initiate a single phase-to-ground fault and switch it off immediately when the trip signal is generated for the corresponding phase. Initiate the second single-phase-to-ground fault in one of the remaining phases within the time interval, shorter than $t_{EvolvingFault}$ (default setting 2.0s) and shorter than the dead-time of SMBRREC (79), when included in the protection scheme.

7. Check, that the output signals, issued for the first fault, correspond to a two-phase trip for included phases. The output signals generated by the second fault must correspond to the three-phase tripping action.

### 10.10.1.4 Circuit breaker lockout

The following tests should be carried out when the built-in lockout function is used in addition to possible other tests, which depends on the complete configuration of an IED.

1. Check that AutoLock and TripLockout are both set to Disabled.
2. Activate shortly the set lockout (SETLKOUT) signal in the IED.
3. Check that the circuit breaker lockout (CLLKOUT) signal is set.
4. Activate shortly thereafter, the reset lockout (RSTLKOUT) signal in the IED.
5. Check that the circuit breaker lockout (CLLKOUT) signal is reset.
6. Initiate a three-phase fault.
   A three-trip should occur and all trip outputs TR_A, TR_B, TR_C should be activated. Functional outputs TRIP and TR3P should be active at each fault. The output CLLUOUT should not be set.
7. Activate the automatic lockout function, set AutoLock = Enabled and repeat.
   Besides the TRIP outputs, CLLUOUT should be set.
8. Reset the lockout signal by activating the reset lockout (RSTLKOUT) signal.
9. Activate the trip signal lockout function, set TripLockout = Enabled and repeat. All trip outputs (TR_A, TR_B, TR_C) and functional outputs TRIP and TR3P must be active and stay active after each fault, CLLKOUT should be set.
10. Reset the lockout. All functional outputs should reset.
11. Deactivate the TRIP signal lockout function, set TripLockout = Disabled and the automatic lockout function, set AutoLock = Disabled.

10.10.1.5 Completing the test

Continue to test another function or end the test by changing the TestMode setting to Disabled. Restore connections and settings to their original values, if they were changed for testing purposes.

10.11 Monitoring

10.11.1 Gas medium supervision SSIMG

Prepare the IED for verification of settings as outlined in section "Testing the liquid medium supervision for alarm and lock out conditions" and section "Completing the test" in this chapter.

Check that the input logical signal BLOCK is logical zero and that on the local HMI, the logical signals PRES_ALM, PRES_LO, TEMP_ALM and TEMP_LO are equal to logical zero.

10.11.1.1 Testing the liquid medium supervision for alarm and lock out conditions

1. Connect binary inputs to consider gas pressure and gas density to initiate the alarms.
2. Consider the analogue pressure input PRESSURE to initiate the alarms.
3. Gas pressure lock out input can be used to set PRES_LO signal, check the signal status in local HMI under Main menu/Test/Function status/Monitoring/Gas medium supervision SSIMG/PRES_LO
4. Reduce the pressure level input below PresAlmLimit, check for PRES_ALM signal status in local HMI under Main menu/Test/Function status/Monitoring/Gas medium supervision SSIMG/PRES_ALM
5. Activate BLOCK binary input, the signals PRES_ALM, PRES_LO should disappear.
6. Reset the BLOCK binary input.
7. Check for reset lock out input $\text{RESET\_LO}$ to reset $\text{PRES\_LO}$ lock out signal.
8. Conduct these steps for temperature input as well to detect and reset $\text{TEMP\_ALM}$ and $\text{TEMP\_LO}$ signals.
9. Continue to test another function or end the test by changing the $\text{TestMode}$ setting to $\text{off}$.

10.11.1.2 Completing the test

Continue to test another function or end the test by changing the $\text{TestMode}$ setting to $\text{Off}$. Restore connections and settings to their original values, if they were changed for testing purposes.

10.11.2 Liquid medium supervision SSIML

Prepare the IED for verification of settings as outlined in section "Liquid medium supervision SSIML" and section "Completing the test" in this chapter.

Check that the input logical signal $\text{BLOCK}$ is logical zero and that on the local HMI, the logical signals $\text{LVL\_ALM}$, $\text{LVL\_LO}$, $\text{TEMP\_ALM}$ and $\text{TEMP\_LO}$ are equal to logical zero.

10.11.2.1 Testing the liquid medium supervision for alarm and lock out conditions

1. Connect the binary inputs to consider liquid level to initiate the alarms.
2. Consider the analogue level input $\text{LEVEL}$ to initiate the alarms.
3. Liquid level lock out input can be used to set $\text{LVL\_LO}$ signal, check the signal status in local HMI under $\text{Main menu/Test/Function status/Monitoring/Liquid medium supervision SSIML/LVL\_LO}$
4. Reduce the liquid level input below LevelAlmLimit, check for $\text{LVL\_ALM}$ signal status in local HMI under $\text{Main menu/Test/Function status/Monitoring/Liquid medium supervision SSIML/LVL\_ALM}$
5. Activate $\text{BLOCK}$ binary input, the signals $\text{LVL\_ALM}$, $\text{LVL\_LO}$ should disappear.
6. Reset the $\text{BLOCK}$ binary input.
7. Check for reset lock out input $\text{RESET\_LO}$ to reset the $\text{LVL\_LO}$ lock out signal.
8. Conduct these steps for temperature input as well to detect and reset $\text{TEMP\_ALM}$ and $\text{TEMP\_LO}$ signals.
9. Continue to test another function or end the test by changing the $\text{TestMode}$ setting to $\text{Off}$. 
10.11.2.2  Completing the test

Continue to test another function or end the test by changing the TestMode setting to Off. Restore connections and settings to their original values, if they were changed for testing purposes.

10.11.3  Breaker monitoring SSCBR

Prepare the IED for verification of settings outlined in section “Testing the IED operation”.

The Signal Monitoring tool in PCM600 shows the service values that are available on the Local HMI as well.

Values of the logical signals belong to the breaker monitoring are available on the local HMI under: Main menu/Test/Function status/Monitoring/BreakerMonitoring/SSCBR:x

10.11.3.1  Verifying the settings

1. Connect the test set for the injection of a three-phase current to the appropriate current terminals of the IED.
2. If current need to be injected for a particular test, it should be done in the phase selected by the PhSel parameter.
3. Follow the sequence for positioning the auxiliary contacts before testing:

<table>
<thead>
<tr>
<th>POSCLOSE</th>
<th>0</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>POSOPEN</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

4. Test of CB contact travel time
   4.1. Test the set timing defined by OpenTimeCorr, CloseTimeCorr, tTrOpenAlm and tTrCloseAlm.
   4.2. Change the status of the auxiliary contacts such that travel time to open TTRVOP and travel time to close TTRVCL exceed the respective set values (tTrOpenAlm and tTrCloseAlm). The measured travel time for opening and closing is shown on TTRVOP and TTRVCL respectively.
   4.3. Check that TRVTOPAL and TRVTCLAL are activated.

5. Test of CB status
   5.1. Test the set current level defined by AccStopCurr.
   5.2. Check the CLOSEPOS output by changing the POSOPEN to 0 and POSCLOSE to 1.
   5.3. Check the OPENPOS output by changing the POSOPEN to 1 and POSCLOSE to 0 and also inject the current in the selected phase slightly
lower and higher than \textit{AccStopCurr} set value. Only for a current lower than set \textit{AccStopCurr} should activate the output \texttt{POSOPEN}.

5.4. Check the circuit breaker is in \texttt{INVDPOS} if auxiliary contacts read same value or CB is open and inject the current in selected phase more than \textit{AccStopCurr} set value.

6. Test of remaining life of CB


6.2. Vary the phase current in the selected phase from below rated operated current, \textit{RatedOperCurr} to above rated fault current, \textit{RatedFltCurr} of a breaker.

6.3. The remaining life of CB output \texttt{CBLIFEPH} is estimated when the CB is changed from closed to open position. Check that the output \texttt{CBLIFEPH} is decreased with a value that corresponds to the injected current.

6.4. \texttt{CBLIFEAL} is activated as soon as \texttt{CBLIFEPH} is below the set \textit{CBLifeAlmLevel} value.

7. Test of accumulated energy

7.1. Test the actual set values defined by \textit{AccSelCal} to \textit{Aux Contact}, \textit{ContTrCorr} and \textit{AlmAccCurrPwr}.

7.2. Inject phase current in the selected phase such that its value is greater than set \textit{AccStopCurr} value.

7.3. When the breaker goes to open position, accumulated energy \texttt{IPOWPH} is calculated. The calculated value can be seen on the output \texttt{IPOWPH}.

7.4. Alarm signal \texttt{IPOWALPH} appears when \texttt{IPOWPH} is greater than set \textit{AlmAccCurrPwr} value.

7.5. Lockout signal \texttt{IPOWLOPH} appears if \texttt{IPOWPH} exceeds further to the threshold value \textit{LOAccCurrPwr}.

7.6. Calculation of accumulated energy \texttt{IPOWPH} is stopped when injected current is lower than set \textit{AccStopCurr} value.

8. Test of CB operation cycles

8.1. Test the actual set values defined by \textit{OperAlmLevel} and \textit{OperLOLevel}.

8.2. The operation counter, NOOPER is updated for every close-open sequence of the breaker by changing the position of auxiliary contacts \texttt{POSCLOSE} and \texttt{POSOPEN}.

8.3. \texttt{OPERALM} is activated when NOOPER value exceeds the set \textit{OperAlmLevel} value. The actual value can be read on the output NOOPER.

8.4. \texttt{OPERLO} is activated when NOOPER value exceeds the set \textit{OperLOLevel} value.

9. Test of CB spring charge monitoring
9.1. Test the actual set value defined by $SpChAlmTime$.
9.2. Enable $SPRCHRST$ input. Also activate $SPRCHRD$ after a time greater than set time $SpChAlmTime$.
9.3. At this condition, $SPCHALM$ is activated.

10. Test of CB gas pressure indication
10.1. Test the actual set value defined by $tDGasPresAlm$ and $tDGasPresLO$.
10.2. The output $GPRESALM$ is activated after a time greater than set time of $tDGasPresAlm$ value if the input $PRESALM$ is enabled.
10.3. The output $GPRESLO$ is activated after a set time of $tDGasPresLO$ value if the input $PRESLO$ is enabled.

10.11.3.2 Completing the test

1. Continue to test another function or end the test by changing the Test mode setting to Disabled.
2. Restore connections and settings to their original values if they were changed for testing purposes.

10.11.4 Event function EVENT

Prepare the IED for verification of settings as outlined in section "Requirements" and section "Preparing for test" in this chapter.

During testing, the IED can be set when in test mode from PST. The functionality of the event reporting during test mode is set in the Parameter Setting tool in PCM600.

• Use event masks
• Report no events
• Report all events

In test mode, individual event blocks can be blocked from PCM600.

10.11.5 Limit counter L4UFCNT

The Limit counter function L4UFCNT can be tested by connecting a binary input to the counter and applying pulses to the counter. The speed of the pulses must not exceed the cycle time of the function. Normally the counter will be tested when testing the function that the counter is connected to, such as the trip function. When the function is configured, test it together with the function that operates it. Trig the function and check that the counter result corresponds to the number of operations.
10.11.5.1 Completing the test

Continue to test another function or end the test by changing the Test mode setting to *Off*. Restore connections and settings to their original values, if they were changed for testing purposes.

10.12 Metering

10.12.1 Pulse-counter logic PCFCNT

The test of the Pulse-counter logic function PCFCNT requires the Parameter Setting tool in PCM600 or an appropriate connection to the local HMI with the necessary functionality. A known number of pulses with different frequencies are connected to the pulse counter input. The test should be performed with settings *Operation = Enable* or *Operation = Disable* and the function blocked or unblocked. The pulse counter value is then checked in PCM600 or on the local HMI.

10.12.2 Function for energy calculation and demand handling ETPMMTR

Prepare the IED for verification of settings as outlined in section "Overview “ and section ”Preparing for test“ in this chapter.

10.12.2.1 Verifying the settings

Common test equipment can be used to determine the injection of current and voltage and time measurement.

**Verification of EAFACC & ERFACC output**

1. Connect the test set for injection of three-phase currents and three phase voltage to the appropriate current and voltage terminals of the IED.
2. Ensure the instantaneous values of active and reactive power from CVMMXN function block are connected to ETPMMTR function block active and reactive power inputs.
3. Enable the *EnaAcc* setting and set *tEnergy* as 1 minute.
4. Activate the *STARTACC* input and supply the IED with three phase currents and voltages at their rated value.
5. Check that the *ACCINPRG* signal appears continuously.
6. Note the EAFACC and ERFACC value after 1 minute and compare it with calculated energy value.
7. Similarly check after each 1 minute whether the calculated integrated energy value and EAFACC and ERFACC outputs are matching.
8. After some time (multiple of minute) remove the current and voltage input from CVMMXN function block.
9. Check the EAFACC and ERFACC output in the next 1 minute cycle for the retaining the same value.
10. Activate STOPACC input after some time and supply the IED with same current and voltage.
11. Check that the ACCINPRG signal disappears immediately and EAFACC and ERFACC outputs also stop updating.
12. Similarly the testing can be done for EAFACC and ERFACC outputs by changing the power inputs directions through direction settings.

Veriﬁcation of MAXPAFD & MAXPRFD outputs
1. Repeat the above test steps 1 to 2.
2. Set tEnergy setting as 1 minute and supply the IED with three phase currents and voltages at their rated value till 1 minute.
3. Check the MAXPAFD and MAXPRFD outputs after 1 minute and compare it with last 1 minute average power values.
4. Increase either three phase current or voltage above the last 1 minute value.
5. After 1 minute check the MAXPAFD and MAXPRFD whether it is showing the last 1 minute average power value as maximum.
6. Next 1 minute cycle reduce the current or voltage below previous value.
7. Check after 1 minute whether the MAXPAFD and MAXPRFD outputs are retaining the old maximum value.
8. Similarly the testing can be done for MAXPAFD and MAXPRFD outputs by changing the power inputs directions through direction settings.

Veriﬁcation of EAFALM & ERFALM outputs
1. Repeat the above test steps 1 to 2.
2. Set tEnergy setting as 1 minute and supply the IED with three phase currents and voltages at their rated value till 1 minute.
3. Ensure that the active and reactive energy values are less than the EALim and ERLim setting default values respectively.
4. Check that EAFALM and ERFALM are low.
5. Increase the supply currents or voltage in next 1 minute cycle such that the active or reactive energy values are greater than the EALim and ERLim setting default values respectively.
6. Check that EAFALM and ERFALM are high after 1 minute.
7. Similarly the testing can be done for EARALM and ERRALM outputs by changing the power inputs directions through direction settings.
10.12.2.2 Completing the test

Continue to test another function or end the test by changing the TestMode setting to Disabled. Restore connections and settings to their original values, if they were changed for testing purposes.

10.13 Station communication

10.13.1 Multiple command and transmit MULTICMDRCV / MULTICMDSND

The multiple command and transmit function (MULTICMDRCV / MULTICMDSND) is only applicable for horizontal communication.

Test of the multiple command function block and multiple transmit is recommended to be performed in a system, that is, either in a complete delivery system as an acceptance test (FAT/SAT) or as parts of that system, because the command function blocks are connected in a delivery-specific way between bays and the station level and transmit.

Command and transmit function blocks included in the operation of different built-in functions must be tested at the same time as their corresponding functions.

10.14 Remote communication

10.14.1 Binary signal transfer BinSignReceive, BinSignTransm

Prepare the IED for verification of settings as outlined in section "Preparing the IED to verify settings".

To perform a test of Binary signal transfer function (BinSignReceive/BinSignTransm), the hardware (LDCM) and binary input and output signals to transfer must be configured as required by the application.

There are two types of internal self supervision of BinSignReceive/BinSignTransm:

- The I/O-circuit board is supervised as an I/O module. For example it generates FAIL if the board is not inserted. I/O-modules not configured are not supervised.
- The communication is supervised and the signal COMFAIL is generated if a communication error is detected.
Status for inputs and outputs as well as self-supervision status are available from the local HMI under:

- Self-supervision status: **Main menu/Diagnostics/Internal events**
- Status for inputs and outputs: **Main menu/Test/Function status**, browse to the function group of interest.
- Remote communication related signals: **Main menu/Test/Function status/Communication/Remote communication**

Test the correct functionality by simulating different kind of faults. Also check that sent and received data is correctly transmitted and read.

A test connection is shown in figure 28. A binary input signal (BI) at End1 is configured to be transferred through the communication link to End2. At End2 the received signal is configured to control a binary output (BO). Check at End2 that the BI signal is received and the BO operates.

Repeat the test for all the signals configured to be transmitted over the communication link.

---

**Figure 28:** Test of RTC with I/O
10.15 Basic IED functions

10.15.1 Parameter setting group handling SETGRPS

Prepare the IED for verification of settings as outlined in section "Requirements" and section "Preparing for test" in this chapter.

10.15.1.1 Verifying the settings

1. Check the configuration of binary inputs that control the selection of the active setting group.
2. Browse to the ActiveGroup menu to achieve information about the active setting group.
   - The ActiveGroup menu is located on the local HMI under Main menu/Test/Function status/Setting groups/ActiveGroup
3. Connect the appropriate dc voltage to the corresponding binary input of the IED and observe the information presented on the local HMI.
   - The displayed information must always correspond to the activated input.
4. Check that the corresponding output indicates the active group.
   - Operating procedures for the PC aided methods of changing the active setting groups are described in the corresponding PCM600 documents and instructions for the operators within the SCS are included in the SCS documentation.

10.15.1.2 Completing the test

Continue to test another function or end the test by changing the TestMode setting to Disabled. Restore connections and settings to their original values, if they were changed for testing purposes.

10.16 Exit test mode

The following procedure is used to return to normal operation.

After exiting the IED test mode, make sure that the MU is returned to normal mode.
1. Navigate to the test mode folder.
2. Change the *Enable* setting to *Disable*. Press the 'E' key and the left arrow key.
3. Answer *YES*, press the 'E' key and exit the menus.
Section 11 Commissioning and maintenance of the fault clearing system

11.1 Commissioning tests

During commissioning all protection functions shall be verified with the setting values used at each plant. The commissioning tests must include verification of all circuits by highlighting the circuit diagrams and the configuration diagrams for the used functions.

Further, the settings for protection functions are tested and recorded carefully as outlined for the future periodic maintenance tests.

The final testing includes primary verification of all directional functions where load currents is checked on the local HMI and in PCM600. The magnitudes and angles of all currents and voltages should be checked and the symmetry verified.

Directional functions have information about the measured direction and, for example, measured impedance. These values must be checked and verified as correct with the export or import of power available.

Finally, final trip tests must be performed. This involves activation of protection functions or tripping outputs with the circuit breaker closed and the tripping of the breaker verified. When several breakers are involved, each breaker must be checked individually and it must be verified that the other involved breakers are not tripped at the same time.

11.2 Periodic maintenance tests

The periodicity of all tests depends on several factors, for example the importance of the installation, environmental conditions, simple or complex equipment, static or electromechanical IEDs, and so on.

The normal maintenance practices of the user should be followed. However, ABB's recommendation is as follows:

Every second to third year
• Visual inspection of all equipment.
• Removal of dust on ventilation louvres and IEDs if necessary.
• Periodic maintenance test for protection IEDs of object where no redundant protections are provided.

Every four to six years

• Periodic maintenance test for protection IEDs of objects with redundant protection system.

First maintenance test should always be carried out after the first half year of service.

When protection IEDs are combined with built-in control, the test interval can be increased drastically, up to for instance 15 years, because the IED continuously reads service values, operates the breakers, and so on.

11.2.1 Visual inspection

Prior to testing, the protection IEDs should be inspected to detect any visible damage that may have occurred (for example, dirt or moisture deposits, overheating).

Make sure that all IEDs are equipped with covers.

11.2.2 Maintenance tests

To be made after the first half year of service, then with the cycle as proposed above and after any suspected maloperation or change of the IED setting.

Testing of protection IEDs shall preferably be made with the primary circuit de-energized. The IED cannot protect the circuit during testing. Trained personnel may test one IED at a time on live circuits where redundant protection is installed and de-energization of the primary circuit is not allowed.

ABB protection IEDs are preferably tested by aid of components from the COMBITEST testing system or FT test systems described in information B03-9510 E. Main components are RTXP 8/18/24 test switch usually located to the left in each protection IED and RTXH 8/18/24 test handle, which is inserted in test switch at secondary testing. All necessary operations such as opening of trip circuits, short-circuiting of current circuits and opening of voltage circuits are automatically
performed in the right order to allow for simple and safe secondary testing even with the object in service.

Important components of FT test system are FT1, FTx, FT19, FT19RS, FR19RX switches and assemblies as well as FT-1 test plug.

11.2.2.1 Preparation

Before starting maintenance testing, the test engineers should scrutinize applicable circuit diagrams and have the following documentation available:

- Test instructions for protection IEDs to be tested
- Test records from previous commissioning and maintenance tests
- List of valid settings
- Blank test records to fill in measured values

11.2.2.2 Recording

It is of utmost importance to carefully record the test results. Special test sheets covering the frequency of test, date of test and achieved test values should be used. IED setting list and protocols from previous tests should be available and all results should be compared for differences. At component failures, spare equipment is used and set to the requested value. A note of the exchange is made and the new measured values are recorded. Test records for several years of testing should be stored in a common file for a station, or a part of a station, to give a simple overview of the period of testing and achieved test values. These test records are valuable when analysis of service disturbances shall be done.

11.2.2.3 Secondary injection

The periodic maintenance test is done by secondary injection from a portable test set. Each protection shall be tested according to the secondary injection test information for the specific protection IED. Only the setting values adopted shall be checked for each protection function. If the discrepancy between obtained value and requested set value is too big the setting should be adjusted, the new value recorded and a note should be made in the test record.

11.2.2.4 Alarm test

When inserting the test handle of RTXP or using FT plugs, the alarm and event signalling is normally blocked. This is done in the IED by setting the event reporting to Disabled during the test. This can be done when the test handle is inserted or the IED is set to test mode from the local HMI. At the end of the secondary injection test it
should be checked that the event and alarm signalling is correct by activating the events and performing some selected tests.

11.2.2.5 Self supervision check

Once secondary testing has been completed, it should be checked that no self-supervision signals are activated continuously or sporadically. Especially check the time synchronization system, GPS or other, and communication signals, both station communication and remote communication.

11.2.2.6 Trip circuit check

When the protection IED undergoes an operational check, a tripping pulse is normally obtained on one or more of the output contacts and preferably on the test switch. The healthy circuit is of utmost importance for the protection operation. If the circuit is not provided with a continuous trip-circuit supervision, it is possible to check that circuit is really closed when the test-plug handle has been removed by using a high-ohmic voltmeter and measuring between the plus and the trip output on the panel. The measurement is then done through the trip coil of the circuit breaker and therefore the complete trip circuit is checked.

Note that the breaker must be closed.

Please observe that the test system does not provide built-in security during this test. If the instrument should be set on Amp instead of Volts, the circuit breaker naturally is tripped, therefore, great care is necessary.

Trip circuit from trip IEDs to circuit breaker is often supervised by trip-circuit supervision. It can then be checked that a circuit is healthy by opening tripping output terminals in the cubicle. When the terminal is opened, an alarm shall be achieved on the signal system after a delay of some seconds.

Remember to close the circuit directly after the test and tighten the terminal carefully.
11.2.2.7 Measurement of service currents

After a maintenance test it is recommended to measure the service currents and service voltages recorded by the protection IED. The service values are checked on the local HMI or in PCM600. Ensure that the correct values and angles between voltages and currents are recorded. Also check the direction of directional functions such as Distance and directional overcurrent functions.

For transformer differential protection, the achieved differential current value is dependent on the tap changer position and can vary between less than 1% up to perhaps 10% of rated current. For line differential functions, the capacitive charging currents can normally be recorded as a differential current.

The zero-sequence current to ground-fault protection IEDs should be measured. The current amounts normally very small but normally it is possible to see if the current circuit is "alive".

The neutral-point voltage to an ground-fault protection IED is checked. The voltage is normally 0.1 to 1V secondary. However, voltage can be considerably higher due to harmonics. Normally a CVT secondary can have around 2.5 - 3% third-harmonic voltage.

11.2.2.8 Restoring

Maintenance is very important to improve the availability of the protection system by detecting failures before the protection is required to operate. There is however little point in testing healthy equipment and then putting it back into service with an open terminal, with a removed fuse or open miniature circuit breaker with an open connection, wrong setting, and so on.

Thus a list should be prepared of all items disturbed during test so that all can be put back into service quickly and without overlooking something. It should be put back into service item by item and signed by the responsible engineer.
Section 12  Troubleshooting

12.1  Checking the self supervision signals

12.1.1  Checking the self supervision function

12.1.1.1  Determine the cause of an internal failure

This procedure describes how to navigate the menus in order to find the cause of an internal failure when indicated by the flashing green LED on the HMI module.

Procedure

1. Display the general diagnostics menu.
   Navigate the menus to: Diagnostics/IED status/General
2. Scroll the supervision values to identify the reason for the failure.
   Use the arrow buttons to scroll between values.

12.1.2  Self supervision HMI data

12.1.2.1  General IED status

The following table shows the general IED status signals.

<table>
<thead>
<tr>
<th>Indicated result</th>
<th>Possible reason</th>
<th>Proposed action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal fail Off</td>
<td>No problem detected.</td>
<td>None.</td>
</tr>
<tr>
<td>Internal fail On</td>
<td>A failure has occurred.</td>
<td>Check the rest of the indicated results to find the fault.</td>
</tr>
<tr>
<td>Internal warning Off</td>
<td>No problem detected.</td>
<td>None.</td>
</tr>
<tr>
<td>Internal warning On</td>
<td>A warning has been issued.</td>
<td>Check the rest of the indicated results to find the fault.</td>
</tr>
<tr>
<td>Time synch Ready</td>
<td>No problem detected.</td>
<td>None.</td>
</tr>
<tr>
<td>Time synch Fail</td>
<td>No time synchronization.</td>
<td>Check the synchronization source for problems. If the problem persists, contact your ABB representative for service.</td>
</tr>
</tbody>
</table>

Table continues on next page
<table>
<thead>
<tr>
<th>Indicated result</th>
<th>Possible reason</th>
<th>Proposed action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real time clock Ready</td>
<td>No problem detected.</td>
<td>None.</td>
</tr>
<tr>
<td>Real time clock Fail</td>
<td>The real time clock has been reset.</td>
<td>Set the clock.</td>
</tr>
<tr>
<td>ADC-module OK</td>
<td>No problem detected.</td>
<td>None.</td>
</tr>
<tr>
<td>ADC-module Fail</td>
<td>The AD conversion module has failed.</td>
<td>Contact your ABB representative for service.</td>
</tr>
<tr>
<td>(Protocol name) Ready</td>
<td>No problem detected.</td>
<td>None.</td>
</tr>
<tr>
<td>(Protocol name) Fail</td>
<td>Protocol has failed.</td>
<td></td>
</tr>
<tr>
<td>(I/O module name) Ready</td>
<td>No problem detected.</td>
<td>None.</td>
</tr>
<tr>
<td>(I/O module name) Fail</td>
<td>I/O modules has failed.</td>
<td>Check that the I/O module has been configured and connected to the IOP1- block. If the problem persists, contact your ABB representative for service.</td>
</tr>
</tbody>
</table>

### 12.1.2.2 Communication Diagnostics

All the communications in the IED (Front port and rear LAN AB/CD ports) can be supervised via the local HMI under **Main menu/Diagnostics/Communication**.

![Figure 29: The PMU communication diagnostic menu](IEC140000115-2-en.vsd)
Denial of Service on Communication Ports

The denial of service functions (DOSFRNT, DOSOEMAB and DOSOEMCD) 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, DOSOEMAB and DOSOEMCD measures 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 following outputs are available in ACT via PCM600 for each DOS function block:

- LINKUP indicates the Ethernet link status
- WARNING indicates that communication (frame rate) is higher than normal
- ALARM indicates the IED limits communication

In addition, it is possible to monitor the status of the communication ports via the Local HMI under **Main menu/Diagnostics/Communication**.

As an example, IED front communication port can be monitored via LHMI under **Main menu/Diagnostics/Communication/Front port/DOSFRNT:1**.
PMU Diagnostics

The PMU diagnostics presents the status of the PMU client connections for the user and also any errors that are encountered by a client during the connection. The status of this component is only shown on the Local HMI under Main menu/Diagnostics/Communication/PMU diagnostics/PMUSTATUS:1.

All these outputs are reset to defaults after the IED reboots or if the user clears the diagnostics from the LHMI clear menu. Following table shows the PMUSTATUS output signals and their possible output states.

<table>
<thead>
<tr>
<th>Name</th>
<th>Status Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMUInst1</td>
<td>Off</td>
<td>PMU instance 1 status</td>
</tr>
<tr>
<td></td>
<td>Ready</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Data Invalid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Config Error</td>
<td></td>
</tr>
<tr>
<td>PMUInst2</td>
<td>Off</td>
<td>PMU instance 2 status</td>
</tr>
<tr>
<td></td>
<td>Ready</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Data Invalid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Config Error</td>
<td></td>
</tr>
</tbody>
</table>

Table continues on next page
<table>
<thead>
<tr>
<th>TCPConnStatus1</th>
<th>Off Active</th>
<th>TCP connection 1 status</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCPConnStatus2</td>
<td>Off Active</td>
<td>TCP connection 2 status</td>
</tr>
<tr>
<td>TCPConnStatus3</td>
<td>Off Active</td>
<td>TCP connection 3 status</td>
</tr>
<tr>
<td>TCPConnStatus4</td>
<td>Off Active</td>
<td>TCP connection 4 status</td>
</tr>
<tr>
<td>TCPConnStatus5</td>
<td>Off Active</td>
<td>TCP connection 5 status</td>
</tr>
<tr>
<td>TCPConnStatus6</td>
<td>Off Active</td>
<td>TCP connection 6 status</td>
</tr>
<tr>
<td>TCPConnStatus7</td>
<td>Off Active</td>
<td>TCP connection 7 status</td>
</tr>
<tr>
<td>TCPConnStatus8</td>
<td>Off Active</td>
<td>TCP connection 8 status</td>
</tr>
<tr>
<td>TCPCtrlDataErrCnt</td>
<td>0 to 4294967295</td>
<td>Number of times IED has failed to respond for a command requested on C37.118 or IEEE1344 on TCP</td>
</tr>
<tr>
<td>TCPCtrlCfgErrCnt</td>
<td>0 to 4294967295</td>
<td>Number of errors that have occurred due to incorrect configuration request by the client on TCP</td>
</tr>
</tbody>
</table>

| UDPStreamStat1       | Off Active Config Error Off by client Client unreachable | UDP data stream status for UDP Group1 |
| UDPStreamStat2       | Off Active Config Error Off by client Client unreachable | UDP data stream status for UDP Group2 |
| UDPStreamStat3       | Off Active Config Error Off by client Client unreachable | UDP data stream status for UDP Group3 |
| UDPStreamStat4       | Off Active Config Error Off by client Client unreachable | UDP data stream status for UDP Group4 |
| UDPCtrlConnCnt1      | 0 to 4 | Number of UDP control client connected on Group1 |
| UDPCtrlConnCnt2      | UDPCtrlConnCnt2 0 to 4 | Number of UDP control client connected on UDP Group2 |
| UDPCtrlConnCnt3      | 0 to 4 | Number of UDP control client connected on UDP Group3 |

Table continues on next page
The following describes the various output states:

- **PMUInst1, PMUInst2** – The outputs on these channels show the status of the two available PMUREPORT instances. Each status output has the following states:
  - **Off** – When the component is not in operation.
  - **Ready** – When it is sending data based on the configuration.
  - **ConfigError** – If the same PMU Id is used for both the instances.
  - **Data Invalid** – When the PMU is producing an invalid data stream and the data from it cannot be trusted.

- **TCPConnStatus1-8** – The 8 TCP connection status outputs show if there is an active TCP connection or not. Each status output has the following states:
  - **Off** - No active connection.
  - **Active** - A client is connected and receiving data.

- **TCPCtrlDataErrCnt** - The output shows the number of times the PMU has failed to send the configuration frame, header frames or data frame on C37.118 or IEEE1344.

- **TCPCtrlCfgErrCnt** - The outputs show the number of errors that have occurred due to incorrect configuration request by the client. These errors can be due to the client trying to send a wrong PMUId on this link than the one that is configured, or trying to request an IEEE1344 configuration on C37.118 channel.

- **UDPStreamStat1-6** - The six UDP stream status outputs have the following states:
- Off - UDP data stream is turned off.
- Active – UDP data stream is on.
- ConfigError – When the stream is set to send a stream from PMU instance not instantiated in ACT.
- Off by client – UDP data stream is turned off by an external client.
- Client Unreachable – Unable to send data to configured client, or host unreachable.

- **UDPCtrlConnStatus1-6** – The 6 UDP stream control connection status output, shows the number of concurrent clients connected to control the UDP data stream. A maximum of 4 clients can be connected concurrently.
- **UDPCtrlDataErrCnt** - The output shows the number of times IED has failed to respond for a command requested on C37.118 or IEEE1344.
- **UDPCtrlCfgErrCnt** - The output shows the number of errors that have occurred due to incorrect configuration request by the client. These errors can be due to client trying to send a wrong PMUId on this link than the one configured, or trying to request an IEEE1344 configuration on C37.118 channel.

The PMUSTATUS output signals can also be mapped on DNP3.0 protocol. Table 9 shows the different numbers corresponding to different output statuses.

<table>
<thead>
<tr>
<th>PMU Diagnostic Output</th>
<th>Status</th>
<th>DNP3.0 Mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMUInst1</td>
<td>Off</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Ready</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Config Error</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Data Invalid</td>
<td>3</td>
</tr>
<tr>
<td>PMUInst2</td>
<td>Off</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Ready</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Config Error</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Data Invalid</td>
<td>3</td>
</tr>
<tr>
<td>TCPConnStatus1</td>
<td>Off</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Active</td>
<td>1</td>
</tr>
<tr>
<td>TCPConnStatus2</td>
<td>Off</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Active</td>
<td>1</td>
</tr>
<tr>
<td>TCPConnStatus3</td>
<td>Off</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Active</td>
<td>1</td>
</tr>
<tr>
<td>TCPConnStatus4</td>
<td>Off</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Active</td>
<td>1</td>
</tr>
<tr>
<td>TCPConnStatus5</td>
<td>Off</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Active</td>
<td>1</td>
</tr>
<tr>
<td>TCPConnStatus6</td>
<td>Off</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Active</td>
<td>1</td>
</tr>
<tr>
<td>TCPConnStatus7</td>
<td>Off</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Active</td>
<td>1</td>
</tr>
</tbody>
</table>

Table continues on next page
## Fault tracing

### 12.2.1 Internal fault indications

If an internal fault has occurred, the local HMI displays information under **Main menu/Diagnostics/IED status/General**

Under the Diagnostics menus, indications of a possible internal failure (serious fault) or internal warning (minor problem) are listed.

Indications regarding the faulty unit are outlined in table 10.
## Table 10: Self-supervision signals on the local HMI

<table>
<thead>
<tr>
<th>HMI Signal Name</th>
<th>Status</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>INT Fail</td>
<td>OFF / ON</td>
<td>This signal will be active if one or more of the following internal signals are active: INT--LMDERROR, INT--WATCHDOG, INT--APPLICATIONERROR, INT--RTEERROR, or any of the HW dependent signals</td>
</tr>
<tr>
<td>INT Warning</td>
<td>OFF / ON</td>
<td>This signal will be active if one or more of the following internal signals are active: INT--RTCERROR, INT--IEC61850ERROR, INT--TIMESYNCHERROR</td>
</tr>
<tr>
<td>ADMnn</td>
<td>READY / FAIL</td>
<td>Analog input module n failed. Signal activation will reset the IED</td>
</tr>
<tr>
<td>BIMnn</td>
<td>READY / FAIL</td>
<td>BIM error. Binary input module Error status. Signal activation will reset the IED</td>
</tr>
<tr>
<td>BOMn</td>
<td>READY / FAIL</td>
<td>BOM error. Binary output module Error status.</td>
</tr>
<tr>
<td>IOMn</td>
<td>READY / FAIL</td>
<td>IOM-error. Input/Output Module Error status.</td>
</tr>
<tr>
<td>MIMn</td>
<td>READY / FAIL</td>
<td>mA input module MIM1 failed. Signal activation will reset the IED</td>
</tr>
<tr>
<td>RTC</td>
<td>READY / FAIL</td>
<td>This signal will be active when there is a hardware error with the real time clock.</td>
</tr>
<tr>
<td>Time Sync</td>
<td>READY / FAIL</td>
<td>This signal will be active when the source of the time synchronization is lost, or when the time system has to make a time reset.</td>
</tr>
<tr>
<td>Application</td>
<td>READY / FAIL</td>
<td>This signal will be active if one or more of the application threads are not in the state that Runtime Engine expects. The states can be CREATED, INITIALIZED, RUNNING, etc.</td>
</tr>
<tr>
<td>RTE</td>
<td>READY / FAIL</td>
<td>This signal will be active if the Runtime Engine failed to do some actions with the application threads. The actions can be loading of settings or parameters for components, changing of setting groups, loading or unloading of application threads.</td>
</tr>
<tr>
<td>IEC61850</td>
<td>READY / FAIL</td>
<td>This signal will be active if the IEC61850 stack did not succeed in some actions like reading IEC61850 configuration, startup etc.</td>
</tr>
<tr>
<td>LMD</td>
<td>READY / FAIL</td>
<td>LON network interface, MIP/DPS, is in an unrecoverable error state.</td>
</tr>
<tr>
<td>LDCMxxx</td>
<td>READY / FAIL</td>
<td>Line Differential Communication Error status</td>
</tr>
<tr>
<td>OEM</td>
<td>READY / FAIL</td>
<td>Optical Ethernet Module error status.</td>
</tr>
</tbody>
</table>
Also the internal signals, such as INT--FAIL and INT--WARNING can be connected to binary output contacts for signalling to a control room.

In the IED Status - Information, the present information from the self-supervision function can be viewed. Indications of failure or warnings for each hardware module are provided, as well as information about the external time synchronization and the internal clock. All according to table 10. Loss of time synchronization can be considered as a warning only. The IED has full functionality without time synchronization.

12.2.2 Using front-connected PC

When an internal fault has occurred, extensive information about the fault can be retrieved from the list of internal events available in the SMS part:

**TRM-STAT TermStatus - Internal Events**

The list of internal events provides valuable information, which can be used during commissioning and fault tracing.

The internal events are time tagged with a resolution of 1ms and stored in a list. The list can store up to 40 events. The list is based on the FIFO principle, when it is full, the oldest event is overwritten. The list cannot be cleared and its content cannot be erased.

The internal events in this list not only refer to faults in the IED, but also to other activities, such as change of settings, clearing of disturbance reports, and loss of external time synchronization.

The information can only be retrieved from the Parameter Setting software package. The PC can be connected either to the port at the front or at the rear of the IED.

These events are logged as internal events.

**Table 11: Events available for the internal event list in the IED**

<table>
<thead>
<tr>
<th>Event message:</th>
<th>Description</th>
<th>Generating signal:</th>
</tr>
</thead>
<tbody>
<tr>
<td>INT--FAIL</td>
<td>Off</td>
<td>INT--FAIL (reset event)</td>
</tr>
<tr>
<td>INT--FAIL</td>
<td></td>
<td>INT--FAIL (set event)</td>
</tr>
<tr>
<td>INT--WARNING</td>
<td>Off</td>
<td>INT--WARNING (reset event)</td>
</tr>
<tr>
<td>INT--WARNING</td>
<td></td>
<td>INT--WARNING (set event)</td>
</tr>
<tr>
<td>IOn--Error</td>
<td>Off</td>
<td>IOn--Error (reset event)</td>
</tr>
<tr>
<td>IOn--Error</td>
<td></td>
<td>IOn--Error (set event)</td>
</tr>
<tr>
<td>ADMn-Error</td>
<td>Off</td>
<td>ADMn-Error (reset event)</td>
</tr>
<tr>
<td>ADMn-Error</td>
<td></td>
<td>ADMn-Error (set event)</td>
</tr>
</tbody>
</table>

Table continues on next page
<table>
<thead>
<tr>
<th>Event message:</th>
<th>Description</th>
<th>Generating signal:</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIM1-Error</td>
<td>mA-input module status</td>
<td>MIM1-Error (reset event)</td>
</tr>
<tr>
<td>MIM1-Error</td>
<td></td>
<td>MIM1-Error (set event)</td>
</tr>
<tr>
<td>INT--RTC</td>
<td>Real Time Clock (RTC) status</td>
<td>INT--RTC (reset event)</td>
</tr>
<tr>
<td>INT--RTC</td>
<td></td>
<td>INT--RTC (set event)</td>
</tr>
<tr>
<td>INT--TSYNC</td>
<td>External time synchronization status</td>
<td>INT--TSYNC (reset event)</td>
</tr>
<tr>
<td>INT--TSYNC</td>
<td></td>
<td>INT--TSYNC (set event)</td>
</tr>
<tr>
<td>INT--SETHCGD</td>
<td>Any settings in IED changed</td>
<td></td>
</tr>
<tr>
<td>DRPC-CLEARED</td>
<td>All disturbances in Disturbance report cleared</td>
<td></td>
</tr>
</tbody>
</table>

The events in the internal event list are time tagged with a resolution of 1ms.

This means that, when using the PC for fault tracing, it provides information on the:

- Module that should be changed.
- Sequence of faults, if more than one unit is faulty.
- Exact time when the fault occurred.

### 12.3 Repair instruction

Never disconnect the secondary connection of a current transformer circuit without short-circuiting the transformer’s secondary winding. Operating a current transformer with the secondary winding open will cause a massive potential build up that may damage the transformer and may cause injuries to humans.

Never connect or disconnect a wire and/or a connector to or from a IED during normal service. Hazardous voltages and currents are present that may be lethal. Operation may be disrupted and IED and measuring circuitry may be damaged.

An alternative is to open the IED and send only the faulty circuit board to ABB for repair. When a printed circuit board is sent to ABB, it must always be placed in a metallic, ESD-proof, protection bag. The user can also purchase separate replacement modules.
Strictly follow the company and country safety regulations.

Most electronic components are sensitive to electrostatic discharge and latent damage may occur. Please observe usual procedures for handling electronics and also use an ESD wrist strap. A semi-conducting layer must be placed on the workbench and connected to ground.

Disassemble and reassemble the IED accordingly:

1. Switch off the dc supply.
2. Short-circuit the current transformers and disconnect all current and voltage connections from the IED.
3. Disconnect all signal wires by removing the female connectors.
4. Disconnect the optical fibers.
5. Unscrew the main back plate of the IED.
6. If the transformer module is to be changed:
   - Remove the IED from the panel if necessary.
   - Remove the rear plate of the IED.
   - Remove the front plate.
   - Remove the screws of the transformer input module, both front and rear.
7. Pull out the faulty module.
8. Check that the new module has a correct identity number.
9. Check that the springs on the card rail are connected to the corresponding metallic area on the circuit board when the new module is inserted.
10. Reassemble the IED.

If the IED has been calibrated with the system inputs, the calibration procedure must be performed again to maintain the total system accuracy.

12.4 Repair support

If an IED needs to be repaired, the whole IED must be removed and sent to an ABB Logistic Center. Please contact the local ABB representative to get more details.

12.5 Maintenance

The IED is self-supervised. No special maintenance is required.
Instructions from the power network company and other maintenance directives valid for maintenance of the power system must be followed.
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<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>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>CB</td>
<td>Circuit breaker</td>
</tr>
<tr>
<td>CBM</td>
<td>Combined backplane module</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 / IEC60255-24</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>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>DBLL</td>
<td>Dead bus live line</td>
</tr>
<tr>
<td>DC</td>
<td>Direct current</td>
</tr>
<tr>
<td>DFC</td>
<td>Data flow control</td>
</tr>
<tr>
<td>DFT</td>
<td>Discrete Fourier transform</td>
</tr>
<tr>
<td>DHCP</td>
<td>Dynamic Host Configuration Protocol</td>
</tr>
<tr>
<td>DIP-switch</td>
<td>Small switch mounted on a printed circuit board</td>
</tr>
<tr>
<td>DI</td>
<td>Digital input</td>
</tr>
<tr>
<td>DLLB</td>
<td>Dead line live bus</td>
</tr>
<tr>
<td>DNP</td>
<td>Distributed Network Protocol as per IEEE Std 1815-2012</td>
</tr>
<tr>
<td>DR</td>
<td>Disturbance recorder</td>
</tr>
<tr>
<td>DRAM</td>
<td>Dynamic random access memory</td>
</tr>
<tr>
<td>DRH</td>
<td>Disturbance report handler</td>
</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>FUN</td>
<td>Function type</td>
</tr>
<tr>
<td>Term</td>
<td>Description</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>G.703</td>
<td>Electrical and functional description for digital lines used by local telephone companies. Can be transported over balanced and unbalanced lines.</td>
</tr>
<tr>
<td>GCM</td>
<td>Communication interface module with carrier of GPS receiver module.</td>
</tr>
<tr>
<td>GDE</td>
<td>Graphical display editor within PCM600.</td>
</tr>
<tr>
<td>GI</td>
<td>General interrogation command.</td>
</tr>
<tr>
<td>GIS</td>
<td>Gas-insulated switchgear.</td>
</tr>
<tr>
<td>GOOSE</td>
<td>Generic object-oriented substation event.</td>
</tr>
<tr>
<td>GPS</td>
<td>Global positioning system.</td>
</tr>
<tr>
<td>GSAL</td>
<td>Generic security application.</td>
</tr>
<tr>
<td>GTM</td>
<td>GPS Time Module.</td>
</tr>
<tr>
<td>HDLC protocol</td>
<td>High-level data link control, protocol based on the HDLC standard.</td>
</tr>
<tr>
<td>HFBR connector type</td>
<td>Plastic fiber connector.</td>
</tr>
<tr>
<td>HMI</td>
<td>Human-machine interface.</td>
</tr>
<tr>
<td>HSAR</td>
<td>High speed autoreclosing.</td>
</tr>
<tr>
<td>HV</td>
<td>High-voltage.</td>
</tr>
<tr>
<td>HVDC</td>
<td>High-voltage direct current.</td>
</tr>
<tr>
<td>IDBS</td>
<td>Integrating deadband supervision.</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electrical Committee.</td>
</tr>
<tr>
<td>IEC 60870-5-103</td>
<td>Communication standard for protection equipment. A serial master/slave protocol for point-to-point communication.</td>
</tr>
<tr>
<td>IEC 61850</td>
<td>Substation automation communication standard.</td>
</tr>
<tr>
<td>IEC 61850–8–1</td>
<td>Communication protocol standard.</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers.</td>
</tr>
<tr>
<td>IEEE 802.12</td>
<td>A network technology standard that provides 100 Mbits/s on twisted-pair or optical fiber cable.</td>
</tr>
<tr>
<td>IEEE P1386.1</td>
<td>PCI Mezzanine Card (PMC) standard for local bus modules. References the CMC (IEEE P1386, also known as Common Mezzanine Card) standard for the mechanics and the PCI specifications from the PCI SIG (Special Interest Group) for the electrical EMF (Electromotive force).</td>
</tr>
</tbody>
</table>
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 IP20- Protected against solid foreign objects of 12.5mm diameter and greater.

IP 40  Ingression protection, according to IEC 60529, level IP40- Protected against solid foreign objects of 1mm diameter and greater.

IP 54  Ingression protection, according to IEC 60529, level IP54-Dust-protected, protected against splashing water.

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
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNT</td>
<td>LON network tool</td>
</tr>
<tr>
<td>LON</td>
<td>Local operating network</td>
</tr>
<tr>
<td>MCB</td>
<td>Miniature circuit breaker</td>
</tr>
<tr>
<td>MCM</td>
<td>Mezzanine carrier module</td>
</tr>
<tr>
<td>MIM</td>
<td>Milli-ampere module</td>
</tr>
<tr>
<td>MPM</td>
<td>Main processing module</td>
</tr>
<tr>
<td>MVAL</td>
<td>Value of measurement</td>
</tr>
<tr>
<td>MVB</td>
<td>Multifunction vehicle bus. Standardized serial bus originally developed for use in trains.</td>
</tr>
<tr>
<td>NCC</td>
<td>National Control Centre</td>
</tr>
<tr>
<td>NOF</td>
<td>Number of grid faults</td>
</tr>
<tr>
<td>NUM</td>
<td>Numerical module</td>
</tr>
<tr>
<td>OCO cycle</td>
<td>Open-close-open cycle</td>
</tr>
<tr>
<td>OCP</td>
<td>Overcurrent protection</td>
</tr>
<tr>
<td>OEM</td>
<td>Optical Ethernet module</td>
</tr>
<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>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</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>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>Term</td>
<td>Definition/Description</td>
</tr>
<tr>
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<tr>
<td>SPA</td>
<td>Strömberg Protection Acquisition (SPA), a serial master/slave protocol for point-to-point 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>
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<tr>
<td>Starpoint</td>
<td>Neutral/Wye point of transformer or generator</td>
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<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>
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<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>
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<tr>
<td>TEF</td>
<td>Time delayed ground-fault protection function</td>
</tr>
<tr>
<td>TM</td>
<td>Transmit (disturbance data)</td>
</tr>
<tr>
<td>TNC connector</td>
<td>Threaded Neill-Concelman, a threaded constant impedance version of a BNC connector</td>
</tr>
<tr>
<td>TP</td>
<td>Trip (recorded fault)</td>
</tr>
<tr>
<td>TPZ, TPY, TPX, TPS</td>
<td>Current transformer class according to IEC</td>
</tr>
<tr>
<td>TRM</td>
<td>Transformer Module. This module transforms currents and voltages taken from the process into levels suitable for further signal processing.</td>
</tr>
<tr>
<td>TYP</td>
<td>Type identification</td>
</tr>
<tr>
<td>UMT</td>
<td>User management tool</td>
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<tr>
<td>Underreach</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>UTC</td>
<td>Coordinated Universal Time. A coordinated time scale, maintained by the Bureau International des Poids et Mesures</td>
</tr>
</tbody>
</table>
(BIPM), which forms the basis of a coordinated dissemination of standard frequencies and time signals. UTC is derived from International Atomic Time (TAI) by the addition of a whole number of "leap seconds" to synchronize it with Universal Time 1 (UT1), thus allowing for the eccentricity of the Earth's orbit, the rotational axis tilt (23.5 degrees), but still showing the Earth's irregular rotation, on which UT1 is based. The Coordinated Universal Time is expressed using a 24-hour clock, and uses the Gregorian calendar. It is used for aeroplane and ship navigation, where it is also sometimes known by the military name, "Zulu time." "Zulu" in the phonetic alphabet stands for "Z", which stands for longitude zero.

<table>
<thead>
<tr>
<th>UV</th>
<th>Undervoltage</th>
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<tbody>
<tr>
<td>WEI</td>
<td>Weak end infeed logic</td>
</tr>
<tr>
<td>VT</td>
<td>Voltage transformer</td>
</tr>
<tr>
<td>X.21</td>
<td>A digital signalling interface primarily used for telecom equipment</td>
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<tr>
<td>3I₀</td>
<td>Three times zero-sequence current. Often referred to as the residual or the ground-fault current</td>
</tr>
<tr>
<td>3V₀</td>
<td>Three times the zero sequence voltage. Often referred to as the residual voltage or the neutral point voltage</td>
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</tbody>
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