Relion® 670 SERIES
Transformer protection RET670
Version 2.2 IEC
Commissioning manual
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This product complies with the directive of the Council of the European Communities on the approximation of the laws of the Member States relating to electromagnetic compatibility (EMC Directive 2004/108/EC) and concerning electrical equipment for use within specified voltage limits (Low-voltage directive 2006/95/EC). This conformity is the result of tests conducted by ABB in accordance with the product standard EN 60255-26 for the EMC directive, and with the product standards EN 60255-1 and EN 60255-27 for the low voltage directive. The product is designed in accordance with the international standards of the IEC 60255 series.
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Section 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, as well as communication engineering for IEC 61850.

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

The commissioning manual contains instructions on how to commission the IED. The manual can also be used by system engineers and maintenance personnel for assistance during the testing phase. The manual provides procedures for the checking of external circuitry and energizing the IED, parameter setting and configuration as well as verifying settings by secondary injection. The manual describes the process of testing an IED in a 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 operation principle descriptions, and lists function blocks, logic diagrams, input and output signals, setting parameters and technical data, sorted per function. The manual can be used as a technical reference during the engineering phase, installation and commissioning phase, and during normal service.

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

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

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

### 1.3.2 Document revision history

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<td>2017–05</td>
<td>2.2.0</td>
<td>First release for product version 2.2</td>
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<td>A</td>
<td>2017–10</td>
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<td>Ethernet ports with RJ45 connector added. Enhancements/updates made to ZMFPDIS and ZMFCPDIS.</td>
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<td>C</td>
<td>2018–06</td>
<td>2.2.2</td>
<td>LDCM galvanic X.21 added. Function PTRSTHR added. Ordering section updated.</td>
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### 1.3.3 Related documents

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<td>Application manual</td>
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### 1.4 Document symbols and conventions

#### 1.4.1 Symbols

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

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

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

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

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

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

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

### 1.4.2 Document conventions

- Abbreviations and acronyms in this manual are spelled out in the glossary. The glossary also contains definitions of important terms.
- Push button navigation in the LHMI menu structure is presented by using the push button icons.
  
  For example, to navigate between the options, use \[ \text{△} \] and \[ \text{▽} \].
- 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 \[ \text{Save} \].
- Parameter names are shown in italics.
  
  For example, the function can be enabled and disabled with the **Operation** setting.
- Each function block symbol shows the available input/output signal.
  
  - the character ^ in front of an input/output signal name indicates that the signal name may be customized using the PCM600 software.
  - the character * after an input signal name indicates that the signal must be connected to another function block in the application configuration to achieve a valid application configuration.
- Dimensions are provided both in inches and millimeters. If it is not specifically mentioned then the dimension is in millimeters.

### 1.5 IEC 61850 edition 1 / edition 2 mapping

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

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

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<th>Function block name</th>
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<tr>
<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.

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

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 earth, 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 earthed.

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.

2.3 Caution signs

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 earth 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.

2.4 Note signs

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

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

### 3.1 Main protection functions

#### Table 2: Example of quantities

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<tr>
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<tr>
<td>3-A03</td>
<td>= optional function included in packages A03 (refer to ordering details)</td>
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<tr>
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<th>Function description</th>
<th>Transformer</th>
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<td>RET670 (Customized)</td>
<td>RET670 A00</td>
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<td>87T</td>
<td>Transformer differential protection, two winding</td>
<td>1-3</td>
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<tr>
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<td>87T</td>
<td>Transformer differential protection, three winding</td>
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<td>HZPDIF</td>
<td>87</td>
<td>High impedance differential protection, single phase</td>
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<td>REFPDIF</td>
<td>87N</td>
<td>Restricted earth fault protection, low impedance</td>
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<td>11REL</td>
<td>Additional security logic for differential protection</td>
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<td>PSTPDIF</td>
<td>87T</td>
<td>Self-adaptive differential protection for two-winding power transformers</td>
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<tr>
<td><strong>Impedance protection</strong></td>
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<td></td>
<td></td>
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<td>21</td>
<td>Distance protection zone, quadrilateral characteristic</td>
<td>0-5</td>
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<tr>
<td>ZDRDIR</td>
<td>21D</td>
<td>Directional impedance quadrilateral</td>
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<tr>
<td>ZMCAPDIS, ZMCPDIS</td>
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<td>Distance measuring zone, quadrilateral characteristic for series compensated lines</td>
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<tr>
<td>ZDSRDIR</td>
<td>21D</td>
<td>Directional impedance quadrilateral, including series compensation</td>
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Table continues on next page
### Available functions

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<td>Phase selection, quadrilateral characteristic with fixed angle</td>
<td>RET670 (Customized) 0-2</td>
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<tr>
<td>ZMHPDIS 21</td>
<td>Full-scheme distance protection, mho characteristic</td>
<td>RET670 (A10) 0-5</td>
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<tr>
<td>ZMMPDIS, ZMMPDIS 21</td>
<td>Full-scheme distance protection, quadrilateral for earth faults</td>
<td>RET670 (B20) 0-5</td>
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<tr>
<td>ZDMRDIR 21D</td>
<td>Directional impedance element for mho characteristic</td>
<td>RET670 (B30) 0-2</td>
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<tr>
<td>ZDARDIR</td>
<td>Additional distance protection directional function for earth faults</td>
<td>RET670 (B40) 0-1</td>
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<td>ZSMGAPC</td>
<td>Mho impedance supervision logic</td>
<td>RET670 (A20) 0-1</td>
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<td>FMSPSPDIS 21</td>
<td>Faulty phase identification with load encroachment</td>
<td>RET670 (A10) 0-2</td>
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<tr>
<td>ZMRPDIS, ZMRAPDIS 21</td>
<td>Distance measuring zone, quad characteristic separate Ph-Ph and Ph-E settings</td>
<td>RET670 (B20) 0-5</td>
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<td>FRPSPDIS 21</td>
<td>Phase selection, quadrilateral characteristic with settable angle</td>
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<td>High speed distance protection, quad and mho characteristic</td>
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<td>High speed distance protection for series comp. lines, quad and mho characteristic</td>
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<td>Phase preference logic</td>
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<td>Poleslip/out-of-step protection</td>
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<td>Out-of-step protection</td>
<td>RET670 (B30) 0-1</td>
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<td>ZCVPFSOF</td>
<td>Automatic switch onto fault logic, voltage and current based</td>
<td>RET670 (B40) 0-1, 1-B15, 1-B15</td>
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### 3.2 Back-up protection functions

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<td>RET670 (Customized) RET670 (A10) RET670 (B30) RET670 (B40) RET670 (A25)</td>
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<td><strong>Current protection</strong></td>
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<td>Thermal overload protection, one time constant, Fahrenheit</td>
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<td>Two step undervoltage protection</td>
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**Frequency protection**

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<td>6-E01</td>
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**Multipurpose protection**

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<th>RET670 (B30)</th>
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**General calculation**

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

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<td>Synchrocheck, energizing check and synchronizing</td>
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<td>1B 4-H03</td>
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<td>APC15</td>
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<td>Control functionality for a single bay, max 15 objects (2CB), including interlocking (see Table 4)</td>
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<td>1-H39</td>
<td>1-H39</td>
<td>1-H39</td>
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<td>APC30</td>
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<td>Control functionality for up to 6 bays, max 30 objects (6CBs), including interlocking (see Table 5)</td>
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<td>1-H39</td>
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<td>Handling of LR-switch positions</td>
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<td>1+5/APC30</td>
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<td>Automatic voltage control for tap changer, single control</td>
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<th>RET670 (Customized)</th>
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<th>RET670 (B30)</th>
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<td>Tap changer control and supervision, 6 binary inputs</td>
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<td>4</td>
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<th>RET670 (A10)</th>
<th>RET670 (B30)</th>
<th>RET670 (B40)</th>
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**Secondary system supervision**

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<td>CCSSPVC</td>
<td>87</td>
<td>Current circuit supervision</td>
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<tr>
<td>FUFSPVC</td>
<td>0-4</td>
<td>Fuse failure supervision</td>
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<td>VDSPVC</td>
<td>60</td>
<td>Fuse failure supervision based on voltage difference</td>
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<td>DELVSPVC</td>
<td>7V, 78V</td>
<td>Voltage delta supervision, 2 phase</td>
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<td>DELISPVC</td>
<td>71</td>
<td>Current delta supervision, 2 phase</td>
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<td>DELSPVC</td>
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<td>Real delta supervision, real</td>
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**Logic**

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<td>Tripping logic</td>
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<tr>
<td>SMAGAPC</td>
<td>12</td>
<td>General start matrix block</td>
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<td>STARTCOMB</td>
<td>32</td>
<td>Start combinator</td>
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<td>TMAGAPC</td>
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<td>Logic for group alarm</td>
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<td>ANSI Function description</td>
<td>Transformer</td>
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<td>WRNCALH</td>
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<tr>
<td>INDCALH</td>
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<td>AND, GATE, INV, LLD, OR, PULSETIMER, RSMEMORY, TIMERSET, XOR</td>
<td>Basic configurable logic blocks (see Table 3)</td>
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<td>AND, GATE, INV, LLD, OR, PULSETIMER, RSMEMORY, SLGAPC, SRMEMORY, TIMERSET, VSGAPC, XOR</td>
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<td>FXDSIGN</td>
<td>Fixed signal function block</td>
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<td>B16I</td>
<td>Boolean to integer conversion, 16 bit</td>
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<td>BTIGAPC</td>
<td>Boolean to integer conversion with logical node representation, 16 bit</td>
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<td>IB16</td>
<td>Integer to Boolean 16 conversion</td>
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<td>Integer to Boolean 16 conversion with Logic Node representation</td>
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<th>RET670 (A30)</th>
<th>RET670 (B40)</th>
<th>RET670 (A25)</th>
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<td>INTCOMP</td>
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<td>REALCOMP</td>
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**Table 3:** Total number of instances for basic configurable logic blocks

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<td>40</td>
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<td>INV</td>
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<td>LLD</td>
<td>40</td>
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<td>OR</td>
<td>298</td>
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<tr>
<td>PULSETIMER</td>
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<td>RSMEMORY</td>
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<td>SRMEMORY</td>
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<td>TIMERSET</td>
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<td>XOR</td>
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### Table 4: Number of function instances in APC15

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<td>A1A2_BS</td>
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<td>2</td>
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<tr>
<td>A1A2_DC</td>
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<td>3</td>
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<td>ABC_BC</td>
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<td>1</td>
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<tr>
<td>BH_CONN</td>
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<td>1</td>
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<tr>
<td>BH_LINE_A</td>
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<td>1</td>
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<tr>
<td>BH_LINE_B</td>
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<tr>
<td>DB_BUS_A</td>
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<td>1</td>
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<td>DB_BUS_B</td>
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<td>DB_LINE</td>
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<tr>
<td>ABC_LINE</td>
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<td>AB_TRAFO</td>
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<tr>
<td>SCSWI</td>
<td>Switch controller</td>
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<tr>
<td>SXSWI</td>
<td>Circuit switch</td>
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<tr>
<td>RESIN1</td>
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<tr>
<td>RESIN2</td>
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<td>POS_EVAL</td>
<td>Evaluation of position indication</td>
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### Table 5: Number of function instances in APC30

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<td>ABC_BC</td>
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<tr>
<td>BH_CONN</td>
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<tr>
<td>BH_LINE_A</td>
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<td>BH_LINE_B</td>
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<td>RESIN2</td>
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<td>QCBAY</td>
<td>Bay control</td>
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<td>LOCREM</td>
<td>Handling of LR-switch positions</td>
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<td>Proxy for signals from switching device via GOOSE</td>
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Table 6: Total number of instances for configurable logic blocks Q/T

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<td>INVERTERQT</td>
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<td>ORQT</td>
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<td>PULSETIMERQT</td>
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Table 7: Total number of instances for extended logic package

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<td>OR</td>
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<td>TIMERSET</td>
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### Transformer protection RET670

#### Available functions

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<td>Generic communication function for Single Point indication 16 inputs</td>
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<td>I103SUPERV</td>
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<td>1</td>
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<td>I103USRDEF</td>
<td>Status for user defined signals for IEC 60870-5-103</td>
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<td>20</td>
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<td>L4UFCNT</td>
<td>Event counter with limit supervision</td>
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<tr>
<td>PTRSTHR</td>
<td>Through fault monitoring</td>
<td>0-2</td>
<td>2-M22</td>
<td>2-M22</td>
<td>2-M22</td>
<td>2-M22</td>
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<tr>
<td>CHMMHAI</td>
<td>Current harmonic monitoring, 3 phase</td>
<td>0-3</td>
<td>0-3</td>
<td>0-3</td>
<td>0-3</td>
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<td>VHMMHAI</td>
<td>Voltage harmonic monitoring, 3 phase</td>
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Table continues on next page
### 3.4 Communication

<table>
<thead>
<tr>
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<th>Function description</th>
<th>Transformer</th>
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<tr>
<td></td>
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<td></td>
<td>RET670 (Customized)</td>
</tr>
<tr>
<td><strong>Metering</strong></td>
<td></td>
<td></td>
<td>RET670 (A10)</td>
</tr>
<tr>
<td>PCFCNT</td>
<td></td>
<td>Pulse-counter logic</td>
<td>16</td>
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<tr>
<td>ETPMMTR</td>
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<td>Function for energy calculation and demand handling</td>
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**Station communication**

<table>
<thead>
<tr>
<th>IEC 61850 or function name</th>
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<th>Function description</th>
<th>Transformer</th>
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<tbody>
<tr>
<td></td>
<td></td>
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<td>RET670 (Customized)</td>
</tr>
<tr>
<td>LONSPA, SPA</td>
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<td>SPA communication protocol</td>
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</tr>
<tr>
<td>HORZCOMM</td>
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<td>Network variables via LON</td>
<td>1</td>
</tr>
<tr>
<td>IEC 61850-8-1</td>
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<td>IEC 61850</td>
<td>1</td>
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<tr>
<td>GOOSEINTLKRCV</td>
<td></td>
<td>Horizontal communication via GOOSE for interlocking</td>
<td>59</td>
</tr>
<tr>
<td>GOOSEBINRCV</td>
<td></td>
<td>GOOSE binary receive</td>
<td>16</td>
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<tr>
<td>GOOSEDPRCV</td>
<td></td>
<td>GOOSE function block to receive a double point value</td>
<td>64</td>
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<tr>
<td>GOOSEINTRCV</td>
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<td>GOOSE function block to receive an integer value</td>
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<td>GOOSEMVRCV</td>
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<td>GOOSE function block to receive a measurand value</td>
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<td>GOOSESPRCV</td>
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<td>GOOSE function block to receive a single point value</td>
<td>64</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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<td>Horizontal communication via GOOSE for VCTR</td>
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<td>GOOSECVRCONF</td>
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<td>GOOSE VCTR configuration for send and receive</td>
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<tr>
<td>MULTICCMDRCV, MULTICMDSND</td>
<td></td>
<td>Multiple command and transmit</td>
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<td>AGSAL</td>
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<td>Generic security application component</td>
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<td>LDOLLN0</td>
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<td>IEC 61850 LD0 LLN0</td>
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<tr>
<td>IEC 61850 or function name</td>
<td>ANSI</td>
<td>Function description</td>
<td>Transformer</td>
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<td>----------------------------</td>
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<tr>
<td></td>
<td></td>
<td>RET670 (Customized)</td>
<td>RET670 (A30) RET670 (B30) RET670 (A40) RET670 (A50)</td>
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<td>SYSLLN0</td>
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<td>LPHD</td>
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<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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<td>FSTACCS</td>
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<td>Field service tool access</td>
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<td></td>
<td></td>
<td>IEC 61850-9-2 Process bus communication, 8 merging units</td>
<td>0-1 1-P30 1-P30 1-P30 1-P30 1-P30</td>
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<tr>
<td>ACTIVLOG</td>
<td></td>
<td>Activity logging</td>
<td>1 1 1 1 1 1</td>
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<tr>
<td>ALTRK</td>
<td></td>
<td>Service tracking</td>
<td>1 1 1 1 1 1</td>
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<tr>
<td>PRP</td>
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<td>IEC 62439-3 Parallel redundancy protocol</td>
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<td>HSR</td>
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<td>IEC 62439-3 High-availability seamless redundancy</td>
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<td>PMUCONF</td>
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<td>Synchrophasor report, 24 phasors (see Table 8)</td>
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<td>PMUREPORT</td>
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<td></td>
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<tr>
<td>PHASORREPORT1</td>
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<td></td>
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<tr>
<td>PHASORREPORT2</td>
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<tr>
<td>PHASORREPORT3</td>
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<td>ANALOGERPORT1</td>
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<tr>
<td>SMAI1 - SMAI2</td>
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<tr>
<td>3PHSUM</td>
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<td></td>
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<tr>
<td>PMUSTATUS</td>
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<td>PTP</td>
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<td>Precision time protocol</td>
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<td>SCHLCCH</td>
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<td>Access point diagnostic for non-redundant Ethernet port</td>
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<td>RCHLCCH</td>
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<td>Access point diagnostic for redundant Ethernet ports</td>
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<td><strong>Remote communication</strong></td>
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<td>BinSignRec1_2</td>
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<td>BinSignRec1_2</td>
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<td>BinSignReceive2</td>
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<td>BinSignTransm2</td>
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<td>BinSigRec1_12M</td>
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<td>Binary signal transfer, 2Mbit receive/transmit</td>
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<td>BinSigRec1_22M</td>
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<tr>
<td>BinSigRec1_22M</td>
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<tr>
<td>BinSigTran1_12M</td>
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<td></td>
</tr>
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<td>BinSigTran1_22M</td>
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<td>LDCMTRN</td>
<td></td>
<td>Transmission of analog data from LDCM</td>
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<tr>
<td>LDCMTRN_2M</td>
<td></td>
<td>Transmission of analog data from LDCM, 2Mbit</td>
<td>6 6 6 6 6 6</td>
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<tr>
<td>LDCMRecBinStat2</td>
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<td></td>
<td></td>
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<td>LDCMRecBinStat3</td>
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<tr>
<td>LDCMRecBinS2_2M</td>
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<td>Receive binary status from LDCM, 2Mbit</td>
<td>3 3 3 3 3 3</td>
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</table>

Table continues on next page
### Table 8: Number of function instances in Synchronphasor report, 24 phasors

<table>
<thead>
<tr>
<th>Function name</th>
<th>Function description</th>
<th>Number of instances</th>
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<tbody>
<tr>
<td>PMUCONF</td>
<td>Configuration parameters for C37.118 2011 and IEEE1344 protocol</td>
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<tr>
<td>PMUREPORT</td>
<td>Protocol reporting via IEEE 1344 and C37.118</td>
<td>1</td>
</tr>
<tr>
<td>PHASORREPORT1</td>
<td>Protocol reporting of phasor data via IEEE 1344 and C37.118, phasors 1-8</td>
<td>1</td>
</tr>
<tr>
<td>PHASORREPORT2</td>
<td>Protocol reporting of phasor data via IEEE 1344 and C37.118, phasors 9-16</td>
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<tr>
<td>PHASORREPORT3</td>
<td>Protocol reporting of phasor data via IEEE 1344 and C37.118, phasors 17-24</td>
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<tr>
<td>ANALOGREPORT1</td>
<td>Protocol reporting of analog data via IEEE 1344 and C37.118, analogs 1-8</td>
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<tr>
<td>BINARYREPORT1</td>
<td>Protocol reporting of binary data via IEEE 1344 and C37.118, binary 1-8</td>
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</tr>
<tr>
<td>SMAI1–SMAI12</td>
<td>Signal Matrix for analog inputs</td>
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</tr>
<tr>
<td>3PHSUM</td>
<td>Summation block 3 phase</td>
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<tr>
<td>PMUSTATUS</td>
<td>Diagnostics for C37.118 2011 and IEEE1344 protocol</td>
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### 3.5 Basic IED functions

#### Table 9: Basic IED functions

<table>
<thead>
<tr>
<th>IEC 61850 or function name</th>
<th>Description</th>
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<tbody>
<tr>
<td>INTERRSIG</td>
<td>Self supervision with internal event list</td>
</tr>
<tr>
<td>TIMESYNCHGEN</td>
<td>Time synchronization module</td>
</tr>
<tr>
<td>BININPUT, SYNCHCAN, SYNCHGPS, SYNCHMPPS, SYNCHLON, SYNCHPPH, SYNCHPPS, SNTP, SYNCHSPA</td>
<td>Time synchronization</td>
</tr>
<tr>
<td>TIMEZONE</td>
<td>Time synchronization</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 - SMAI12</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>
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<tr>
<td>FTPACCS</td>
<td>FTP access with password</td>
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<tr>
<td>ALTMS</td>
<td>Time master supervision</td>
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<tr>
<td>ALTIM</td>
<td>Time management</td>
</tr>
<tr>
<td>COMSTATUS</td>
<td>Protocol diagnostic</td>
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#### Table 10: Local HMI functions

<table>
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<th>IEC 61850 or function name</th>
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<tr>
<td>LHMICTRL</td>
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<td>Local HMI signals</td>
</tr>
<tr>
<td>LANGUAGE</td>
<td></td>
<td>Local human machine language</td>
</tr>
<tr>
<td>SCREEN</td>
<td></td>
<td>Local HMI Local human machine screen behavior</td>
</tr>
<tr>
<td>FKKEYTY1–FKKEYTY5</td>
<td></td>
<td>Parameter setting function for HMI in PCM600</td>
</tr>
<tr>
<td>FKKEYMD1–FKKEYMD5</td>
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<td>Parameter setting function for HMI in PCM600</td>
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Table continues on next page
<table>
<thead>
<tr>
<th>IEC 61850 or function name</th>
<th>ANSI</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEDGEN</td>
<td></td>
<td>General LED indication part for LHMI</td>
</tr>
<tr>
<td>OPENCLOSE_LED</td>
<td></td>
<td>LHMI LEDs for open and close keys</td>
</tr>
<tr>
<td>GRP1_LED1–GRP1_LED15</td>
<td></td>
<td>Basic part for CP HW LED indication module</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRP2_LED1–GRP2_LED15</td>
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<tr>
<td>GRP3_LED1–GRP3_LED15</td>
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</tr>
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</table>
Section 4  Starting up

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
- RJ-45 Ethernet cable (CAT 5)
- Three-phase test kit or other test equipment depending on the complexity of the configuration and functions to be tested.
- PC with PCM600 installed along with the connectivity packages corresponding to the IEDs to be tested.
- Administration rights on the PC, to set up IP addresses
4.3 Checking the power supply

Do not insert anything else to the female connector but the corresponding male connector. Inserting anything else (such as a measurement probe) may damage the female connector and prevent a proper electrical contact between the printed circuit board and the external wiring connected to the screw terminal block.

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.

Energize the power supply of the IED to start it up. Keep the DC power supply on until the Root menu or the selected default screen is shown on the HMI before interrupting the DC power supply again. The energization could be done in a number of ways, from energizing a whole cubicle with many IEDs to energizing each single IED one by one.

If HW (i.e. I/O and/or communication boards etc.) have been changed (i.e. removed, replaced, or added), the user should re-configure the IED by navigating in the local HMI menu to: **Main menu/Configuration/Reconfigure HW modules** to activate the changed hardware modules in order to enable the self-supervision function to detect possible hardware errors.

Check also the self-supervision function in **Main menu/Diagnostics/IED status/General menu** in local HMI to verify that the IED operates properly.

Set the IED time if no time synchronization source is configured.

To ensure that the IED is according to the delivery and ordering specifications documents delivered together with each IED, the user should also after start-up use the built in HMI to check the IED’s:

- Software version, **Main menu/Diagnostics/IED status/Product identifiers**.
- Serial number, **Main menu/Diagnostics/IED status/Product identifiers**.
- Installed modules and their ordering number, **Main menu/Diagnostics/IED status/Installed HW**.

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 ‘Ready’ after about 90 seconds. A steady green light indicates a successful startup.
**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 transport layer is TCP/IP.

Each IED has an RJ-45 Ethernet interface connector on the front. The front Ethernet connector is recommended to 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.
- A 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**

Communication between the IED and PCM600 is enabled from the LHMI. The IP address and the corresponding communication subnetwork mask must be set via the Ethernet configuration tool (ECT) for each available Ethernet interface in the IED. Each Ethernet interface has a default factory IP address when the IED is delivered. The IP address and the subnetwork mask might have to be reset when an additional Ethernet interface is installed or an interface is replaced.
DHCP is available for the front port, and a device connected to it can thereby obtain an automatically assigned IP address via the local HMI path Main menu/Configuration/Communication/Ethernet configuration/Front port/DHCP.

Alternatively 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/TCP-IP configuration/ETHFRNT:1Main menu/Configuration/Communication/Ethernet configuration/AP_FRONT.

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

An ethernet cable (max 2 m length) with RJ-45 connectors is needed to connect two physical Ethernet interfaces together without a hub, router, bridge or switch in between.

If an IED is equipped with optical LC interface, a converter between RJ-45 and LC is needed.

1. Select Search programs and files in the Start menu in Windows.

![Search programs and files](image)

Figure 3: 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 6: 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 7. The IP address must be different from the IP address chosen for the IED.

Figure 7: Select: Use the following IP address

6. Use the **ping** command to verify connectivity with the IED.
7. Close all open windows and start PCM600.
The PC and IED must belong to the same subnetwork for this set-up to work.

**Setting up the PC to access the IED via a network**

The same method is used as for connecting to the front port.

The PC and IED must belong to the same subnetwork for this set-up to work.

### 4.6 Writing an application configuration to the IED

When writing a configuration to the IED with PCM600, 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 L1, L2, L3.)
- 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.
- Earthing check of the individual CT secondary circuits to verify that each three-phase set of main CTs is properly connected to the station earth 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 earth 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)
- Earthing 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 input/output circuits

Do not insert anything else to the female connector but the corresponding male connector. Inserting anything else (such as a measurement probe) may damage the female connector and prevent a proper electrical contact between the printed circuit board and the external wiring connected to the screw terminal block.

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 has an minimum space requirement of 180 mm for plastic fiber cables and 275 mm 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.

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. The Parameter Setting Tool in PCM600 is used when changing setting parameters.

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.

Make sure that the DC supply is not turned off when the IED saves the written configuration.

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.

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 commissioner 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/Configurations/Analog modules

The following parameter shall be set for every current transformer connected to the IED:
Table 11: CT configuration

<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>$CTPRIM_{n}$</td>
<td>$n = \text{channel number}$</td>
<td>from 0 to 99999</td>
</tr>
</tbody>
</table>

This parameter defines the primary rated current of the CT. For two sets 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. This might be necessary if two sets of CTs have different star point locations in relation to the protected busbar.

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 Supervision of input/output modules

I/O modules configured with PCM600 (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/IEC103 port, the SPA/IEC103 port has to be set either for SPA or IEC103 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:

- plastic fibers with connector type HFBR
- glass fibers with connector type ST

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

Procedure:

1. Set the port for SPA use on the local HMI under Main menu /Configuration /Communication /Station communication/Port configuration/SLM optical serial port/PROTOCOL:1. When the communication protocol is selected, the IED is automatically restarted, and the port then operates as a SPA port.
2. Set the SlaveAddress and BaudRate for the rear SPA port on the local HMI under Main menu/Configuration/Communication/Station communication/SPA/SPA:1. Use the same settings for these as is set in the SMS system for the IED.

6.1.2  Entering IEC settings

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

- plastic fibers with connector type HFBR
- glass fibers with connector type ST

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

Procedure:

1. Set the port for IEC use on the local HMI under Main menu /Configuration /Communication /Station communication/Port configuration/SLM optical serial port/PROTOCOL:1. When the communication protocol is selected, the IED is automatically restarted, and the port then operates as an IEC port.
2. Set the SlaveAddress and BaudRate for the rear IEC port on the local HMI under Main menu/Configuration/Communication/Station communication/IEC60870-5-103/OPTICAL103:1. Use the same settings for these as is set in the SMS 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, “REL670 2.1...”.
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 Fiber optic loop

The SPA communication is mainly used for SMS. It can include different numerical IEDs with remote communication possibilities. The fiber 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 12: Max distances between IEDs/nodes

<table>
<thead>
<tr>
<th>Material</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>glass</td>
<td>&lt; 1000 m according to optical budget</td>
</tr>
<tr>
<td>plastic</td>
<td>&lt; 25 m (inside cubicle) according to optical budget</td>
</tr>
</tbody>
</table>
6.4 Optical budget calculation for serial communication with SPA/IEC

Table 13: Example

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

7.1  Communication via the rear ports

7.1.1  LON communication

LON communication is normally used in substation automation systems. Optical fiber is used within the substation as the physical communication link.

The test can only be carried out when the whole communication system is installed. Thus, the test is a system test and is not dealt with here.

An optical network can be used within the substation automation system. This enables communication with the IEDs through the LON bus from the operator’s workplace, from the control center and also from other IEDs via bay-to-bay horizontal communication. For LON communication an SLM card should be ordered for the IEDs.

The fiber optic LON bus is implemented using either glass core or plastic core fiber optic cables.
Table 14: Specification of the fiber optic connectors

<table>
<thead>
<tr>
<th></th>
<th>Glass fiber</th>
<th>Plastic fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable connector</td>
<td>ST-connector</td>
<td>snap-in connector</td>
</tr>
<tr>
<td>Cable diameter</td>
<td>62.5/125 m</td>
<td>1 mm</td>
</tr>
<tr>
<td>Max. cable length</td>
<td>1000 m</td>
<td>10 m</td>
</tr>
<tr>
<td>Wavelength</td>
<td>820-900 nm</td>
<td>660 nm</td>
</tr>
<tr>
<td>Transmitted power</td>
<td>-13 dBm (HFBR-1414)</td>
<td>-13 dBm (HFBR-1521)</td>
</tr>
<tr>
<td>Receiver sensitivity</td>
<td>-24 dBm (HFBR-2412)</td>
<td>-20 dBm (HFBR-2521)</td>
</tr>
</tbody>
</table>

7.1.2 The LON Protocol

The LON protocol is specified in the LonTalkProtocol Specification Version 3 from Echelon Corporation. This protocol is designed for communication in control networks and is a peer-to-peer protocol where all the devices connected to the network can communicate with each other directly. For more information of the bay-to-bay communication, refer to the section Multiple command function.

7.1.3 Hardware and software modules

The hardware needed for applying LON communication depends on the application, but one very central unit needed is the LON Star Coupler and optical fibers connecting the star coupler to the IEDs. To interface the IEDs from the MicroSCADA with Classic Monitor, application library LIB520 is required.

The HV Control 670 software module is included in the LIB520 high-voltage process package, which is a part of the Application Software Library in MicroSCADA applications.

The HV Control 670 software module is used for control functions in the IEDs. The module contains a process picture, dialogues and a tool to generate a process database for the control application in MicroSCADA.

When using MicroSCADA Monitor Pro instead of the Classic Monitor, SA LIB is used together with 670 series Object Type files.

The HV Control 670 software module and 670 series Object Type files are used with both 650 and 670 series IEDs.

Use the LON Network Tool (LNT) to set the LON communication. This is a software tool applied as one node on the LON bus. To communicate via LON, the IEDs need to know

- The node addresses of the other connected IEDs.
- The network variable selectors to be used.

This is organized by LNT.

The node address is transferred to LNT via the local HMI by setting the parameter ServicePinMsg = Yes. The node address is sent to LNT via the LON bus, or LNT can scan the network for new nodes.

The communication speed of the LON bus is set to the default of 1.25 Mbit/s. This can be changed by LNT.
The LON communication setting parameters are set via the local HMI. Refer to the Technical manual for more detailed specifications.

If LON communication from the IED stops because of illegal communication parameter settings (outside the setting range) or due to other kind of disturbance, it is possible to reset the IED's LON port.

LON communication setting parameters (Table 15) and LON node information parameters (Table 16) can only be set via the LON Network Tool (LNT).

Some of these parameters can be viewed on the local HMI under Main menu/Configuration/Communication/Station communication/Port configuration/SLM optical LON port/LONGEN:1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Default</th>
<th>Unit</th>
<th>Parameter description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DomainID</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>Domain identification number</td>
</tr>
<tr>
<td>SubnNetAddr*</td>
<td>0 - 255</td>
<td>0</td>
<td>-</td>
<td>Subnet address</td>
</tr>
<tr>
<td>NodeAddr*</td>
<td>0 - 127</td>
<td>0</td>
<td>-</td>
<td>Node address</td>
</tr>
</tbody>
</table>

*Can be viewed on the local HMI

Table 15: LON communication setting parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Default</th>
<th>Unit</th>
<th>Parameter description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NeuronID*</td>
<td>0 - 12</td>
<td>Not loaded</td>
<td>-</td>
<td>Neuron hardware identification number in hexadecimal code</td>
</tr>
<tr>
<td>Location</td>
<td>0 - 6</td>
<td>No value</td>
<td>-</td>
<td>Location of the node</td>
</tr>
</tbody>
</table>

*Can be viewed on the local HMI

Table 16: LON node information parameters

ADE settings are available on the local HMI under Main menu/Configuration/Communication/Station communication/LON/ADE:1

<table>
<thead>
<tr>
<th>Name</th>
<th>Values (Range)</th>
<th>Unit</th>
<th>Step</th>
<th>Default</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td>Off</td>
<td>-</td>
<td>-</td>
<td>Off</td>
<td>Operation</td>
</tr>
<tr>
<td>TimerClass</td>
<td>Slow</td>
<td>-</td>
<td>-</td>
<td>Slow</td>
<td>Timer class</td>
</tr>
</tbody>
</table>

LON commands are available on the local HMI under Main menu/Configuration/Communication/Station communication/Port configuration/SLM optical LON pot/Service Pin Message/Generate service pin message

<table>
<thead>
<tr>
<th>Command</th>
<th>Command description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ServPinMess</td>
<td>Command with confirmation. Transfers the node address to the LON Network Tool.</td>
</tr>
</tbody>
</table>
### 7.2 Optical budget calculation for serial communication with LON

Table 19: Example

<table>
<thead>
<tr>
<th></th>
<th>Distance 1 km Glass</th>
<th>Distance 10 m Plastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum attenuation</td>
<td>-11 dB</td>
<td>-7 dB</td>
</tr>
<tr>
<td>4 dB/km multi mode: 820 nm - 62.5/125 um</td>
<td>4 dB</td>
<td>-</td>
</tr>
<tr>
<td>0.3 dB/m plastic: 620 nm - 1 mm</td>
<td>-</td>
<td>3 dB</td>
</tr>
<tr>
<td>Margins for installation, aging, and so on</td>
<td>5 dB</td>
<td>2 dB</td>
</tr>
<tr>
<td>Losses in connection box, two contacts (0.75 dB/contact)</td>
<td>1.5 dB</td>
<td>-</td>
</tr>
<tr>
<td>Losses in connection box, two contacts (1 dB/contact)</td>
<td>-</td>
<td>2 dB</td>
</tr>
<tr>
<td>Margin for repair splices (0.5 dB/splice)</td>
<td>0.5 dB</td>
<td>-</td>
</tr>
<tr>
<td>Maximum total attenuation</td>
<td>11 dB</td>
<td>7 dB</td>
</tr>
</tbody>
</table>
Section 8 Establishing connection and verifying the IEC 61850 communication

8.1 Overview

The rear optical Ethernet ports are used for:

- process bus (IEC/UCA 61850-9-2LE) communication
- IEEE C37.118/1344 communication
- substation bus (IEC 61850-8-1) communication

8.2 Setting the station communication

To enable IEC 61850 communication, the corresponding ports must be activated. The rear access points can be used for IEC 61850-8-1 and IEC/UCA 61850-9-2LE communication. IEC 61850-8-1 redundant communication requires the use of two Ethernet ports, when it is activated for Ethernet port the next immediate port is selected as the second Ethernet port and will become hidden.

To enable IEC 61850 station communication:

1. Activate IEC 61850-8-1 (substation bus) communication.
   Navigate to: Main menu/Configuration/Communication/Station communication/IEC61850–8–1/IEC61850–8–1:1
2. Enable operation for Access Point 1 and 3 in the Ethernet configuration tool (ECT) in PCM600.
3. Enable redundant communication for Acess point 1 using ECT.
4. Enable IEC/UCA 61850-9-2LE (process bus) communication for Access point 3 by connecting it to a Merging unit in the Merging units tab in ECT.

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

8.3 Verifying the communication

To verify that the communication is working a test/analyzing tool, for example ITT600, can be used.

Verifying redundant IEC 61850-8-1 communication

Ensure that the IED receives IEC 61850-8-1 data on the selected Ethernet ports. Browse in the local HMI to Main menu/Diagnostics/Communication/Ethernet status/Access point/
APStatusRedundant/RCHLCCCH:1 and check that ChARedStatus and ChBRedStatus are shown as Ok. Remove the optical connection to one of the Ethernet ports. Verify that either signal status (depending on which connection that was removed) is shown as Error and that the other signal is shown as Ok. Be sure to re-connect the removed connection after completed verification.
Section 9 Establishing connection and verifying the IEEE C37.118/1344 communication

9.1 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/UCA 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.

9.2 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 On.
   1.2. Enable sending the frequency data by setting the parameter SendFreqInfo to On.

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

9.3 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 the rear optical ports can be used for IEEE C37.118/1344 communication.

To enable IEEE C37.118/1344 synchrophasor communication:

1. Enable communication for by navigating to: Main menu/Configuration/Communication/Ethernet configuration.
   1.1. Select the port.
   1.2. Set values for Mode, IPAddress and IPMask. Mode must be set to Normal.
   1.3. Check that the correct IP address is assigned to the port.

2. Set the TCP communication parameters by navigating to: Main menu/Configuration/Communication/Station communication/phasor measurement/PMU Configuration/
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 the 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 the 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 On.
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.

9.4 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.

![PMU Connection Tester tool](IEC140000133-1-en.vsd)

Figure 9: 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.
1. Navigate to the **Settings** tab.
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 the IED's 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
9.5 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 communication explains how to set the PMU Connection Tester parameters in order to establish an IEEE C37.118 connection with the PMU.

9.5.1 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...
Figure 15: Stop capturing the IEEE C37.118 synchrophasor data

- 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.
9.5.2 Verifying the IEEE C37.118/1344 UDP communication

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.

- 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.
9.6 Optical budget calculation for PMU - PDC communication

Most of the times, the PMU IEDs are located in the substations. A local PDC might be located in the substation. For communications within the substation or between the IED 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.

![Graph showing optical power budget for fiber optic cable lengths](image)

*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 10 Testing IED operation

10.1 Preparing for test

10.1.1 Requirements

IED test requirements:

- Calculated settings
- Application configuration diagram
- Signal matrix (SMT) configuration
- Terminal connection diagram
- Technical manual
- Three-phase test equipment
- Process bus, IEC/UCA 61850-9-2LE, MU test simulator, if IEC/UCA 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 On) 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 work online 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/UCA 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.

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”.

If the IED is used together with a merging unit and no time synchronization is available, for example, in the laboratory test, the IED will synchronize to the SV data stream. During the re-synchronization, the protection functions will be blocked once a second for about 45 ms, and this will continue for up to 10 minutes. To avoid this, configure PTP (IEEE 1588) to On for the access point where the merging unit is configured.

10.1.2 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 start 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.

10.2 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 test switch should then be connected to the IED. Test mode is indicated when the yellow StartLED 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.
2. Use the up and down arrows to choose On and press E.
3. Press the left arrow to exit the menu.
4. The dialog box Save changes appears.
5. Choose Yes, press E and exit the menu.
   The yellow startLED above the LCD will start flashing when the IED is in test mode.

10.3 Preparing the connection to the test equipment

The IED can be equipped with a test switch of type RTXP8, RTXP18 or RTXP24. The test switch and its associated test plug handle (RTXH8, RTXH18 or RTXH24) are a part of the COMBITEST system, 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.

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.

### 10.4 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.

To ensure correct results, make sure that the IED as well as the test equipment are properly earthed before testing.
10.5 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 On, 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 On, 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.
10.6 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/UCA 61850-9-2LE 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/Configuration/Analog modules

If the IEC/UCA 61850-9-2LE communication is interrupted during current injection, the report tool in PCM600 will display the current that was injected before the interruption.
10.7 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.

10.8 Forcing of binary input/output signals for testing

10.8.1 Forcing concept

Forcing of binary inputs and outputs is a convenient way to test wiring in substations as well as testing configuration logic in the IEDs. Basically it means that all binary inputs and outputs on the IED I/O modules (BOM, BIM, IOM & SOM) can be set to a value (i.e active or not-active), selected by the user, while the IED is in test mode. For inputs, this is true regardless of the actual signal voltage present on the input. For outputs, any output relay can be forced to be active or not, regardless of the current requested state of the output in the IED logic configuration.

Be observant that forcing of binary inputs and outputs on an IED, with inappropriate setup, can result in potential danger.
10.8.2 How to enable forcing

To enable forcing, the IED must first be put into IED test mode. While the IED is not in test mode, the LHMI/PCM600 menus that relate to forcing will not have any effect on the input/output status due to safety reasons.

10.8.2.1 Enable forcing by using LHMI

1. Enable IED TESTMODE by setting IEDTestMode to On under Main menu/Test/IED test mode/TESTMODE:1.

2. Exit back to the root menu.
3. Select Yes in the save dialogue box.
   Once the IED is in test mode the yellow Start LED starts to blink.

10.8.2.2 Enable forcing using TESTMODE function block

- Use the TESTMODE function block, appropriately configured in PCM600/ACT.

It may be convenient to control the input on mentioned component from, for example, an LHMI function key or similar during commissioning to quickly and easily enter IED test mode.

10.8.3 How to change binary input/output signals using forcing

Once the IED is in IED test mode, the LHMI/PCM600 menus can be used to control input/output signals freely.

10.8.3.1 Forcing by using LHMI

Editing a signal value directly

- Edit the input/output value directly to select the desired logical level, by doing following:
  1. Select the value line of the desired signal, see figure 21.
  2. Press the Enter key to edit the value.
3. Use the up/down arrows on the LHMI to change the signal value or the appropriate menu in PCM600. The status of the signal changes automatically to Forced (i.e. there is no need to set the status to Forced manually).

On the LHMI, these edit changes have immediate effect. This means that the value changes directly when the up/down arrow is pressed (i.e. there is no need to press the Enter key to effectuate the change).

When navigating away from a LHMI forcing menu for an I/O board, the user is prompted to either leave the signals forced, or to revert all of them back to the unforced state.

It is possible to power-cycle the IED in this state without losing the forcing states and values. This means that once a signal is forced, and the IED remains in IED test mode, the input or output will appear “frozen” at the value selected by the user, even if the IED is switched off and back on again.

**Freezing a signal value without changing it**

- Set the status of a signal to Forced, in the forcing menu that corresponds to the I/O card in question. See example of LHMI menu in figure 22.
The signal “freezes” and will not change value even if, for example, a binary input signal voltage changes level, or if a binary output is activated as the result of a protection function block activating.

### 10.8.3.2 Forcing by using PCM600

In PCM600 the concept is a bit different compared to LHMI. The forcing is accomplished by entering a forcing session. Within such a session, multiple signals on multiple I/O boards may be edited and changed at the same time and has no effect on the IED. Once the user is satisfied with the forcing setup, then all the changes can be effectuated simultaneously towards the IED, potentially changing inputs and outputs on multiple I/O boards at the same time. It is also possible to abort this operation (described in step 6 below) and to undo all forcing.

1. Right click on the IED in the plant structure and select Signal Monitoring.
2. Click on the List View tab.
3. Click Forcing Session in the menu IED/Start Forcing.

4. Click Start editing signal value for forcing on the tool bar.

The Signal Monitoring menu changes and indicates the forcing values that can be edited.
5. Select and edit the values.
6. Click Acknowledge and send.

This commits the values to the IED and exits the editing session.

7. Click Cancel to abort the changes and revert back to actual IED values.

Regardless if the forcing changes are committed or canceled, the forcing is still active.

To force more signals, click the button Start editing signal value for forcing again.

10.8.4 How to undo forcing changes and return the IED to normal operation

Regardless of which input/output signals have been forced, all forced signals will return to their normal states immediately when the IED is taken out of test mode.

When the forcing is removed by exiting from IED test mode, both input and output signals may change values. This means that logic input signals may activate functions in the IED and that output relays may change state, which can be potentially dangerous.
10.8.4.1 Undo forcing by using TESTMODE component

- If the IED test mode was entered through the test mode function block:
  1. Deactivate the control input on that block.

  This immediately undoes all forcing, regardless of how it was accomplished and disabled all the way to force signals.

10.8.4.2 Undo forcing by using LHMI

- If the IED test mode was enabled to using the LHMI:
  1. Set \textit{IEDTestMode} to \textit{Off} in the LHMI menu.
  2. Exit from the menu and click \textit{Yes} in the Save dialogue box.

  This immediately undoes all forcing, regardless of how it was accomplished and disabled.

10.8.4.3 Undo forcing by using PCM600

1. Uncheck \textit{Forcing Session} under the menu \textit{IED}.

2. Click \textit{Yes} in the confirmation dialogue box.

   PCM600 will revert all forced signals back to unforced and the real signal values will immediately take effect again.

   This may change both binary input values and output relay states and will undo any forcing done by using the LHMI.

   If the IED is left in test mode, then it is still possible to perform new forcing operations, both from LHMI and from PCM600.
Section 11  Testing functionality by secondary injection

11.1  Testing disturbance report

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

11.1.2  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.

11.1.3  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**.

### 11.1.4 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.

### 11.2 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.

### 11.3 Differential protection

#### 11.3.1 Transformer differential protection T2WPDIFF and T3WPDIFF

Prepare the IED for verification of settings outlined in Section "[Preparing the IED to verify settings](#)".

#### 11.3.1.1 Verifying the settings
1. Go to Main menu/Test/Function test modes/Differential protection and make sure that the restricted earth fault protection, low impedance function REFPDIF is set to Off and that the four step residual overcurrent function EF4PTOC under Main menu/Test/Function test modes/Current protection is set to Off, since they are configured to the same current transformer inputs as the transformer differential protection. Make sure that the transformer differential functions T2WPDIF or T3WPDIF are unblocked.

2. Connect the test set for injection of three-phase currents to the current terminals of the IED, which are connected to the CTs on the HV side of the power transformer.

3. Increase the current in phase L1 until the protection function operates and note the operating current.

4. Check that the trip and alarm contacts operate according to the configuration logic.

5. Decrease the current slowly from operate value and note the reset value. Depending on the power transformer vector group (Yd and so on), the single-phase injection current may appear as differential current in one or two phases and the operating value of the injected single-phase current will be different.

6. Check in the same way the function by injecting current in phases L2 and L3 respectively.

7. Inject a symmetrical three-phase current and note the operate value.

8. Connect the timer and set the current to twice the operate value.

9. Switch on the current and note the operate time.

10. Check in the same way the measuring circuits connected to the CTs on the LV side and other current inputs to the transformer differential protection.

11. Finally check that trip information is stored in the event menu.

Information on how to use the event menu is found in the operator’s manual.

12. If available on the test set, a second harmonic current of about 20% (assumes 15% setting on I1/I2 ratio parameter) can be added to the fundamental frequency in phase L1. Increase the current in phase L1 above the start value measured in step 6. Repeat test with current injection in phases L2 and L3 respectively. The balancing of currents flowing into and out of the differential zone is checked by primary injection testing. Fifth harmonic blocking can be tested in a similar way.

For more detailed formulas, please refer to the Application manual.

### 11.3.1.2 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.

### 11.3.2 High impedance differential protection HZPDIF

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

### 11.3.2.1 Verifying the settings
1. Connect single-phase or three-phase test set to inject the operating voltage. The injection is done across the measuring branch. The required trip and alarm voltage, as well as the used stabilizing resistance value must be set in the function. Note as well that used CT input in the IED must have ratio set as 1:1. This is essential for the measurement of the expected value. Normally a slightly higher operating value is no problem as the sensitivity is not influenced much.

2. Increase the voltage and make note of the operate value $U_{\text{Trip}}$. This is done by manual testing and without trip of the test set.

3. Connect the trip contact to the test set to stop the test set for measurement of trip times below.

4. Reduce the voltage slowly and make note of the reset value. The reset value must be high for this function.

5. Check the operating time by injecting a voltage corresponding to $1.2 \times U_{\text{Trip}}$ level. Make note of the measured trip time.

6. If required, verify the trip time at another voltage. Normally $2 \times U_{\text{Trip}}$ is selected.

7. If used, measure the alarm level operating value. Increase the voltage and make note of the operate value $U_{\text{Alarm}}$. This is done with manual test and without trip of the test set.

8. Measure the operating time on the alarm output by connecting the stop of the test set to an output from $t_{\text{Alarm}}$. Inject a voltage $1.2 \times U_{\text{Alarm}}$ and measure the alarm time.

9. Check that trip and alarm outputs operate according to the configuration logic.

10. Finally check that start and alarm information is stored in the event menu and if a serial connection to the SA is available verify that the correct and only the required signals are presented on the local HMI and on the SCADA system.

Information on how to use the event menu is found in the operator’s manual.

11.3.2.2 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.

11.3.3 Restricted earth fault protection, low impedance REFPDIF

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

11.3.3.1 Verifying the settings

1. Connect the test set for single-phase current injection to the protection terminals connected to the CT in the power transformer neutral-to-earth circuit.

2. Increase the injection current and note the operating value of the protection function.

3. Check that all trip and start signals appear according to the configuration logic.

4. Decrease the current slowly from operate value and note the reset value.

5. Connect the timer and set the current to ten times the value of the $Id_{\text{Min}}$ setting.

6. Switch on the current and note the operate time.

7. Connect the test set to terminal L1 and neutral of the three-phase current input configured to REFPDIF. Also inject a current higher than half the $Id_{\text{Min}}$ setting in the
neutral-to-earth circuit with the same phase angle and with polarity corresponding to an internal fault.

8. Increase the current injected in L1, and note the operate value. Decrease the current slowly and note the reset value.

9. Inject current into terminals L2 and L3 in the same way as in step 7 above and note the operate and reset values.

10. Inject a current equal to 10% of rated current into terminal L1.

11. Inject a current in the neutral-to-earth circuit with the same phase angle and with polarity corresponding to an external fault.

12. Increase the current to five times the operating value and check that the protection does not operate.

13. Finally check that trip information is stored in the event and disturbance recorder.

### 11.3.3.2 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.

### 11.3.4 Additional security logic for differential protection LDRGFC

#### 11.3.4.1 Verifying the settings

Prepare the IED for verification of settings outlined in section 1 “Overview” and section 2 “Preparing for test” in this chapter.

**Current variation local criteria**

Procedure

1. Set Operation to On.
2. Connect the test set for three phase current injection to the appropriate IED terminals.
3. Inject symmetrical phase currents equal to half the rated current.
4. Increase the injected current in phase L1 slowly by more than the set $ICV>$. No signal shall be activated.
5. Decrease the injected current in phase L1 to half the rated current.
6. Increase the injected current in phase L1 in a step by more than the set $ICV>$. Start shall be activated.

**Undervoltage criteria**

Procedure

1. Connect the test set for three phase current injection and three phase voltage to the appropriate IED terminals.
2. Inject symmetrical phase voltages equal to the rated voltage.
3. Decrease the injected voltage in phase L1 and note the operated value (start value) of the function.
4. Increase the voltage slowly and note the reset value.
5. Connect a trip output contact to a timer.
6. Reduce the injected voltage stepwise to 90% of the operate level, and check the time delay.
7. Repeat points 3–6 for phases L2 and L3.
8. Inject symmetrical phase voltages equal to the rated voltage.
9. Decrease the injected phase-phase voltage L1-L2 and note the operated value (start value) of the function.
10. Increase the voltage slowly and note the reset value.
11. Connect a trip output contact to a timer.
12. Reduce the injected voltage stepwise to 90 % of the operate level, and check the time delay.
13. Repeat points 9 – 12 for phases L2-L3 and L3-L1.

**Zero sequence overcurrent criteria**

**Procedure**

1. Connect the test set for three phase voltage injection (L1, L2, L3) or residual voltage injection (N) to the appropriate IED terminals. This is dependent on how the IED is fed from the CT.
2. Increase the injected zero sequence current and note the operate value (start value) of the studied step of the function.
3. Decrease the current slowly and note the reset value.
4. Connect a trip output contact to a timer.
5. Set the injected current to 200 % of the operate level of the tested stage, switch on the current and check the time delay.

**Low current criteria**

**Procedure**

1. Connect the test set for three phase current injection to the appropriate IED terminals.
2. Inject a symmetrical three phase current larger than the set value \( IUC \).
3. Decrease the injected current in phase L1 and note the operate value (start value) of the studied step of the function.
4. Increase the current slowly and note the reset value.
5. Connect a trip output contact to a timer.
6. Decrease the injected current stepwise to 50 % of the operate level and check the time delay.
7. Repeat steps 3 – 6 for phases L2 and L3.

### 11.3.4.2 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.

### 11.3.5 Self-adaptive differential protection for two-winding power transformers PSTPDIF

#### 11.3.5.1 Preparing the function for testing

Prepare the IED in general for verification of settings outlined in Section Preparing the IED to verify settings.
Navigate to **Main menu/Test/Function test mode** and make sure that only the PSTPDIF function and associated trip function blocks are enabled. All other protection functions, which may interfere with testing or tripping shall have the setting *Blocked* set to *Yes*.

The PSTPDIF function is self-adaptive. Thus, special measures and procedures shall be used during testing. Off-the-shelf available test sets with associated software and their testing routines for standard transformer differential protection will not work, in general, for this function. They may work for special case, when the phase angle shift is zero degree (i.e. as for Yy0 standard power transformer). However, for specific phase angle shift (e.g. tap position) of the protected PST, which is different from zero degree, this standard routines cannot be used.

To test this function, it is strongly recommended to use a test set with six current sources and then follow the sequence-wise testing procedure as explained for the traditional transformer differential protection in the paper *Easy and Intuitive Method for Testing Transformer Differential Relays* published by ABB. This paper is available on the ABB website.

To prepare the function to be tested for specific phase angle shift (e.g. specific tap position) of the protected PST, proceed as follows:

1. Make sure that the binary input STOPCOMP into PSTPDIF function has the logical value zero.
2. Wait for five seconds and inject the rated load using the positive sequence current systems only on both sides of the PST, which correspond to the set default transformation ratio and phase angle shift (typically, zero degree). Instructions on magnitude calculation and phase angles for the six currents to be injected are available in the above mentioned paper. When currents are injected correctly, check that all three differential currents are approximately 0% and the bias current is 100%. These values are available as outputs and service values from the PSTPDIF function.
3. Slowly (for example, one degree per second) rotate the positive sequence currents (i.e. all three phases together) for winding two side until the required phase angle shift is achieved. Note that the rotation in anti-clock-wise direction of winding two positive sequence current will result in corresponding but negative value of the estimated phase angle shift displayed on the IED. When PST is of an asymmetrical design, the magnitudes of the currents on the winding two side shall also be adjusted accordingly. Once the desired tap is reached, make sure that all three differential currents are still approximately 0% and the bias current is still 100%. Also, check that DIFRATIO and DIFANGLE outputs have value that corresponds to the PST tap position at which the function needs to be tested.
4. Apply the logical value one to the binary input STOPCOMP into PSTPDIF function. The function will now remember the transformation ratio and phase angle shift, which corresponds to this particular PST tap. These two values will be stored and used as long as the input STOPCOMP has a logical value one. To perform this, the IED shall be configured accordingly beforehand. Typically, one front LHMI key or one binary input can be configured in the configuration tool to perform this task. If additional security is needed, this action can be only allowed when the IED is in Testmode.
5. Interrupt all six currents from the test set and verify that DIFRATIO and DIFANGLE outputs still have value that corresponds to the PST tap position, at which the function needs to be tested. The function is now prepared to be tested at this particular tap position in a similar way as the standard transformer differential protection.

The following sections explain how the PSTPDIF shall be tested for this particular tap position. Note that, the above procedure and the following tests shall be repeated for every PST tap position, at which the function needs to be tested.

Note that the following tests can be used for any dedicated tap-position available in the protected PST. In actual installation, perform these tests for two extrema tap positions, mid-tap position and one or two more freely selected tap-position(s).
11.3.5.2 Verifying the zero-sequence current reduction from the winding one side

1. Connect the test set for three-phase currents injection to the current terminals of the IED, which are connected to the CTs on the winding one side of the power transformer.
2. Inject current in all three phases with equal magnitudes corresponding to the rated load of the PST (i.e. 100%) in secondary amperes as given below:

\[ I_{\text{Injected}_{W1}} = \frac{CT_{\text{sec}_W1}}{CT_{\text{prim}_{W1}}} \cdot I_{\text{Base}_{W1}} \]

(Equation 1)

The phase angle for all three injected currents on the test set shall have the same value of zero degree. As a consequence, the PSTPDIF function will work in either of the following two ways:

- Trip, if the parameter ZSCurrSubtrW1 = Off and all three differential currents and the bias current shall be 100%. These values are available as outputs and service values from the PSTPDIF function.
- Not trip, if the parameter ZSCurrSubtrW1 = On and all three differential currents and the bias current shall be 0%. These values are available as outputs and service values from the PSTPDIF function.

11.3.5.3 Verifying the three-phase pickup from winding one side

1. Connect the test set for three-phase currents injection to the current terminals of the IED, which are connected to the CTs on the winding one side of the power transformer.
2. Inject symmetrical three-phase currents (for example, positive sequence current only). Increase the current magnitude symmetrically in all three phases until the protection function operates and note the operating current. The operating secondary current should have the following value:

\[ I_{\text{Pickup}_{W1}} = \frac{CT_{\text{sec}_W1}}{CT_{\text{prim}_{W1}}} \cdot Id_{\text{Min}} \cdot I_{\text{Base}_{W1}} \]

(Equation 2)

The pickup current is independent of the actual phase angle shift across the protected PST.

3. Check that the trip and alarm contacts operate according to the configuration logic.
4. Decrease the current slowly from the operate value and note the reset value.
5. Switch off the currents and connect an external timer to measure the operate time of the function. Set the current in all three phases to twice the above measured pickup value.
6. Switch on the currents and note the operate time of the PSTPDIF function.
7. Check that the trip information is stored in the IED internal Event List and Disturbance Recorder.
8. Check that the trip information is properly indicated on the LHMI LEDs.
11.3.5.4 Verifying the single-phase pickup from winding one side

1. Connect the test set for three-phase currents injection to the current terminals of the IED, which are connected to the CTs on the winding one side of the power transformer.
2. Increase the current magnitude in phase L1 only until the protection function operates and note the secondary current at the moment of pickup. The operating secondary current should have one of the following two values:
   - Equal to the tested three-phase pickup value from winding one side if the parameter ZSCurrSubtrW1 = Off.
   - Greater for factor 1.5 from the tested three-phase pickup value from winding one side if the parameter ZSCurrSubtrW1 = On.

   The pickup current is independent of the actual phase angle shift across the protected PST.
3. Check that the trip and alarm contacts operate according to the configuration logic.
4. Decrease the current slowly from the operate value and note the reset value.
5. If available on the test set, a second harmonic current of about 20% (assumes 15% default setting value for I2/I1Ratio parameter) shall be added to the fundamental frequency current in phase L1. Increase the fundamental frequency current magnitude in phase L1 above the pickup value measured in step 2. Make sure that trip signal from the PSTPDIF function is not given. Check that the second harmonic blocking is active in the corresponding phase.
6. If available on the test set, a fifth harmonic current of about 30% (assumes 25% default setting value for I5/I1Ratio parameter) shall be added to the fundamental frequency current in phase L1. Increase the fundamental frequency current magnitude in phase L1 more than the pickup value measured in step 2. Make sure that trip signal from the PSTPDIF function is not given. Check that the fifth harmonic blocking is active in the corresponding phase.
7. Repeat the procedure by injecting current in phases L2 and L3 respectively.

11.3.5.5 Verifying the zero-sequence current reduction from winding two side

1. Connect the test set for three-phase currents injection to the current terminals of the IED, which are connected to the CTs on the winding two side of the power transformer.
2. Inject current in all three phases with equal magnitudes corresponding to the rated load of the PST (i.e. 100%) in secondary amperes as given below:

   \[
   I_{\text{Injected, W2}} = \frac{CTsec_{W2}}{CTprim_{W2}} \times I_{\text{Base, W2}}
   \]

   (Equation 3)

   The phase angle for all three injected current on the test set shall have the same value of zero degree. As a consequence the, PSTPDIF function will work in either of the following two ways:

   - Trip, if parameter ZSCurrSubtrW2 = Off and all three differential currents and the bias current shall be 100%. These values are available as outputs and service values from the PSTPDIF function.
   - Not trip, if parameter ZSCurrSubtrW2 = On and all three differential currents and the bias current shall be 0%. These values are available as outputs and service values from the PSTPDIF function.
11.3.5.6 Verifying the three-phase pickup from winding two side

1. Connect the test set for three-phase currents injection to the current terminals of the IED, which are connected to the CTs on the winding two side of the power transformer.
2. Inject symmetrical three-phase currents (for example, positive sequence current only). Increase the current magnitude symmetrically in all three phases until the protection function operates and note the operating current. The operating secondary current should have the following value:

\[
I_{\text{pickup}_{W2}} = \frac{CT_{secW2} \cdot I_{\text{IdMin}} \cdot I\text{Base}_{W2}}{CT_{primW2}}
\]

(Equation 4)

The pickup current is independent of the actual phase angle shift across the protected PST.

3. Check that the trip and alarm contacts operate according to the configuration logic.
4. Decrease the current slowly from the operate value and note the reset value.
5. Switch off the currents and connect an external timer to measure the operate time of the function. Set the current in all three phases to twice the above measured pickup value.
6. Switch on the currents and note the operate time of the PSTPDIF function.
7. Check that the trip information is stored in the IED internal Event List and Disturbance Recorder.
8. Check that the trip information is properly indicated on the LHMI LEDs.

11.3.5.7 Verifying the single-phase pickup from winding two side

1. Connect the test set for three-phase currents injection to the current terminals of the IED, which are connected to the CTs on the winding two side of the power transformer.
2. Increase the current magnitude in phase L1 only until the protection function operates and note the operating current. The secondary current at the moment of pickup will be greater for a certain factor from the measured three-phase pickup value depending on the set value for the parameter ZSCurrSubtrW2 and the actual phase angle shift across the protected power transformer for which the test is conducted, as explained below:
   - When ZSCurrSubtrW2 = Off, this factor will have a value between 1.00 and 1.50 depending on the actual phase angle shift as shown in Figure 23:

   ![Figure 23: Single-phase pickup factor when ZSCurrSubtrW2 = Off](image-url)
For phase angle shifts greater than ±60 degrees, actual operation will happen in one of other two phases where current has not been injected.

- When \(ZSCurrSubtrW2 = \text{On}\), this factor will have a value between 1.50 and 1.732 depending on the actual phase angle shift as shown in Figure 24:

![Figure 24: Single-phase pickup factor when ZSCurrSubtrW2 = On](image)

For phase angle shifts greater than ±30 degrees, actual operation will happen in one of the other two phases where the current has not been injected.

The pickup current is dependent on the actual phase angle shift across the protected PST.

3. Check that the trip and alarm contacts operate according to the configuration logic.
4. Decrease the current slowly from operate value and note the reset value.
5. Repeat the procedure by injecting current in phases L2 and L3 respectively.

### 11.3.5.8 Verifying the operate characteristic

1. Connect the test set for injection of two three-phase current sets to the current terminals of the IED, which are connected to the CTs on the winding one and winding two sides respectively of the power transformer.
2. Inject the x-times (where, \(x = \) any value between \(1.25 \times IdMin\) and \(0.95 \times IdUnre\) parameters) the rated load current using the positive sequence current systems only on both sides of the PST. For actual secondary current magnitudes of the rated PST load, see tests for zero-sequence current reduction given above. For more details on how to calculate magnitudes and the phase angles for the six currents to be injected, refer to the paper *Easy and Intuitive Method for Testing Transformer Differential Relays* published by ABB. When correct currents are injected, check that all three differential currents are approximately 0% and the bias current is equal to \(x \times 100\%\). These values are available as outputs and service values from the PSTPDF function. At this point, a stable condition for bias current of \(x \times 100\%\) is being injected.
3. If the factor \(x\) has a value greater than 5, make sure that the testing is done relatively quickly to avoid overheating of the input current transformers inside IED. Their continuous rating is 4 times the rated current (i.e. 1 A or 5 A secondary).
4. Slowly decrease the positive sequence currents (i.e. all three phases together) for winding two side until the PSTPDIF function gives a trip signal. At that moment, pause the injection and note down the values of all three differential currents in percent. The bias current still should have the same value (i.e. x*100%). Similarly, note the secondary current magnitude for winding one and two sides injected at that point of time.

5. Stop the injection and repeat above points 1-4 for different x-values.

6. From the recorded differential and bias values in percent, draw the operating characteristic from the measurements. Compare the values as described in the Technical Manual.

**11.3.5.9 Completing the test**

Continue to test another function or end the test by navigating to Main menu/Test/IED test mode/TESTMODE:1 and change the IEDTestMode setting to Off. Restore connections and settings to their original values, if they were changed for testing purposes.

**11.4 Impedance protection**

**11.4.1 Distance protection zones, quadrilateral characteristic ZMQPDIS**

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

Measure operating characteristics during constant current conditions. Keep the measured current as close as possible to its rated value or lower. But make sure it is higher than the set minimum operating current.

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.

The test procedure has to take into consideration that the shaped load encroachment characteristic is active. It is therefore necessary to check the setting. To verify the settings with the shaped load encroachment characteristic the test should be carried out according to figures 25 and 26 and tables 20 and 21. In cases where the load encroachment characteristic is activated tests according to the adjusted figures should be carried out.

To verify the settings for the operating points according to the following fault types should be tested:

- One phase-to-phase fault
- One phase-to-earth fault

The shape of the operating characteristic depends on the values of the setting parameters.

The figures illustrating the characteristic for the distance protection function can be used for settings with and without load encroachment. The solid lines designate the diagram applicable when the load current compensation is active. The solid line and all test points except 13 are valid for this case. When the load current compensation is inactive, the dotted lines and test point 13 are valid. Test points 5, 6, and 7 are not valid for this measurement.
Figure 25: Distance protection characteristic with test points for phase-to-phase measurements

Table 20: Test points for phase-to-phase loops L1-L2 (Ohm/Loop)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Set value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X1\text{set}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>X1\text{set}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>R1\text{set}</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.8 \times X1\text{set}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 \times R1\text{set} + \text{RFPP}/2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.5 \times X1\text{set}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 \times R1\text{set} + \text{RFPP}/2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.85 \times \text{RFPP} \times \tan(\text{ArgRLd})</td>
<td>\text{ArgLd} = \text{angle for the maximal load transfer}</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85 \times \text{RFPP}</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>\text{RLdFw} \times \tan(\text{ArgLd})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>\text{RLdFw}</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>\text{RLdFw}</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td>-0.2143 \times \text{RFPP}/2</td>
<td>\text{Exact: 0.8} \times \text{RFPP}/2 (\text{ArgDir}=20°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 \times \text{RFPP}/2</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>X</td>
<td>-0.4 \times \text{RLdFw} \times \tan(\text{ArgDir}=20°)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.4 \times \text{RLdFw}</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>X</td>
<td>0.5 \times X1\text{set}</td>
<td>\text{Exact} -0.5 \times R1\text{set} \times \tan(\text{ArgNegRes}=30°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.23 \times X1\text{set}</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>X</td>
<td>0.8 \times X1\text{set}</td>
<td>\text{Exact} -0.5 \times R1\text{set} \times \tan(\text{ArgNegRes}=30°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.37 \times X1\text{set}</td>
<td></td>
</tr>
</tbody>
</table>

Table continues on next page
Table 20 is used in conjunction with figure 25.

![Distance protection characteristic with test points for phase-to-earth measurements](EC05000369-4-en.vsdx)

**Figure 26**: Distance protection characteristic with test points for phase-to-earth measurements

Table 21 is used in conjunction with figure 26.

**Table 21: Test points for phase-to-earth L3-E (Ohm/Loop)**

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>(2 × X1set + X0set)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>(2 × X1set + X0set)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>2 × R1set + R0set)/3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.8 × (2 × X1set + X0set)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 × (2 × R1set + R0set)/3 + RFPEset</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.5 × (2 × X1set + R0set)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 × (2 × R1set + R0set)/3 + RFPEset</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.85 × RFPEset × tan(ArgLdset)</td>
<td>ArgLd = angle for the maximal load transfer</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85 × RFPE</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>RLdFwset × tan(ArgLdSet)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFwset</td>
<td></td>
</tr>
</tbody>
</table>

Table continues on next page
<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLD_Fw_set</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td>-0.1072 \times RLD_Fw_set</td>
<td>Exact: 0.4 \times RFPE \times \tan (\text{ArgDir}=20^\circ)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.4 \times RLD_Fw_set</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>X</td>
<td>-0.8 \times RLD_Fw_set \times \tan(\text{ArgDir}=20^\circ)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 \times RLD_Fw_set</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>X</td>
<td>0.17 \times (2 \times X1_{\text{set}} + X0_{\text{set}})</td>
<td>Exact: 0.5 \times (2 \times X1_{\text{set}} + X0_{\text{set}})/3</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.36 \times (2 \times X1_{\text{set}} + X0_{\text{set}})</td>
<td>Exact: 0.5 \times (2\times X1_{\text{set}} + X0_{\text{set}})/(3 \times \tan(\text{AgNegDir}=30^\circ))</td>
</tr>
<tr>
<td>11</td>
<td>X</td>
<td>0.27 \times (2 \times X1_{\text{set}} + X0_{\text{set}})</td>
<td>Exact: 0.8 \times (2 \times X1_{\text{set}} + X0_{\text{set}})/3</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.57 \times (2 \times X1_{\text{set}} + X0_{\text{set}})</td>
<td>Exact: 0.8 \times (2\times X1_{\text{set}} + X0_{\text{set}})/(3 \times \tan(\text{AgNegDir}=30^\circ))</td>
</tr>
<tr>
<td>12</td>
<td>X</td>
<td>0.5 \times (2 \times X1_{\text{set}} + X0_{\text{set}})/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 \times (2 \times R1_{\text{set}} + R0_{\text{set}})/3</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>X</td>
<td>0</td>
<td>Only used when RLD_Fw &gt; RFPE</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RFPE</td>
<td></td>
</tr>
</tbody>
</table>

### 11.4.1.1 Measuring the operating limit of set values

**Procedure:**

1. Subject the IED to healthy normal load conditions for at least two seconds.
2. Apply the fault condition and slowly decrease the measured impedance to find the operating value of the phase-to-phase fault for zone 1 according to test point 1 in figure 25 and table 20. Compare the result of the measurement with the set value.
3. Repeat steps 1 to 2 to find the operating value for test points 2, 3 in table 20. Observe that the zones that are not tested have to be blocked and the zone that is tested has to be released.
4. Repeat steps 1 to 3 to find the operating value for the phase-to-earth fault L3–E according to figure 26 and table 21.

Test points 8, 9, 10 and 11 are intended to test the directional lines of impedance protection. Since directionality is a common function for all 5 measuring zones, it is only necessary to test points 8, 9, 10 and 11 once in the forward direction in order to test the accuracy of directionality (directional angles). Directional functionality testing (trip inside, no-trip outside) should always be made for all impedance zones set with directionality (forward or reverse).

### 11.4.1.2 Measuring the operating time of distance protection zones

**Procedure:**
1. Subject the IED to healthy normal load conditions for at least two seconds.
2. Apply the fault condition to find the operating time for the phase-to-phase fault according to test point 12 in figure 25 and table 20 for zone 1. Compare the result of the measurement with the setting $t_{IPP}$.
3. Repeat steps 1 to 2 to find the operating time for the phase-to-earth fault according to test point 12 in figure 26 and table 21. Compare the result of the measurement with the setting $t_{IPE}$.
4. Repeat steps 1 to 3 to find the operating time for all other used measuring zones. Observe that the zones that are not tested have to be blocked and the zone that is tested has to be released.

11.4.1.3 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.

11.4.2 Phase selection, quad, fixed angle, load encroachment FDPSPDIS

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

The phase selectors operate on the same measuring principles as the impedance measuring zones. So it is necessary to follow the same principles as for distance protection, when performing the secondary injection tests.

Measure operating characteristics during constant current conditions. Keep the measured current as close as possible to the rated value of its associated input transformer, or lower. But ensure that it is higher than the set minimum operating current.

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.

To verify the settings the operating points according to figures 27 and 28 should be tested. See also tables 22 and 23 for information.
Figure 27: Operating characteristic for phase selection function, forward direction single-phase faults

Table 22: Test points for phase-to-earth loop L3-E (Ohm/loop)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>[X1+XN]</td>
<td>XN=(X₀-X₁)/3</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFw</td>
<td>When RLdFW &lt; RFFwPE</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RFFwPE</td>
<td>When RLdFwPE &gt; RFFwPE</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.85·[X1+XN]</td>
<td>R≈0.491·(X₁+XN)+RFFwPE</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85·[X1+XN]-1/tan(60°)+RFFwPE</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.85·[X1+XN]</td>
<td>Can be limited by RFFwPE</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.85·[X1+XN]-tan(ArgNegRes-90°)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>RFFwPE·tan(ArgLd)</td>
<td>Only when RLdFw &lt; RFFwPE</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RFFwPE</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>-0.5·RLdFw·tan(ArgDir)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5·RLdFw</td>
<td></td>
</tr>
</tbody>
</table>

Table 22 is used together with figure 27.
Table 23: Test points for phase-to-phase loops L1-L2 (Ohm/phase)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFw</td>
<td>When RLdFw &lt; 0.5·RFFwPP</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5·RFFwPP</td>
<td>When RLdFw &gt; 0.5·RFFwPP</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.85·X1</td>
<td>R=0.491·X1+0.5·RFFwPP</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85·X1·1/tan(60°)+0.5·RFFwPP</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.85·X1</td>
<td>Can be limited by RFFwPP</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.85·X1·tan(ArgNegRes-90°)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.5·RFFwPP·tan(ArgLd)</td>
<td>Only when RLdFW &lt; RFFwPP</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5·RFFwPP</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>-0.5·RLdFw·tan(ArgDir)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5·RLdFw</td>
<td></td>
</tr>
</tbody>
</table>

Table 23 is used together with figure 28.

11.4.2.1 Measuring the operating limit of set values

Procedure:
1. Supply the IED with healthy conditions for at least two seconds.
2. Apply the fault condition and slowly decrease the measured impedance to find the operate value for of the phase-to-earth loop L3, test point 1, according to figure 27. Compare the result of the measurement with the expected value according to table 22. The corresponding binary signals that inform about the operation of the phase selection measuring elements are available in the local HMI under Main menu/Test/Function status/Impedance Protection/PhaseSelection(PDIS, 21)/FDPSPDIS:x.
3. Repeat steps 1 to 2 to find the operate values for the remaining test points according to figure 27 and table 22. When the load encroachment characteristic is deliberately set very high in order not to have an influence, then the test points 2 and 5 can be replaced by test point 7.
4. Repeat steps 1 to 3 to find the operate value for the phase-to-phase fault in L1 — L2 according to figure 28 and table 23.

11.4.2.2 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.

11.4.3 Full scheme distance protection, mho characteristic ZMHPDIS

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

Consider releasing of the zone to be tested by setting the phase selector FMPSPDIS to On.

Keep the current constant when measuring operating characteristics. Keep the current as close as possible to its rated value or lower. But make sure it is higher than the set minimum operating current.

Ensure that the maximum continuous current in an IED does not exceed four times its rated value, if the measurement of the operating characteristics runs under constant voltage conditions.

To verify the mho characteristic, at least two points should be tested.

In the following, three test points are proposed. The mho characteristic always goes through the origin, which automatically gives a fourth point for the characteristic.
11.4.3.1 Phase-to-phase faults

Figure 29: Proposed test points for phase-to-phase fault

Table 24: Test points for phase-to-phase (ohms / phase)

<table>
<thead>
<tr>
<th>Test points</th>
<th>reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>ZPP · sin(ZAngPP)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>ZPP · sin(ZAngPP)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>0,5 · (ZPP · sin(ZAngPP))</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0,5 · ZPP + ΔR = 0,5 · ZPP · (1 + cos(ZAngPP))</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0,5 · ZPP · sin(ZAngPP)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0,5 · ZPP - ΔR = 0,5 · ZPP · (1 - cos(ZAngPP))</td>
<td></td>
</tr>
</tbody>
</table>

Change the magnitude and angle of phase-to-phase voltage to achieve impedances at test points 1, 2 and 3. For each test point, observe that the output signals, START, STLx and STPP are activated where x refers to the actual phase to be tested. After the timer tPP for the actual zone has elapsed, also the signals TRIP, TRPP and TRx shall be activated.

11.4.3.2 Phase-to-earth faults

For simplicity, the same test points as for phase-to-phase faults are proposed, but considering new impedance values.
Check also in the same way as for phase-to-earth fault for each test point that the output signals STPE, are activated where x refers to the actual phase to be tested. After the timer $t_{PE}$ for the zone has elapsed, also the signals TRIP, TRPE and TRx shall be activated.

### 11.4.4 Faulty phase identification with load encroachment FMSPDIS

There is no specific test routine for this function. The function is tested in conjunction with other impedance (mho) functions.

### 11.4.5 Distance protection zones, quadrilateral characteristic, separate settings ZMRPDIS

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

Consider releasing Zone 1 with the Phase selection with load encroachment, quadrilateral characteristic (FRPSDPIS). If the autorecloser is not released and in service, trip will always be three phase.

Measure operating characteristics during constant current conditions. Keep the measured current as close as possible to its rated value or lower. But make sure it is higher than 30% of the rated current.
Ensure that the maximum continuous current in an IED does not exceed four times its rated value, if the measurement of the operating characteristics runs under constant voltage conditions.

The test procedure has to take into consideration that the shaped load encroachment characteristic is active. It is therefore necessary to check the setting. To verify the settings with the shaped load encroachment characteristic the test should be carried out according to figures 31 and 32 and tables 26 and 27. In cases where the load encroachment characteristic is activated tests according to the adjusted figures should be carried out.

To verify the settings for the operating points according to the following fault types should be tested:

- One phase-to-phase fault
- One phase-to-earth fault

The shape of the operating characteristic depends on the values of the setting parameters.

The figures illustrating the characteristic for the distance protection function can be used for settings with and without load encroachment. The solid lines designate the diagram applicable when the load current compensation is active. The solid line and all test points except 13 are valid for this case. When the load current compensation is inactive, the dotted lines and test point 13 are valid. Test points 5, 6, and 7 are not valid for this measurement.

![Distance protection characteristic with test points for phase-to-phase measurements](image)

**Figure 31:** Distance protection characteristic with test points for phase-to-phase measurements

Table 26 is used in conjunction with figure 31.
Table 26: Test points for phase-to-phase loops L1-L2 (Ohm/Loop)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Set value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X₁_set</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>X₁_set</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>R₁_set</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.8 x X₁_set</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x R₁_set + RFPP/2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.5 x X₁_set</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x R₁_set + RFPP/2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.85 x RFPP x tan(ArgRLd)</td>
<td>ArgRLd = angle for the maximal load transfer</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85 x RFPP</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>RLdFw x tan(ArgLd)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFw</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td>RLdFw x tan(ArgLd)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td>−0.2143 x RFPP/2</td>
<td>Exact: 0.8 x RFPP/2 (ArgDir)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x RFPP/2</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>X</td>
<td>−0.4 x RLdFw x tan(ArgDir)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.4 x RLdFw</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>X</td>
<td>0.5 x X₁_set</td>
<td>Exact −0.5 x R₁_set x tan(ArgNegRes-90)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>−0.23 x X₁_set</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>X</td>
<td>0.8 x X₁_set</td>
<td>Exact −0.5 x R₁_set x tan(ArgNegRes-90)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>−0.37 x X₁_set</td>
<td></td>
</tr>
</tbody>
</table>

Figure 32: Distance protection characteristic with test points for phase-to-earth measurements

Table 27 is used in conjunction with figure 32.
## Measuring the operating limit of set values

### Procedure:

### Table 27: Test points for phase-to-earth L3-E (Ohm/Loop)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>(\frac{(2 \times X_{1_{\text{set}}} + X_{0_{\text{set}}})}{3})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>(\frac{(2 \times X_{1_{\text{set}}} + X_{0_{\text{set}}})}{3})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>(2 \times X_{1_{\text{set}}} + R_{0_{\text{set}}}/3)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>(\frac{0.8 \times (2 \times X_{1_{\text{set}}} + X_{0_{\text{set}}})}{3})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>(\frac{0.8 \times (2 \times X_{1_{\text{set}}} + X_{0_{\text{set}}})}{3} + RFPE_{\text{set}})</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>(\frac{0.5 \times (2 \times X_{1_{\text{set}}} + R_{0_{\text{set}}})}{3})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>(\frac{0.5 \times (2 \times X_{1_{\text{set}}} + R_{0_{\text{set}}})}{3} + RFPE_{\text{set}})</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.85 \times RFPE_{\text{set}} \times \tan(\text{ArgLd}_{\text{set}}) \text{ ArgLd = angle for the maximal load transfer.}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85 \times RFPE</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>RLdFw_{\text{set}} \times \tan(\text{ArgLd}_{\text{set}})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFw_{\text{set}}</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFw_{\text{set}}</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td>(-0.2143 \times RLdFw_{\text{set}}) Exact: 0.8 \times \text{RFPE} \times \tan(\text{ArgDir})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 \times RLdFw_{\text{set}}</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>X</td>
<td>(-0.8 \times RLdFw_{\text{set}} \times \tan(\text{ArgDir})) Exact: 0.8 \times RLdFw_{\text{set}}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 \times RLdFw_{\text{set}}</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>X</td>
<td>0.17 \times (2 \times X_{1_{\text{set}}} + X_{0_{\text{set}}}) Exact: 0.5 \times (2 \times X_{1_{\text{set}}} X_{0_{\text{set}}})/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.36 \times (2 \times X_{1_{\text{set}}} + X_{0_{\text{set}}}) Exact: 0.5 \times (2X_{1_{\text{set}}} + X_{0_{\text{set}}})/(3 \times \tan(\text{AngNegDir}_{90}))</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>X</td>
<td>0.27 \times (2 \times X_{1_{\text{set}}} + X_{0_{\text{set}}}) Exact: 0.8 \times (2 \times X_{1_{\text{set}}} + X_{0_{\text{set}}})/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.57 \times (2 \times X_{1_{\text{set}}} + X_{0_{\text{set}}}) Exact: 0.8 \times (2X_{1\text{set}} + X_{0\text{set}})/(3 \times \tan(\text{AngNegDir}_{90}))</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>X</td>
<td>0.5 \times (2 \times X_{1_{\text{set}}} + X_{0_{\text{set}}})/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 \times (2 \times X_{1_{\text{set}}} + R_{0_{\text{set}}})/3</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RFPE</td>
<td></td>
</tr>
</tbody>
</table>
1. Subject the IED to healthy normal load conditions for at least two seconds.
2. Apply the fault condition and slowly decrease the measured impedance to find the operating value of the phase-to-phase fault for zone 1 according to test point 1 in figure 31 and table 26. Compare the result of the measurement with the set value.
3. Repeat steps 1 to 2 to find the operating value for test points 2, 3 in table 26. Observe that the zones that are not tested have to be blocked and the zone that is tested has to be released.
4. Repeat steps 1 to 3 above to find the operating value for the phase-to-earth fault L3-E according to figure 32 and table 27.

Information:
Test points 8, 9, 10 and 11 are intended to test the directional lines of impedance protection. Since directionality is a common function for all 5 measuring zones, it is only necessary to test points 8, 9, 10 and 11 once, in the forward direction in order to test the accuracy of directionality (directional angles). Directional functionality testing (trip inside, no-trip outside) should always be made for all impedance zones set with directionality (forward or reverse).

11.4.5.2 Measuring the operating time of distance protection zones

Procedure:

1. Subject the IED to healthy normal load conditions for at least two seconds.
2. Apply the fault condition to find the operating time for the phase-to-phase fault according to test point 10 in figure 31 and table 26 for zone 1. Compare the result of the measurement with the setting tPP.
3. Repeat steps 1 to 2 to find the operating time for the phase-to-earth fault according to test point 10 in figure 32 and table 27. Compare the result of the measurement with the setting tPE.
4. Repeat steps 1 to 2 to find the operating time for all other used measuring zones. Observe that the zones that are not tested have to be blocked and the zone that is tested has to be released.

11.4.6 Phase selection, quadrilateral characteristic with settable angle FRPSPDIS

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

The phase selectors operate on the same measuring principles as the impedance measuring zones. So it is necessary to follow the same principles as for distance protection, when performing the secondary injection tests.

Measure operating characteristics during constant current conditions. Keep the measured current as close as possible to the rated value of its associated input transformer, or lower. But ensure that it is higher than 30% of the rated current.

Ensure that the maximum continuous current of an IED does not exceed four times its rated value, if the measurement of the operating characteristics runs under constant voltage conditions.

To verify the settings the operating points according to figures 33 and 34 should be tested. See also tables 28 and 29 for information.
Figure 33: Operating characteristic for phase selection function, forward direction single-phase faults

Figure 34: Operating characteristic for phase selection function, forward direction phase-to-phase faults

Table 28: Test points for phase-to-earth loop L3-E (Ohm/loop)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X [X1+XN]</td>
<td>XN=(X₀-X₁)/3</td>
</tr>
<tr>
<td></td>
<td>R 0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R RLdFw</td>
<td></td>
</tr>
</tbody>
</table>

Table continues on next page
### Test point

<table>
<thead>
<tr>
<th>Test point</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>X</td>
<td>0.85·[X1+XN]</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85·[X1+XN]·1/tan(60°)+RFFwPE</td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.85·[X1+XN]</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.85·[X1+XN]·tan (AngNegRes-90°)</td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>RFFwPE·tan (ArgLd)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RFFwPE</td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>-0.5·RLdFw·tan (ArgDir)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5·RLdFw</td>
</tr>
</tbody>
</table>

The table showing test points for phase-to-earth loops is used together with figure 33.

**Table 29:** Test points for phase-to-phase loops L1–L2

<table>
<thead>
<tr>
<th>Test point</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X1</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFw</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.85·X1</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85·X1·1/tan(60°)+0.5 RFFwPP</td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.85·X1</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.85·X1·tan (AngNegRes-90°)</td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.5·RFFwPP·tan (ArgLd)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5·RFFwPP</td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>-0.5·RLdFw·tan (ArgDir)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5·RLdFw</td>
</tr>
</tbody>
</table>

The table showing test points for phase-to-phase loops is used together with figure 34.

### 11.4.6.1 Measuring the operating limit of set values

**Procedure:**

1. Supply the IED with healthy conditions for at least two seconds.
2. Apply the fault condition and slowly decrease the measured impedance to find the operate value for of the phase-to-earth loop L3, test point 1, according to figure 33. Compare the result of the measurement with the expected value according to table 28. The corresponding binary signals that inform about the operation of the phase selection measuring elements are available in the local HMI under **Main menu/Test/Function status/Impedance Protection/PhaseSelection(PDIS, 21)/FRPSPDIS:x**.
3. Repeat steps 1 to 2 to find the operate values for the remaining test points according to figure 33 and table 28.
When the load encroachment characteristic is deliberately set very high in order not to have an influence, then the test points 2 and 5 can be replaced by test point 7.

4. Repeat steps 1 to 3 to find the operate value for the phase-to-phase fault in L1 — L2 according to figure 34 and table 29.

11.4.6.2 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.

11.4.7 High speed distance protection zones, quadrilateral and mho characteristic ZMFPDIS

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

Measure operating characteristics during constant current conditions. Keep the measured current as close as possible to its rated value or lower. But make sure it is higher than the set minimum operating current.

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.

The test procedure has to take into consideration that the shaped load encroachment characteristic is active. It is therefore necessary to check the setting. To verify the settings with the shaped load encroachment characteristic the test should be carried out according to figures 35 and 36 and tables 30 and 31. In cases where the load encroachment characteristic is activated tests according to the adjusted figures should be carried out.

To verify the settings for the operating points according to the following fault types should be tested:

- One phase-to-phase fault
- One phase-to-earth fault

The shape of the operating characteristic depends on the values of the setting parameters.

The figures illustrating the characteristic for the distance protection function can be used for settings with and without load encroachment. The solid lines designate the diagram applicable when the load current compensation is active. The solid line and all test points except 13 are valid for this case. When the load current compensation is inactive, the dotted lines and test point 13 are valid. Test points 5, 6, and 7 are not valid for this measurement.
Figure 35: Distance protection characteristic with test points for phase-to-phase measurements

Table 30: Test points for phase-to-phase loops L1-L2 (Ohm/Loop)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Set value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X1_set</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>X1_set</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>R1_set</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.8 x X1_set</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x R1_set + RFPPZx/2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.5 x X1_set</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x R1_set + RFPPZx/2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.85 x RFPPZx x tan(ArgLd)</td>
<td>ArgLd = angle for the maximal load transfer</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85 x RFPPZx</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>RLdFw x tan(ArgLd)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFw</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFw</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td>–0.2143 x RFPPZx/2</td>
<td>Exact: 0.8 x RFPPZx/2 (ArgDir=20°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x RFPPZx/2</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>X</td>
<td>–0.4 x RLdFw x tan(ArgDir=20°)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.4 x RLdFw</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>X</td>
<td>0.5 x X1_set</td>
<td>Exact –0.5 x R1_set x tan(ArgNegRes=30°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>–0.23 x X1_set</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>X</td>
<td>0.8 x X1_set</td>
<td>Exact –0.5 x R1_set x tan(ArgNegRes=30°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>–0.37 x X1_set</td>
<td></td>
</tr>
</tbody>
</table>
Table 30 is used in conjunction with figure 35.

![Diagram](EC2500369-4-en.vsdx)

**Figure 36**: Distance protection characteristic with test points for phase-to-earth measurements

Table 31 is used in conjunction with figure 36.

**Table 31: Test points for phase-to-earth L3-E (Ohm/Loop)**

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>((2 \times X1_{set} + X0_{set})/3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>((2 \times X1_{set} + X0_{set})/3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>(2 \times R1_{set} + R0_{set})/3)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>(0.8 \times (2 \times X1_{set} + X0_{set})/3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>(0.8 \times (2 \times R1_{set} + R0_{set})/3 + RFPEZ_{Xset})</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>(0.5 \times (2 \times X1_{set} + R0_{set})/3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>(0.5 \times (2 \times R1_{set} + R0_{set})/3 + RFPEZ_{Xset})</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>(0.85 \times RFPEZ_{Xset} \times \tan(\text{ArgLdset})) (\text{ArgLd = angle for the maximal load transfer})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85 x RFPEZx</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>RLdFwset x (\tan(\text{ArgLdSet}))</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFwset</td>
<td></td>
</tr>
</tbody>
</table>

Table continues on next page
### 11.4.7.1 Measuring the operating limit of set values

**Procedure:**

1. Subject the IED to healthy normal load conditions for at least two seconds.
2. Apply the fault condition and slowly decrease the measured impedance to find the operating value of the phase-to-phase fault for zone 1 according to test point 1 in figure 35 and table 30. Compare the result of the measurement with the set value.
3. Repeat steps 1 to 2 to find the operating value for test points 2, 3 in table 30. Observe that the zones that are not tested have to be blocked and the zone that is tested has to be released.
4. Repeat steps 1 to 3 to find the operating value for the phase-to-earth fault L3-E according to figure 36 and table 31.

Test points 8, 9, 10 and 11 are intended to test the directional lines of impedance protection. Since directionality is a common function for all six measuring zones, it is only necessary to test 8, 9, 10 and 11 once, in the forward direction in order to test the accuracy of directionality (directional angles). Directional functionality testing (trip inside, no-trip outside) should always be made for all impedance zones set with directionality (forward or reverse).

### 11.4.7.2 Measuring the operating time of distance protection zones

**Procedure:**

---

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFw_set</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td>-0.2143 x RLdFw_set</td>
<td>Exact: 0.8 x RFPEZx x tan (ArgDir=20°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x RLdFw_set</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>X</td>
<td>-0.8 x RLdFw_set x tan(ArgDir=20°) / 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x RLdFw_set</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>X</td>
<td>0.17 x (2 x X1_set + X0_set)</td>
<td>Exact: 0.5 x (2 x X1_set + X0_set)/3</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.36 x (2 x X1_set + X0_set)</td>
<td>Exact: 0.5 x (2 x X1_set + X0_set)/(3 x tan(AgNegDir=30°))</td>
</tr>
<tr>
<td>11</td>
<td>X</td>
<td>0.27 x (2 x X1_set + X0_set)</td>
<td>Exact: 0.8 x (2 x X1_set + X0_set)/3</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.57 x (2 x X1_set + X0_set)</td>
<td>Exact: 0.8 x (2 x X1_set + X0_set)/(3 x tan(AgNegDir=30°))</td>
</tr>
<tr>
<td>12</td>
<td>X</td>
<td>0.5 x (2 x X1_set + X0_set)</td>
<td>Exact: 0.5 x (2 x X1_set + X0_set)/3</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x (2 x R1_set + R0_set)/3</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RFPEZx</td>
<td></td>
</tr>
</tbody>
</table>
1. Subject the IED to healthy normal load conditions for at least two seconds.
2. Apply the fault condition to find the operating time for the phase-to-phase fault according to test point 12 in figure 35 and table 30 for zone 1. Compare the result of the measurement to the setting tPPZ1.
3. Repeat steps 1 to 2 to find the operating time for the phase-to-earth fault according to test point 12 in figure 36 and table 31. Compare the result of the measurement to the setting tPEZ1.
4. Repeat steps 1 to 2 to find the operating time for all other used measuring zones. The zones that are not tested have to be blocked and the zone that is tested has to be released.

11.4.7.3 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.

11.4.8 High Speed distance for series compensated line zones, quadrilateral and mho characteristic ZMFCPDIS

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

Measure operating characteristics during constant current conditions. Keep the measured current as close as possible to its rated value or lower. But make sure it is higher than the set minimum operating current.

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.

The test procedure has to take into consideration that the shaped load encroachment characteristic is active. It is therefore necessary to check the setting. To verify the settings with the shaped load encroachment characteristic the test should be carried out according to figures 37 and 38 and tables 32 and 33. In cases where the load encroachment characteristic is activated tests according to the adjusted figures should be carried out.

To verify the settings for the operating points according to the following fault types should be tested:

• One phase-to-phase fault
• One phase-to-earth fault

The shape of the operating characteristic depends on the values of the setting parameters.

The figures illustrating the characteristic for the distance protection function can be used for settings with and without load encroachment. The solid lines designate the diagram applicable when the load current compensation is active. The solid line and all test points except 13 are valid for this case. When the load current compensation is inactive, the dotted lines and test point 13 are valid. Test points 5, 6, and 7 are not valid for this measurement.
Figure 37: Distance protection characteristic with test points for phase-to-phase measurements

Table 32: Test points for phase-to-phase loops L1-L2 (Ohm/Loop)

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Set value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X1&lt;sub&gt;set&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>X1&lt;sub&gt;set&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>R1&lt;sub&gt;set&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.8 x X1&lt;sub&gt;set&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x R1&lt;sub&gt;set&lt;/sub&gt; + RFPPZx/2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.5 x X1&lt;sub&gt;set&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x R1&lt;sub&gt;set&lt;/sub&gt; + RFPPZx/2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.85 x RFPPZx x tan (ArgLd)</td>
<td>ArgLd = angle for the maximal load transfer</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85 x RFPPZx</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>RLdFw x tan (ArgLd)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLdFw</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td>RLdFw x tan (ArgLd)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td>–0.2143 x RFPPZx/2</td>
<td>Exact: 0.8 x RFPPZx/2 (ArgDir=20°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x RFPPZx/2</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>X</td>
<td>–0.4 x RLdFw x tan(ArgDir=20°)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.4 x RLdFw</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>X</td>
<td>0.5 x X1&lt;sub&gt;set&lt;/sub&gt;</td>
<td>Exact –0.5 x R1&lt;sub&gt;set&lt;/sub&gt; x tan(ArgNegRes=30°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>–0.23 x X1&lt;sub&gt;set&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>X</td>
<td>0.8 x X1&lt;sub&gt;set&lt;/sub&gt;</td>
<td>Exact –0.5 x R1&lt;sub&gt;set&lt;/sub&gt; x tan(ArgNegRes=30°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>–0.37 x X1&lt;sub&gt;set&lt;/sub&gt;</td>
<td></td>
</tr>
</tbody>
</table>

Table continues on next page
### Table 32

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>X</td>
<td>0.5 x X₁₅₁₁₁</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x R₁₅₁₁</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x RFₚₚ₁₅₁</td>
<td></td>
</tr>
</tbody>
</table>

Table 32 is used in conjunction with figure 37.

---

**Figure 38: Distance protection characteristic with test points for phase-to-earth measurements**

**Table 33: Test points for phase-to-earth L₃-E (Ohm/Loop)**

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>(2 x X₁₅₁₁₁ + X₀₁₅₁₁₁)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>(2 x X₁₅₁₁₁ + X₀₁₅₁₁₁)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>2 x R₁₅₁₁₁ + R₀₁₅₁₁₁)/3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>0.8 x (2 x X₁₅₁₁₁ + X₀₁₅₁₁₁)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x (2 x R₁₅₁₁₁ + R₀₁₅₁₁₁)/3 + RFₚₚ₁₅₁₁</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>0.5 x (2 x X₁₅₁₁₁ + R₀₁₅₁₁₁)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x (2 x R₁₅₁₁₁ + R₀₁₅₁₁₁)/3 + RFₚₚ₁₅₁₁</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>0.85 x RFₚₚ₁₅₁₁ x tan(ArgLd₁₅₁₁₁₁)</td>
<td>ArgLd = angle for the maximal load transfer</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.85 x RFₚₚ₁₅₁₁</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>RLₕ₁₅₁₁₁₁ x tan(ArgLd₁₅₁₁₁₁)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLₕ₁₅₁₁₁₁</td>
<td></td>
</tr>
</tbody>
</table>

Table continues on next page
### Measuring the operating limit of set values

**Procedure:**

1. Subject the IED to healthy normal load conditions for at least two seconds.
2. Apply the fault condition and slowly decrease the measured impedance to find the operating value of the phase-to-phase fault for zone 1 according to test point 1 in figure 37 and table 32. Compare the result of the measurement with the set value.
3. Repeat steps 1 to 2 to find the operating value for test points 2, 3 in table 32. Observe that the zones that are not tested have to be blocked and the zone that is tested has to be released.
4. Repeat steps 1 to 3 to find the operating value for the phase-to-earth fault L3-E according to figure 38 and table 33.

Test points 8, 9, 10 and 11 are intended to test the directional lines of impedance protection. Since directionality is a common function for all six measuring zones, it is only necessary to test points 8, 9, 10 and 11 once, in the forward direction in order to test the accuracy of directionality (directional angles). Directional functionality testing (trip inside, no-trip outside) should always be made for all impedance zones set with directionality (forward or reverse).

### Measuring the operating time of distance protection zones

**Procedure:**

<table>
<thead>
<tr>
<th>Test point</th>
<th>Reach</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RLD_FW_set</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td>-0.2143 x RLD_FW_set</td>
<td>Exact: 0.8 x RFPE_Z x tan (ArgDir=20°)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x RLD_FW_set</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>X</td>
<td>-0.8 x RLD_FW_set x</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>tan(ArgDir=20°)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.8 x RLD_FW_set</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>X</td>
<td>0.17 x (2 x X1_set + X0_set)</td>
<td>Exact: 0.5 x (2 x X1_set + X0_set)/3</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.36 x (2 x X1_set + X0_set)</td>
<td>Exact: 0.5 x (2X1_set + X0_set)/3 x tan(AgNegDir=30°)</td>
</tr>
<tr>
<td>11</td>
<td>X</td>
<td>0.27 x (2 x X1_set+X0_set)</td>
<td>Exact: 0.8 x (2 x X1_set + X0_set)/3</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.57 x (2 x X1_set+X0_set)</td>
<td>Exact: 0.8 x (2X1_set + X0_set)/3 x tan(AgNegDir=30°)</td>
</tr>
<tr>
<td>12</td>
<td>X</td>
<td>0.5 x (2 x X1_set + X0_set)/3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.5 x (2 x R1_set + R0_set)/3</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>X</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>RFPE_Z</td>
<td></td>
</tr>
</tbody>
</table>
1. Subject the IED to healthy normal load conditions for at least two seconds.

2. Apply the fault condition to find the operating time for the phase-to-phase fault according to test point 10 in figure 37 and table 32 for zone 1. Compare the result of the measurement with the setting $t_{1PP}$.

3. Repeat steps 1 to 2 to find the operating time for the phase-to-earth fault according to test point 10 in figure 38 and table 33. Compare the result of the measurement with the setting $t_{1PE}$.

4. Repeat steps 1 to 2 to find the operating time for all other used measuring zones. Observe that the zones that are not tested have to be blocked and the zone that is tested has to be released.

11.4.8.3 Transient directional element

Since the transient directional element is operating in the time domain, based on an RL circuit model, it expects that the input current signals have proper transitions going from healthy to faulty state. This essentially means that the test equipment has to be able to generate currents with a DC-component bridging the two states, without discontinuities, even when a pre-fault load current is present. If not, the result of the test will not be valid.

11.4.8.4 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.

11.4.9 Power swing detection ZMRPSB

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

Values of the logical signals for ZMRPSB are available on the local HMI under Main menu/Test/Function status/Impedance protection/PowerSwingDetection(68,Zpsb)/ZMRPSB(68;Zpsb):1

The Signal Monitoring tool in PCM600 shows same signals that are available on the local HMI.

11.4.9.1 Verifying the signal and settings

Measure the operating characteristics during constant current conditions. Keep the measured current as close as possible to the rated value of the IED or lower. Ensure that it is higher than the set minimum operating current.

Ensure that the maximum continuous current to the IED does not exceed four times of its rated value, if the measurement of the operating characteristics runs under constant voltage conditions.

The test is mainly divided into two parts, one aim is to verify that the settings are in accordance with the selectivity plan and another aim is to verify the operation of ZMRPSB.

Before starting this testing process, all impedance measuring zones shall be set and in operation. Ensure that the inner zone of ZMRPSB must cover all impedance measuring zones that are set for operation.

Test of the interactions or combinations that are not configured are not considered in this instruction.
Always set *Operation* to *On* to check the performance of power swing detection during testing.

**Testing the operating characteristics**

**Preconditions**

The following output signals shall be configured to binary output available: *ZOUT*, measured impedance within outer impedance boundary and *ZIN*, measured impedance within inner impedance boundary.

1. Set *X1InFw*, *R1LIn*, *X1InRv*, *R1FInFw*, *R1FInRv*, *ArgLd*, *RLdOutFw*, *RLdOutRv*, *kLdRFw* and *kLdRRv* to values that are in accordance with the selectivity plan and the corresponding operating characteristic is as shown in Figure 39.
2. Set *OperationLdCh* to *On*.
3. The test points that are to be considered for the measurement accuracy of set resistive and reactive reaches for outer and inner boundaries are shown in Figure 39, Table 34 and Table 35.

![Proposed test points to measure the outer and inner boundaries of operating characteristics](IEC18000101-1-en.vsdx)

**Where,**

\[
\Delta Fw = RLdOutFw - (kLdRFw \times RLdOutFw)
\]

\[
\Delta Rv = RLdOutRv - (kLdRRv \times RLdOutRv)
\]

\[
RLdInFw = kLdRFw \times RLdOutFw
\]

\[
RLdInRv = kLdRRv \times RLdOutFw
\]

\[
X1OutFw = X1InFw + \Delta Fw
\]
\[ X1OutFw = X1InRv + \Delta Rv \]

### Table 34: Testing points to measure the outer boundary

<table>
<thead>
<tr>
<th>Test point</th>
<th>R</th>
<th>X</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>0.0</td>
<td>(X1OutFw)</td>
<td></td>
</tr>
<tr>
<td>P2</td>
<td>0.8 * (R1LIn + R1FInFw + \Delta Fw)</td>
<td>0.8 * (X1OutFw)</td>
<td></td>
</tr>
<tr>
<td>P3</td>
<td>0.8 * ((R1FInFw + \Delta Fw))</td>
<td>0.8 * ((R1FInFw + \Delta Fw)) * tan (ArgLd)</td>
<td></td>
</tr>
<tr>
<td>P4</td>
<td>(RLdOutFw)</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>P5</td>
<td>(R1FInFw + \Delta Fw)</td>
<td>0.0</td>
<td>If OperationLdCh = Off</td>
</tr>
<tr>
<td>P6</td>
<td>0.8 * ((R1FInFw + \Delta Fw))</td>
<td>-0.8 * ((R1FInFw + \Delta Fw)) * tan (ArgLd)</td>
<td></td>
</tr>
<tr>
<td>P7</td>
<td>(R1FInFw + \Delta Fw)</td>
<td>-0.8 * (X1OutRv)</td>
<td></td>
</tr>
<tr>
<td>P8</td>
<td>0.0</td>
<td>-(X1OutRv)</td>
<td></td>
</tr>
<tr>
<td>P9</td>
<td>-(0.8 * (R1LIn + R1FInRv + \Delta Rv))</td>
<td>-0.8 * (X1OutRv)</td>
<td></td>
</tr>
<tr>
<td>P10</td>
<td>-0.8 * ((R1FInRv + \Delta Rv))</td>
<td>-0.8 * ((R1FInRv + \Delta Rv)) * tan (ArgLd)</td>
<td></td>
</tr>
<tr>
<td>P11</td>
<td>(-RLdOutRv)</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>P12</td>
<td>(-R1FInRv + \Delta Rv)</td>
<td>0.0</td>
<td>If OperationLdCh = Off</td>
</tr>
<tr>
<td>P13</td>
<td>-0.8 * ((R1FInRv + \Delta Rv))</td>
<td>0.8 * ((R1FInRv + \Delta Rv)) * tan (ArgLd)</td>
<td></td>
</tr>
<tr>
<td>P14</td>
<td>-(R1FInRv + (\Delta Rv))</td>
<td>0.8 * (X1OutFw)</td>
<td></td>
</tr>
</tbody>
</table>

### Table 35: Testing points to measure the inner boundary

<table>
<thead>
<tr>
<th>Test point</th>
<th>R</th>
<th>X</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>P15</td>
<td>0.0</td>
<td>(X1InFw)</td>
<td></td>
</tr>
<tr>
<td>P16</td>
<td>0.8 * (R1LIn + R1FInFw)</td>
<td>0.8 * (X1InFw)</td>
<td></td>
</tr>
<tr>
<td>P17</td>
<td>0.8 * (R1FInFw)</td>
<td>(0.8 * (R1FInFw + \Delta Fw)) * tan (ArgLd)</td>
<td></td>
</tr>
<tr>
<td>P18</td>
<td>(RLdInFw)</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>P19</td>
<td>(R1FInFw)</td>
<td>0.0</td>
<td>If OperationLdCh = Off</td>
</tr>
<tr>
<td>P20</td>
<td>0.8 * (R1FInFw)</td>
<td>-(0.8 * (R1FInFw + \Delta Fw)) * tan (ArgLd)</td>
<td></td>
</tr>
<tr>
<td>P21</td>
<td>(R1FInFw)</td>
<td>-0.8 * (X1InRv)</td>
<td></td>
</tr>
<tr>
<td>P22</td>
<td>0.0</td>
<td>-(X1InRv)</td>
<td></td>
</tr>
<tr>
<td>P23</td>
<td>-0.8 * (R1LIn + R1FInRv)</td>
<td>-0.8 * (X1InRv)</td>
<td></td>
</tr>
<tr>
<td>P24</td>
<td>-0.8 * (R1FInRv)</td>
<td>-(0.8 * (-(R1FInRv + \Delta Rv))) * tan (ArgLd)</td>
<td></td>
</tr>
<tr>
<td>P25</td>
<td>(-RLdInRv)</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

Table continues on next page
4. Change the magnitude and angle of three phase voltages to achieve the impedances at test points P1, P2, ..., P28.
5. For test points P1 to P14, observe the operation value for the signal ZOUT and compare the operation value with the set value.
6. For test points P15 to P28, observe the operation value for the signal ZIN and compare the operation value with the set value.

**Testing the power swing detection logic ZMRPSB**

**Preconditions**

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

1. Set X1InFw, R1Lin, X1InRv, R1FInFw, R1FInRv, ArgLd, RLdOutFw, RLdOutRv, kLdRFw and kLdRRv to values that are in accordance with the selectivity plan and the corresponding operating characteristic is shown in Figure 40.
2. Set OperationLdCh to On and set timers tP1, tP2, tW and tH to their default values.
3. Enable the input signal REL1PH to detect the power swing in one of the three phases.
4. The test points that are to be considered for the power swing detection are shown in Figure 40.
Figure 40: Proposed test points to detect power swing conditions

Where,

\[ \Phi = \tan^{-1}\left(\frac{X1InFw}{RLdIn}\right) \]

5. Inject voltage in one of the three phases in accordance with the test point P1 by keeping constant current in three phases throughout testing and maintaining rated voltage for other two phases.

6. Vary the faulty phase voltage to achieve the impedance at the test point P2. At this point, observe that the output ZOUT is activated and then continue to inject for a duration greater than tP1.

7. Inject the faulty phase voltage to achieve the impedance at the test point P3. At this point, observe that the outputs ZIN and START are activated. It indicates that power swing has been detected.

8. Inject the faulty phase voltage in accordance with the test point P1.

9. At this condition, the outputs ZIN and ZOUT get deactivated and START signal will be maintained for a set duration of tH.

10. To detect consecutive power swings, repeat steps 5, 6, 7 and 8. With this condition, the output START will be activated.

11. Repeat step 6 and inject before the expiration of timer tW. The output ZOUT will be activated.

12. Repeat step 7 after a set duration of tP2. The output ZIN will be activated.

13. At this condition, it will be detected as consecutive power swing and the output signal START will be maintained.

14. Repeat step 8 and the outputs ZOUT and ZIN get deactivated. The output signal START will be disappeared after set duration of tH from the instance of step 13.

15. Repeat the above steps to test and detect power swing condition in at least two phases by enabling input REL2PH.

16. By enabling the input BLK1H, operation mode for power swing detection in any phase will be blocked.
17. Similarly, operation mode for power swing detection in at least two phases will be blocked by enabling the input BLK2PH.

18. Repeat steps 5, 6 and 7, and enable the input signal BLOCK. At this condition, the outputs START, ZOUT and ZIN will be disappeared.

19. Output signal START will also get activated instantaneously by enabling input EXTERNAL and this input signal can be configured in ACT to the output derived from some external logics used to detect power swings. By enabling the input signal BLOCK, the output signal START will be deactivated.

**Testing the inhibit logic of power swing detection function**

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

1. Set X1InFw, R1In, X1InRv, R1FInFw, R1FInRv, ArgLd, RLdOutFw, RLdOutRv, kLdRFw and kLdRRv to values that are in accordance with the selectivity plan and the corresponding operating characteristic is shown in Figure 40.

2. Set OperationLdCh to On and set timers tP1, tP2, tW, tH, tR1, tR2 and tEF to their default values.

3. Enable the input signal REL1PH to detect the power swing in one of the three phases.

**Inhibit START output by the presence of residual current**

**Preconditions**

The input signal I0CHECK, residual current (3I0) detection used to inhibit the start output, must be configured to the output signal STPE on the FDPSPDIS, FRPSPDIS, ZMFPDIS or ZMFCPDPS function.

The input signal BLKI02, block inhibit of the start output for subsequent residual current detection, is connected to FALSE.

1. Create a test sequence such that power swing has been detected, which can be done by referring to steps 5, 6 and 7 described in section "Testing the power swing detection logic ZMRPSB" and inject voltage in one of the phases accordingly by keeping constant current in all three phases. With this condition, the output signal START will be activated.

2. Create a condition such that residual current is measured (that is, earth fault occurs in the power system) and its value should be above the value seen during unbalanced loading condition. It can be done by increasing current in one of the phases without disturbing faulty phase current.

3. With this condition, I0CHECK connected to STPE output of FDPSPDIS, FRPSPDIS, ZMFPDIS or ZMFCPDPS function, will be activated and I0CHECK should be activated before the expiration of timer tR1.

4. By doing this, the output START will be disappeared after a set time delay of tR1.

5. If required to block inhibit of start output by the presence of residual current, BLKI02 must be configured to TRUE and thereby, the output signal START will be maintained as long as the power swing condition exists.

**Inhibit START output by the presence of slow power swings**

**Preconditions**

The input signal BLKI01, block inhibit of the start output for slow power swings is connected to FALSE.

1. Create a test sequence such that the power swing should be detected. This can be done by referring to steps 5, 6, and 7 described in section "Testing the power swing detection
Logic ZMRPSB and inject voltage in one of the phases accordingly by keeping constant current in all three phases. With this condition, the output signal START will be activated.

2. After expiration of the set time delay by a timer \( tR2 \), the output START will disappear.

3. If required to block inhibit of start output by the presence of slow power swings, BLKI01 must be configured to TRUE. Thereby, the output signal START will be maintained as long as the power swing condition exists.

Inhibit START output by the single pole reclosing

Preconditions

The input signal I0CHECK, residual current (3I0) detection used to inhibit the start output, must be configured to the output signal STPE on the FDPSPDIS, FRPSPDIS, ZMFPDIS or ZMFCPDIS function.

The input signal BLKI02, block inhibit of the start output for subsequent residual current detection and BLKI01, block inhibit of the start output for slow power swings must be connected to TRUE.

1. Create a phase-to-earth fault such that the input signal I0CHECK will be activated and a trip signal from any impedance protection function will be generated.

2. With this condition, the input signal TRSP connected to a tripping function is activated.

3. Clear the fault by injecting zero current magnitude in the fault phase and maintain healthy conditions in other phases. With this, I0CHECK and TRSP will be deactivated.

4. Make a test sequence to create power swing condition in healthy phases in accordance with steps 5, 6, and 7 described in section "Testing the power swing detection logic ZMRPSB". With this condition, the output signal START will be activated.

5. Repeat step 1 to create phase-to-earth fault and thereby, I0CHECK will be activated again.

6. Steps 4 and 5 must be performed before the expiration of set time delay of \( tEF \). There may exist a two phase power swing during single pole autoreclosing time and then switched-on-to the persistent phase-to-earth fault after single pole autoreclosing time.

7. By doing this, the output signal START will be inhibited.

8. If I0CHECK appears the expiration of a timer \( tEF \), the condition will be seen as power swing and thereby, the output signal START will be maintained as long as the power swing exists in the power system.

11.4.9.2 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.

11.4.10 Power swing logic PSLPSCH

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

Most readily available test equipment does not permit simulation of power-swing conditions and the simultaneous occurrence of different faults with controlled fault impedance. For this reason it is necessary to enable the logic by connecting the STPSD input signal to some other functional signal, which is used for testing purposes.

Make sure that the existing configuration permits monitoring of the CS, TRIP signals on the binary outputs of the IED. If not, configure connections to unused binary outputs, for test purposes.
11.4.10.1 Testing the carrier send and trip signals

Procedure

1. Set the operation of all distance zones, which are supposed to be blocked by the operation of ZMRPSB, to Off.
2. Configure the STPSD functional inputs to the TRIP output of the underreaching power-swing zone, if the underreaching communication scheme is used.
3. Start instantaneously any kind of fault within the underreaching power-swing zone and check, that:
   - The CS signal appears after the time delay, which is equal to the sum of set time delays for the underreaching zone $tnPP$ or $tnPE$ (dependent on the type of fault) and for the carrier send security timer $tCS$. Also add the usual operate time for the underreaching zone (approximately 30ms).
   - The TRIP signal appears after the time delay, which is equal to the sum of set time delays for the underreaching zone $tnPP$ or $tnPE$ (dependent on the type of fault) and for the trip security timer $tTrip$. Also add the usual operate time for the underreaching zone (approximately 30ms).
4. Simulate the receiving of the carrier signal so that the functional input signal CR becomes a logical one.
5. Configure the STPSD input to connect to the output START of the carrier accelerating zone (Power-swing overreaching zone).
6. Initiate any kind of fault within the carrier accelerating zone and check that the TRIP signal appears after the time, which is equal to the time delay set on the trip timer $tTrip$. Also consider the (average) operate time of the carrier acceleration zone (approximately 30ms).

11.4.10.2 Testing the influence of the residual overcurrent protection

Additionally connect the IED according to the test instructions for the four step residual overcurrent protection function EF4PTOC, if the Power swing logic (PSLPSC) is configured in a way that is controlled by this protection.

Procedure

1. Initiate a single phase-to-earth fault within both power-swing zones. Make sure that none of CS or TRIP output signals appear after the time delays $tCS$ and $tTrip$. BLKZMUR must appear together with the fault and must remain active until the fault has been switched off plus the time delay, as set on the $tBlkTr$ timer.
2. Initiate a phase-to-phase fault within the operating area of both power-swing zones. Make sure that CS and TRIP output signals appear after the time delays $tCS$.
3. Switch the operation of the zone 1 distance protection function on and fulfill all the conditions for single-pole autoreclosing.
4. Simulate a single phase-to-earth fault within the reach of zone 1 and both power-swing zones. The fault should cause a single-pole tripping with the normal operating time of zone 1.
5. Repeat the fault within the dead time of single-pole autoreclosing. Make sure, that PSLPSC generates a BLKZMUR signal and no CS and TRIP.

11.4.10.3 Checking the underreaching zone

Procedure

1. Set the operation of all normal distance protection zones to On.
2. Simulate a fault without fault resistance in the middle of distance protection zone 1.
Make sure that the trip appears within the operate time for the distance protection zone 1 and no BLKZMOR output signal appears.

3. Switch off the fault and prepare a new fault without fault resistance within the normal distance protection zone 2 operate area, but outside the zone 1 operate area.

4. Switch on the fault and move it into the zone 1 operate area with a time delay longer than the time set on the tDZ timer and faster than the time set on timer tZL.

5. Observe the operate time, which must be equal to the operate time of zone 1, after the measured impedance enters its operate area.
   No delayed operation of zone 1 must be observed.

6. Configure the STPSD functional input to connect to the START functional output and repeat the previous fault.
   Fast trip, caused by the operation of zone 1 must appear with a time delay, which is equal to the set time delay on the timer tZL plus zone 1 normal operate time. Also, observe the BLKZMOR functional output signal, which must appear for a short time.

7. Be sure to establish the original configuration of the IED and the original settings of all setting parameters.

11.4.10.4 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.

11.4.11 Pole slip protection PSPPPAM

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

11.4.11.1 Verifying the settings

It is assumed that setting of the pole slip protection function PSPPPAM is done according to impedances as seen in figure 41 and figure 42.

The test is done by means of injection of three-phase current and three-phase voltage from a modern test device. This test device shall be able to give voltage and current with the possibility to change voltage and current amplitude and the angle between the injected voltage and current. The parameter setting shall be according to the real application chosen values.

Procedure

1. Feed the IED with current and voltage corresponding to a normal operation point Injected voltage U equal to base voltage (UBase) and the injected current I equal to half the base current (IBase). The angle between the voltage and current shall be 0°.
2. With maintained amplitude of the injected voltage the current amplitude and angle is changed to a value ZC/2.
   This is done with a speed so that the final impedance is reached after 1 second. As the injected voltage is higher than 0.92 UBase no START signal should be activated.
3. With reduced amplitude of the injected voltage to 0.8 UBase the current amplitude and angle is changed to a value ZC/2.
   This is done with a speed so that the final impedance is reached after 1 second. As the injected voltage is lower than 0.92 UBase the START signal should be activated.
4. With reduced amplitude of the injected voltage to 0.8 UBase the current amplitude and angle is changed via ZC/2 to a value corresponding to half IBase and 180° between the injected current and voltage.
This is done with a speed so that the final impedance is reached after 1 second. As the injected voltage is lower than 0.92 \( U_{\text{Base}} \) the START signal should be activated. In addition to this the signal ZONE1 should be activated.

5. Set \( N1\text{Limit} \) to 1 and repeat step 4.
Now the signals TRIP1 and TRIP should be activated.

6. With reduced amplitude of the injected voltage to 0.8 \( U_{\text{Base}} \) the current amplitude and angle is changed via \( Z_C + (Z_A - Z_C)/2 \) to a value corresponding to half \( I_{\text{Base}} \) and 180° between the injected current and voltage.
This is done with a speed so that the final impedance is reached after 1s. As the injected voltage is lower than 0.92 \( U_{\text{Base}} \) the START signal should be activated. In addition to this the signal ZONE2 should be activated.

7. Set \( N2\text{Limit} \) to 1 and repeat step 6.
Now the signals TRIP2 and TRIP should be activated.

---

**Figure 41:** Setting of the pole slip protection PSPPPAM
### 11.4.11.2 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.

### 11.4.12 Out-of-step protection OOSPPAM

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

The main purpose of the OOSPPAM function is to detect, evaluate, and take the required action during pole slipping occurrences in the power system.

The OOSPPAM 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.
11.4.12.1 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 43:

- 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)

![Figure 43: Trajectory of the impedance Z(R, X) for the injected current with two components: a 50 Hz component and a 49.5 Hz current component](image)

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 5)

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 6)

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.
\[ I_1 = 2.5 \times I_{\text{max}} = 2.5 \times 8367 = 20918A \]  
\text{(Equation 7)}

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 corresponding primary value of the reactance is

\[ X_{\text{ReachZ1}} = \frac{\text{ReachZ1}}{100} \times \frac{\text{ForwardX}}{100} \times Z_{\text{Base}} = \frac{12}{100} \times \frac{59.33}{100} \times 0.9522 = 0.068\Omega \]
\text{(Equation 8)}

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 \( R_{\text{RZ1}} \):

\[ R\text{RZ1} = \frac{\text{ReachZ1}}{100} \times \frac{\text{ForwardR}}{100} \times Z_{\text{Base}} = \frac{12}{100} \times \frac{8.19}{100} \times 0.9522 = 0.009\Omega \]
\text{(Equation 9)}

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

\[ Z_{\text{RZ1}} = \sqrt{R_{\text{RZ1}}^2 + X_{\text{RZ1}}^2} = \sqrt{0.009^2 + 0.068^2} = 0.069\Omega \]
\text{(Equation 10)}

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

\[ V_{\text{RZ1}} = Z_{\text{RZ1}} \times I_1 = 0.069 \times 20918 = 1435V \]
\text{(Equation 11)}

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

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

\[ R_{\text{FwdR}} = \frac{\text{ForwardR}}{100} \times Z_{\text{Base}} = \frac{8.19}{100} \times 0.9522 = 0.078\Omega \]
\text{(Equation 12)}

\[ X_{\text{FwdX}} = \frac{\text{ForwardX}}{100} \times Z_{\text{Base}} = \frac{59.33}{100} \times 0.9522 = 0.565\Omega \]
\text{(Equation 13)}

\[ R_{\text{RvsR}} = \frac{\text{ReverseR}}{100} \times Z_{\text{Base}} = \frac{0.29}{100} \times 0.9522 = 0.003\Omega \]
\text{(Equation 14)}

\[ X_{\text{RvsX}} = \frac{\text{ReverseX}}{100} \times Z_{\text{Base}} = \frac{29.6}{100} \times 0.9522 = 0.282\Omega \]
\text{(Equation 15)}

and the voltages that are related to them:

\[ V_{\text{FwdZ}} = Z_{\text{FwdR}} \times I_1 = \sqrt{R_{\text{FwdR}}^2 + X_{\text{FwdX}}^2} \times I_1 = \sqrt{0.078^2 + 0.565^2} \times 20918 = 0.570 \times 20918 = 11931V \]
\text{(Equation 16)}

\[ V_{\text{RvsZ}} = Z_{\text{RvsR}} \times I_1 = \sqrt{R_{\text{RvsR}}^2 + X_{\text{RvsX}}^2} \times I_1 = \sqrt{0.003^2 + 0.282^2} \times 20918 = 0.282 \times 20918 = 5899V \]
\text{(Equation 17)}
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}):**

\[
V_{r,FwdR} = V_{t,FwdZ} \times \frac{V_{T,t}}{V_{T,p}} = 11931 \times \frac{0.1}{13.8} = 86.45V
\]

(Equation 18)

**SE (R_{RvsR}, X_{RvsX}):**

\[
V_{r,RvsR} = V_{t,RvsZ} \times \frac{V_{T,t}}{V_{T,p}} = 5899 \times \frac{0.1}{13.8} = 42.75V
\]

(Equation 19)

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 point RE (R_{FwdR}, X_{FwdX})
  - a point which is related to the parameter ReachZ1 (boundary between zone 1 and zone 2)
  - the point SE (R_{RvsR}, X_{RvsX})

The phase angle of the test voltages is equal to:

- arctan (ForwardX/ForwardR) for tests in the quadrant 1 and 2 of the R-X plane
- arctan (ReverseX/ReverseR) -180° 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.

\[
I_{50} = I_1 = \frac{I_f}{2} = \frac{20918}{2} = 10459A
\]

(Equation 20)

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 \( I_f \) 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.

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.

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

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):

$$
V_u = 1.1 \times V_{FwdR} \times V_{TR+} / V_{TR-} = 1.1 \times 11931 \times \frac{0.1}{13.8} = 95.1V
$$

(Equation 21)
\[ \angle V_n = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]  

(Equation 22)

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

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

(Equation 23)

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

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

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

(Equation 24)

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

frequency of \( I_{fts} = 50 \) 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):

\[ V_u = 1.1 \times V_{(r,rad)} \times \frac{V_{ts}}{V_{T,p}} = 1.1 \times 11931 \times \frac{0.1}{13.8} = 95.1 \text{V} \]  

(Equation 25)

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

(Equation 26)

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

\[ I_{50s} = 0 \text{ A} \]

\[ I_{fts} = 0 \text{ A} \]

- State 2: main test step.
  - Define the following test three-phase symmetrical quantities (the phase angle is related to phase L1):
\[ V_u = 1.1 \times V_{r,rad} \times \frac{V_{r, ph}}{V_{r, p}} = 1.1 \times 11931 \times \frac{0.1}{13.8} = 95.1V \]  
\[ \angle V_u = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]  
(Equation 27)

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

\[ I_{so} = I_s \times \frac{I_{ct}}{I_{ctp}} = 10459 \times \frac{1}{9000} = 1.162A \]  
\[ \angle I_{so} = 0^\circ \]  
(Equation 28)

Frequency of \( h_{so} = 50 \) Hz

\[ I_{s} = I_s \times \frac{I_{ct}}{I_{ctp}} = 10459 \times \frac{1}{9000} = 1.162A \]  
\[ \angle I_{s} = 0^\circ \]  
(Equation 29)

\[ \angle I_{ts} = 180^\circ \]  
Expected result: the protection function does not issue either start or trip.

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):

\[ V_u = 0.9 \times V_{r,rad} \times \frac{V_{r, ph}}{V_{r, p}} = 0.9 \times 11931 \times \frac{0.1}{13.8} = 77.81V \]  
\[ \angle V_u = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]  
(Equation 30)

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

\[ I_{so} = I_s \times \frac{I_{ct}}{I_{ctp}} = 10459 \times \frac{1}{9000} = 1.162A \]  
\[ \angle I_{so} = 0^\circ \]  
(Equation 31)

Frequency of \( h_{so} = 50 \) Hz

\[ I_{s} = I_s \times \frac{I_{ct}}{I_{ctp}} = 10459 \times \frac{1}{9000} = 1.162A \]  
\[ \angle I_{s} = 0^\circ \]  
(Equation 32)

\[ \angle I_{ts} = 180^\circ \]  
(Equation 33)

\[ \angle I_{ts} = 0^\circ \]  
(Equation 34)
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):

  \[ V_n = 0.9 \times V_{r,rad} \times \frac{V_{r,s}}{V_{r,p}} = 0.9 \times 11931 \times \frac{0.1}{13.8} = 77.81 \text{ V} \]

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

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

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

  \[ V_n = 0.9 \times V_{r,rad} \times \frac{V_{r,s}}{V_{r,p}} = 0.9 \times 11931 \times \frac{0.1}{13.8} = 77.81 \text{ V} \]

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

  frequency of \( V_{ts} = 50 \text{ Hz} \)
  \( I_{s0} = I_0 \times \frac{I_{cp}}{I_{cp}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \)

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


\[ H_p = I_{df} \times \frac{I_{cu}}{I_{cp}} = 10459 \times \frac{1}{9000} = 1.162 \text{A} \]

(Equation 40)

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

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.

11.4.12.3 Test of the boundary between zone 1 and zone 2, which is defined by the parameter \textit{ReachZ1}

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):

\[ V_u = 1.1 \times V_{s,RE1} \times \frac{V_{s,RE2}}{V_{s,RE3}} = 1.1 \times 1435 \times \frac{0.1}{13.8} = 11.44 \text{V} \]

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

\[ I_{ts} = I_{so} \times \frac{I_{cu}}{I_{cp}} = 10459 \times \frac{1}{9000} = 1.162 \text{A} \]

(Equation 43)

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

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

\[ H_p = I_{df} \times \frac{I_{cu}}{I_{cp}} = 10459 \times \frac{1}{9000} = 1.162 \text{A} \]

(Equation 44)

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

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):

  \[ V_n = 1.1 \times V_{t,ez} \times \frac{V_{tr,c}}{V_{tr,p}} = 1.1 \times 1435 \times \frac{0.1}{13.8} = 11.44V \]

  (Equation 45)

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

  (Equation 46)

  frequency of \( V_t = 50 \text{ Hz} \).
  \( I_{s5s} = 0 \text{ A} \)
  \( I_{fs} = 0 \text{ A} \)

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

  \[ V_n = 1.1 \times V_{t,ez} \times \frac{V_{tr,c}}{V_{tr,p}} = 1.1 \times 1435 \times \frac{0.1}{13.8} = 11.44V \]

  (Equation 47)

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

  (Equation 48)

  frequency of \( V_t = 50 \text{ Hz} \)
  \( I_{s5s} = I_n \times \frac{I_{ctp}}{I_{ct}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \)

  (Equation 49)

  \( \angle I_{s5s} = 0^\circ \)
  frequency of \( I_{s5s} = 50 \text{ Hz} \)
  \( I_{ts} = I_f \times \frac{I_{ct}}{I_{ctp}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \)

  (Equation 50)

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

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

  \[
  V_u = 0.9 \times V_{r,ext} \times \frac{V_{V,T}}{V_{T,R}} = 0.9 \times 1435 \times \frac{0.1}{13.8} = 9.36V
  \]

  (Equation 51)

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

  (Equation 52)

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

  \[
  I_{ns} = I_{sp} \times \frac{I_{ctp}}{I_{ctp}} = 10459 \times \frac{1}{9000} = 1.162A
  \]

  (Equation 53)

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

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

  \[
  I_f = I_{fs} \times \frac{I_{ctp}}{I_{ctp}} = 10459 \times \frac{1}{9000} = 1.162A
  \]

  (Equation 54)

  \(\angle I_{1fs} = 0^\circ\)

  frequency of \(I_{1fs}\) = 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):
\[ V_u = 0.9 \times V_{x,ui} \times \frac{V_{y,u}}{V_{x,y}} = 0.9 \times 1435 \times \frac{0.1}{13.8} = 9.36V \]  
(Equation 55)

\[ \angle V_u = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]  
(Equation 56)

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

\[ I_{50s} = 0 \ A \]

\[ I_{tfs} = 0 \ A \]

• **State 2: main test step.**

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

\[ V_u = 0.9 \times V_{x,ui} \times \frac{V_{y,u}}{V_{x,y}} = 0.9 \times 1435 \times \frac{0.1}{13.8} = 9.36V \]  
(Equation 57)

\[ \angle V_u = \arctan \left( \frac{\text{ForwardX}}{\text{ForwardR}} \right) = \arctan \left( \frac{59.33}{8.19} \right) = 82.14^\circ \]  
(Equation 58)

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

\[ I_{50s} = 0 \ A \]

\[ I_{tfs} = 0 \ A \]

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

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

### 11.4.12.4 Test of the point SE (R<sub>RvsR</sub>, X<sub>RvsX</sub>)

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):
\[ V_u = 0.9 \times V_{\text{in},z} \times \frac{V_{\text{in},z}}{V_{	ext{in},p}} = 0.9 \times 5899 \times \frac{0.1}{13.8} = 38.47V \]  

(Equation 61)

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

(Equation 62)

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

\[ I_{so} = I_{so} \times \frac{I_{so}}{I_{otp}} = 10459 \times \frac{1}{9000} = 1.162 A \]  

(Equation 63)

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

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

\[ I_{tf} = I_{tf} \times \frac{I_{tf}}{I_{otp}} = 10459 \times \frac{1}{9000} = 1.162 A \]  

(Equation 64)

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

frequency of \( I_{tf} = 50 \) 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 = 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):

\[ V_u = 0.9 \times V_{\text{in},z} \times \frac{V_{\text{in},z}}{V_{	ext{in},p}} = 0.9 \times 5899 \times \frac{0.1}{13.8} = 38.47V \]  

(Equation 65)

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

(Equation 66)

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

\[ I_{so} = 0 \text{ A} \]

\[ I_{tf} = 0 \text{ A} \]
• State 2: main test step.
Define the following three-phase symmetrical quantities (the phase angle is related to phase L1):

\[ V_a = 0.9 \times V_{r,uL} \times \frac{V_{17,L}}{V_{17,p}} = 0.9 \times 5899 \times \frac{0.1}{13.8} = 38.47V \]  

(Equation 67)

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

(Equation 68)

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

\[ I_{s0} = I_{s0} \times \frac{I_{cp}}{I_{cp}} = 10459 \times \frac{1}{9000} = 1.162 \text{A} \]  

(Equation 69)

\[ \angle I_{S0s} = 0^\circ \]  
frequency of \( I_{S0s} = 50 \) Hz

\[ I_{t0} = I_{t0} \times \frac{I_{cp}}{I_{cp}} = 10459 \times \frac{1}{9000} = 1.162 \text{A} \]  

(Equation 70)

\[ \angle I_{TSs} = 180^\circ \]  
frequency of \( I_{TSs} = 50.5 \) Hz

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

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):

\[ V_a = 1.1 \times V_{r,uL} \times \frac{V_{17,L}}{V_{17,p}} = 1.1 \times 5899 \times \frac{0.1}{13.8} = 47.02V \]  

(Equation 71)

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

(Equation 72)

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

\[ I_{s0} = I_{s0} \times \frac{I_{cp}}{I_{cp}} = 10459 \times \frac{1}{9000} = 1.162 \text{A} \]  

(Equation 73)

\[ \angle I_{S0s} = 0^\circ \]  
frequency of \( I_{S0s} = 50 \) Hz
\[ H_y = I' g \times \frac{I_{CU}}{I_{CP}} = 10459 \times \frac{1}{9000} = 1.162 \text{A} \]  
(Equation 74)

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

frequency of \( \lambda_{ft} \) = 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 = 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):

\[ V_u = 1.1 \times V_{1,roz} \times \frac{V_{17s}}{V_{17p}} = 1.1 \times 5899 \times \frac{0.1}{13.8} = 47.02 \text{V} \]  
(Equation 75)

\[ \angle V_u = \arctan \left( \frac{\text{ReverseX}}{\text{ReverseR}} \right) - 180^\circ = \arctan \left( \frac{29.60}{0.29} \right) - 180^\circ = -90.56^\circ \]  
(Equation 76)

frequency of \( V_{ts} \) = 50 Hz
\( I_{50s} = 0 \text{ A} \)
\( I_{ft5} = 0 \text{ A} \)

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

\[ V_u = 1.1 \times V_{1,roz} \times \frac{V_{17s}}{V_{17p}} = 1.1 \times 5899 \times \frac{0.1}{13.8} = 47.02 \text{V} \]  
(Equation 77)

\[ \angle V_u = \arctan \left( \frac{\text{ReverseX}}{\text{ReverseR}} \right) - 180^\circ = \arctan \left( \frac{29.60}{0.29} \right) - 180^\circ = -90.56^\circ \]  
(Equation 78)

frequency of \( V_{ts} \) = 50 Hz
\[ I_{50s} = I_w \times \frac{I_{ctp}}{I_{ctp}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \]

(Equation 79)

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

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

\[ I_{tf5} = I_f \times \frac{I_{ctp}}{I_{ctp}} = 10459 \times \frac{1}{9000} = 1.162 \text{ A} \]

(Equation 80)

\[ \angle I_{tf5} = 180^\circ \]

frequency of \( I_{tf5} = 50.5 \text{ Hz} \)

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.

Figure 44: Boolean output signals for the injected current with two components: a 50 Hz current component and a 49.5 Hz current component

11.4.13 Automatic switch onto fault logic ZCVPSONF

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

The automatic switch onto fault logic function ZCVPSONF is checked using secondary injection tests. ZCVPSONF is activated either by the external input BC or by the internal DLD. FUFSPVC is done with a pre-fault condition where the phase voltages and currents are at zero. A three-
phase fault with zero impedance and a three-phase fault with an impedance corresponding to the whole line is applied. This fault shall cause an instantaneous trip and result in a TRIP indication.

11.4.13 Activating ZCVPSOF externally

1. Set AutoInitMode to DLD disabled and Mode to Impedance.
2. Activate the switch onto fault BC input.
   During normal operating conditions, the BC input is de-energized.
3. Apply a three-phase fault condition corresponding to a fault at approximately 45% of the line or with impedance at 50% of the used zone setting and current greater than 30% of IBase.
   The ZACC input is activated.
4. Check that the TRIP output, external signals and indication are obtained.

11.4.13.2 Initiating ZCVPSOF automatically and setting mode to impedance

1. Set AutoInitMode to Voltage and Mode to Impedance.
2. Deactivate the switch onto fault BC input.
3. Set the current and voltage inputs to lower than IPh< and UPh< for at least one second.
4. Apply a three-phase fault condition corresponding to a fault at approximately 45% of the line or with impedance at 50% of the used zone setting and current greater than 30% of IBase.
   Apply a two-phase fault condition corresponding to a fault at approximately 45% of the line or with impedance at 50% of the used zone setting and current greater than 30% of IBase.
   The ZACC input is activated.
5. Check that the correct TRIP output, external signals and indication are obtained.

11.4.13.3 Initiating ZCVPSOF automatically and setting mode to UILevel

1. Set AutoInitMode to Voltage and Mode to UILevel.
2. Deactivate the switch onto fault BC input.
3. Set the current and voltage inputs to lower than IPh< and UPh< for at least one second.
4. Apply the three-phase currents in such a way that the magnitudes are greater than IPh< and the three-phase voltages in such a way that the magnitudes and lower than UPh< at least for the duration of the tDuration setting.
5. Check that the correct TRIP output, external signals and indication are obtained.

11.4.13.4 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.

11.4.14 Phase preference logic PPLPHIZ

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

The Phase preference logic function PPLPHIZ is tested with a three-phase testing equipment for distance protections. PPLPHIZ is tested in co-operation with the Distance protection zone, quadrilateral characteristic function ZMQPDIS. The distance protection and the phase...
preference logic 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 following binary signals (outputs) shall be monitored:

- Trip signal from distance protection
- Start signal from phase preference logic

1. Connect the test set for injection of voltage and current.
2. Inject voltages and currents corresponding to a phase-to-phase to earth fault within zone 1 of the distance protection function. In the test one of the current inputs (one of the faulted phases) is disconnected. The remaining current is the fault current out on the protected line. All combinations of two phase-to-earth faults with one phase current are tested. The result shall be according to table 36. It should be checked that the fault will give phase-to-phase voltage, phase-to-earth voltage, zero-sequence voltage and phase current so that the conditions set for the logic are fulfilled.

Table 36: Operation at different combinations of faults and operation mode

<table>
<thead>
<tr>
<th>OperMode</th>
<th>Fault type/Faulted phase current to the IED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L1L2N/IL1</td>
</tr>
<tr>
<td>No Filter</td>
<td>Trip</td>
</tr>
<tr>
<td>No Pref</td>
<td>Trip</td>
</tr>
<tr>
<td>1231c</td>
<td>Trip</td>
</tr>
<tr>
<td>1321c</td>
<td>No Trip</td>
</tr>
<tr>
<td>123a</td>
<td>Trip</td>
</tr>
<tr>
<td>132a</td>
<td>Trip</td>
</tr>
<tr>
<td>213a</td>
<td>No Trip</td>
</tr>
<tr>
<td>231a</td>
<td>No Trip</td>
</tr>
<tr>
<td>312a</td>
<td>Trip</td>
</tr>
<tr>
<td>321a</td>
<td>No Trip</td>
</tr>
</tbody>
</table>

11.4.14.1 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.

11.4.15 Phase preference logic PPL2PHIZ

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

The Phase preference logic function PPL2PHIZ is tested with a three-phase testing equipment for distance protections. PPL2PHIZ is tested in co-operation with the High speed distance protection ZMFPDIS. The distance protection and the phase preference logic 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 following binary signals (outputs) shall be monitored:
• Trip signal from distance protection
• Start signal from phase preference logic

1. Connect the test set for injection of voltage and current.
2. Inject voltages and currents corresponding to a phase-to-phase to earth fault within zone 1 of the distance protection function. In the test one of the current inputs (one of the faulted phases) is disconnected. The remaining current is the fault current out on the protected line. All combinations of two phase-to-earth faults with one phase current are tested. The result shall be according to table 37. It should be checked that the fault will give phase-to-phase voltage, phase-to-earth voltage, zero-sequence voltage and phase current so that the conditions set for the logic are fulfilled.

**Table 37: Operation at different combinations of faults and operation mode**

<table>
<thead>
<tr>
<th>OperMode</th>
<th>Fault type/Faulted phase current to the IED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L1L2N/I1</td>
</tr>
<tr>
<td>No Filter</td>
<td>Trip</td>
</tr>
<tr>
<td>No Pref</td>
<td>Trip</td>
</tr>
<tr>
<td>1231c</td>
<td>Trip</td>
</tr>
<tr>
<td>1321c</td>
<td>No Trip</td>
</tr>
<tr>
<td>123a</td>
<td>Trip</td>
</tr>
<tr>
<td>132a</td>
<td>Trip</td>
</tr>
<tr>
<td>213a</td>
<td>No Trip</td>
</tr>
<tr>
<td>231a</td>
<td>No Trip</td>
</tr>
<tr>
<td>312a</td>
<td>Trip</td>
</tr>
<tr>
<td>321a</td>
<td>No Trip</td>
</tr>
</tbody>
</table>

11.4.16 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.

11.4.17 Under impedance protection for Generator ZGVPDIS

Prepare the IED for verification of settings.

Values of the logical signals for ZGVPDIS are available on the local HMI under Main menu/Tests/Function status/Impedance/ZGVPDIS (21G, Z<)/1:ZGVPDIS:ZGVPDIS. The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.

11.4.17.1 Verifying the settings

**Distance protection zones**

While measuring operating characteristics, keep the current constant. Keep the current as close as possible to its rated value or lower, however make sure it is higher than 30% of the rated current.
If the measurement of the operating characteristics runs under constant voltage conditions, ensure that the maximum continuous current in an IED does not exceed four times its rated value.

To verify the zone 1 mho characteristic, at least two points must be tested.

Where,

- $Z_{1Fwd}$ is the forward positive sequence impedance setting for zone 1
- $Z_{1Rev}$ is the reverse positive sequence impedance setting for zone 1
- $\text{LineAngle}$ is the Impedance angle for phase-to-phase fault in degrees

<table>
<thead>
<tr>
<th>Test points</th>
<th>X</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>$Z_{1Fwd} \cdot \sin(\text{LineAngle})$</td>
<td>$Z_{1Fwd} \cdot \cos(\text{LineAngle})$</td>
</tr>
<tr>
<td>P2</td>
<td>$(Z_{1Fwd} - Z_{1Rev} / 2) \cdot \sin(\text{LineAngle})$</td>
<td>$Z_{1Fwd} / 2 \cdot (1 + \cos(\text{LineAngle})) + Z_{1Rev} / 2 \cdot (1 - \cos(\text{LineAngle}))$</td>
</tr>
<tr>
<td>P3</td>
<td>$(Z_{1Fwd} - Z_{1Rev} / 2) \cdot \sin(\text{LineAngle})$</td>
<td>$-Z_{1Fwd} / 2 \cdot (1 - \cos(\text{LineAngle})) + Z_{1Rev} / 2 \cdot (1 + \cos(\text{LineAngle}))$</td>
</tr>
<tr>
<td>P4</td>
<td>$-Z_{1Rev} \cdot \sin(\text{LineAngle})$</td>
<td>$-Z_{1Rev} \cdot \cos(\text{LineAngle})$</td>
</tr>
</tbody>
</table>

Change the magnitude and angle of phase-to-phase voltage, to achieve impedances at test points P1, P2, P3 and P4. For each test point, observe that the output signals, START and STZ1 are activated where x refers to the actual phase to be tested. After the operate time delay for the zone 1 has elapsed, the signals TRIP and TRZ1 shall be activated.

To verify zone 2 and zone 3 mho characteristic, at least two points must be tested.
Figure 46: Proposed four test points for phase-to-earth fault

Where,

- \( ZxFwd \) is the forward positive sequence impedance setting for zone x (where, x is 2-3 depending on the zone selected)
- \( ZxRev \) is the reverse positive sequence impedance setting for zone x (where x is 2-3 depending on the zone selected)
- \( \text{LineAngle} \) is the Impedance angle for phase-to-phase fault in degrees

<table>
<thead>
<tr>
<th>Test points</th>
<th>X</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>( ZxFwd \cdot \sin(\text{LineAngle}) )</td>
<td>( ZxFwd \cdot \cos(\text{LineAngle}) )</td>
</tr>
<tr>
<td>P2</td>
<td>( ((ZxFwd-ZxRev/2) \cdot \sin(\text{LineAngle})) )</td>
<td>( ZxFwd / 2 \cdot (1 + \cos(\text{LineAngle}) + ZxRev/2 \cdot (1 - \cos(\text{LineAngle}))) )</td>
</tr>
<tr>
<td>P3</td>
<td>( ((ZxFwd-ZxRev/2) \cdot \sin(\text{LineAngle})) )</td>
<td>( -ZxFwd / 2 \cdot (1 - \cos(\text{LineAngle}) + ZxRev / 2 \cdot (1 + \cos(\text{LineAngle})) )</td>
</tr>
<tr>
<td>P4</td>
<td>( -ZxRev \cdot \sin(\text{LineAngle}) )</td>
<td>( -ZxRev \cdot \cos(\text{LineAngle}) )</td>
</tr>
</tbody>
</table>

Change the magnitude and angle of phase-to-phase voltage to achieve impedances at test points P1, P2, P3 and P4. For each test point, observe that the output signals, START and STZX are activated (where x is 2 or 3 depending on selected zone). After the operate time delay of the respective zone has elapsed, also the signals TRIP and TRZX (where x is 2 or 3 depending on selected zone) shall be activated.

**Load encroachment**

Load encroachment operates on the same measuring principles as the impedance measuring zones. Thus, it is necessary to follow the same principles as for distance protection when performing the secondary injection tests. Measure operating characteristics during constant current conditions. Keep the injected current as close as possible to the rated value of its associated input transformer or lower. Ensure, however, that it is higher than 30% of the rated current. Ensure that the maximum continuous current of an IED does not exceed four times its...
rated value, if the measurement of the operating characteristics runs under constant voltage conditions.

**Measuring the operate limit of set values of load encroachment function**

The load encroachment does not have any special output to be verified. It can only be verified with the distance START and TRIP outputs.

Steps to test the load encroachment:

1. Supply the IED with healthy conditions for at least two seconds.
2. Apply the fault condition and slowly decrease the injected impedance to find the operate value for of the phase-to-earth and phase-to-phase loops.

**Under voltage seal-in**

The under voltage seal-in logic can be verified using the TRUV and STUV outputs.

Steps to verify the logic:

1. Keep all the current and voltage in normal balanced condition.
2. Keeping the phase current at rated value, slowly reduce the voltage till it enters into the respective zone mho characteristics and also below the set value of the under voltage seal-in logic.
3. Before the operate time delay of the respective zone, reduce the current magnitude so that the operating impedance moves out of the mho characteristics.
4. The under voltage seal-in should give a START and TRIP after the operate time delay is set for the under voltage logic.

**11.4.17.2 Completing the test**

Continue to test another function or end the testing by setting the parameter TestMode to Off under Main menu/Tests/IED test mode/1: TESTMODE. If another function is tested, then set the parameter Blocked to No under Main menu/Tests/Function test modes/Impedance/ZGVPDIS/1: ZGVPDIS for the function, or for each individual function in a chain, to be tested next. Remember to set the parameter Blocked to Yes, for each individual function that has been tested.

**11.5 Current protection**

**11.5.1 Instantaneous phase overcurrent protection 3-phase output PHPIOC**

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

Values of the logical signals for PHPIOC are available on the local HMI under Main menu/Tests/Function status/Current protection/InstPhaseOverCurrent(50,3I>>)/PHPIOC(50;3I>>):x, where x = 1, 2, and 3.

The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.

To verify the settings the following fault type should be tested:

- Phase-to-earth fault
Ensure that the maximum continuous current, supplied from the current source used for the test of the IED, does not exceed four times the rated current value of the IED.

### 11.5.1 Measuring the operate limit of set values

1. Set the operation mode to 1 out of 3.
2. Inject a phase current into the IED with an initial value below the set value of $IP_{>>}$ and also make sure that the set value $IP_{>>}$ is in between $IP_{>>Min}$ and $IP_{>>Max}$.
3. Increase the injected current in the Ln phase until the TRLn (n=1–3) signal appears.
4. Switch the fault current off.
   
   ![Information]
   
   *Observe: Do not exceed the maximum permitted overloading of the current circuits in the IED.*

5. Compare the measured operating current with the set value.
6. Set the operation mode to 2 out of 3 and inject current into one of the phases and then check that no TRLn signal appears.

### 11.5.2 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.

### 11.5.2 Directional phase overcurrent protection, four steps OC4PTOC

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

Values of the logical signals for OC4PTOC are available on the local HMI under Main menu/Tests/Function status/Current protection/PhaseOverCurrent4Step(51_67,4(3I>))/OC4PTOC(51_67,4(3I>));x, where x = instance number.

The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.

#### 11.5.2.1 Verifying the settings

The verification of the non-directional phase overcurrent function is done as instructed below, but without applying any polarizing voltage.

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 are chosen for operation: Connect the injection current to phases L1 and neutral.
   
   If 2 out of 3 currents are chosen for operation: Connect the injection current into phase L1 and out from phase L2.
If 3 out of 3 currents are chosen for operation: Connect the symmetrical three-phase injection current into phases L1, L2 and L3.

2. Connect the test set for the appropriate three-phase voltage injection to the IED phases L1, L2 and L3. The protection shall be fed with a symmetrical three-phase voltage.

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

3.1. Set the injected polarizing voltage larger than the set minimum polarizing voltage (default is 5% of UBase) 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 are chosen for operation: The voltage angle of phase L1 is the reference.

   If 2 out of 3 currents are chosen for operation: The phase angle of the phase-to-phase voltage L1L2 is the reference for L1Phase.

   If 3 out of 3 currents are chosen for operation: The voltage angle of phase L1 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°).

3.2. Increase the injected current, note the operate value of the tested step of the function and compare it to the set value.

3.3. Decrease the current slowly, note the reset value and compare it to the reset ratio 95%.

4. If the test has been performed by injection of current in phase L1, repeat the test, injecting current into phases L2 and L3 with polarizing voltage connected to phases L2, respectively L3 (1 out of 3 currents for operation).

5. If the test has been performed by injection of current in phases L1 – L2, repeat the test, injecting current into phases L2 – L3 and L3 – L1 with the appropriate phase angle of injected currents.

6. Connect a trip output contact to a timer.

7. 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 operate time at a current equal to 110% of the operate current for txMin.

8. Check that all operate and start contacts operate according to the configuration (signal matrixes).

9. Reverse the direction of the injected current and check that the protection does not operate.

10. If 2 out of 3 or 3 out of 3 currents are chosen for operation: Check that the function will not operate with current in one phase only.

11. Repeat the above described tests for the higher set stages.

12. Check that start and trip information is stored in the event menu.

11.5.2.2 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.

11.5.3 Instantaneous residual overcurrent protection EFPIOC

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

Values of the logical signals for EFPIOC are available on the local HMI under Main menu/Tests/ Function status/Current protection/InstResidualOverCurrent(50N,IN>>)/EFPIOC(50N;IN>>):x, where x = 1, 2, and 3.

The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.
To verify the settings the following fault type should be tested:

- Phase-to-earth fault

Ensure that the maximum continuous current, supplied from the current source used for the test of the IED, does not exceed four times the rated current value of the IED.

11.5.3.1 Measuring the operate limit of set values

1. Inject a phase current into the IED with an initial value below the set value of \( I_{N >>} \) and also make sure that the set value \( I_{N >>} \) is in between \( I_{N >> \text{Min}} \) and \( I_{N >> \text{Max}} \).
2. Increase the injected current in the \( L_n \) or in the neutral (summated current input) phase until the TRIP signal appears.
3. Switch the fault current off.
4. Compare the measured operating current with the set value.

Do not exceed the maximum permitted overloading of the current circuits in the IED.

11.5.3.2 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.

11.5.4 Four step residual overcurrent protection, (Zero sequence or negative sequence directionality) EF4PTOC

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

Values of the logical signals for D2PTOC are available on the local HMI under Main menu/Tests/Function status/Current protection/ResidualOverCurr4Step(51N_67N,4(IN>))/EF4PTOC(51N_67N;4(IN>)):x, where \( x \) = instance number.

The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.

11.5.4.1 Four step directional earth fault protection

1. Connect the test set for single current injection to the appropriate IED terminals.
   Connect the injection current to terminals L1 and neutral.
2. Set the injected polarizing voltage slightly larger than the set minimum polarizing voltage (5% of \( U_r \)) 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 \( \text{RCA} + 180^\circ \).
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 L1, repeat the test, injecting current into terminals L2 and L3 with a polarizing voltage connected to terminals L2, respectively L3.
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 operate and start contacts operate according to the configuration (signal matrices).
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 start and trip information is stored in the event menu.

11.5.4.2 Four step non-directional earth fault protection

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

11.5.4.3 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.

11.5.5 Four step negative sequence overcurrent protection NS4PTOC

Prepare the IED for verification of settings as outlined in 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 important to set the definite time delay for that stage to zero.

Procedure

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 Ub) and set the injection current to lag the voltage by an angle equal to the set reference characteristic angle (180° - 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 \( t_{min} \).
9. Check that all operate and start 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 start and trip information is stored in the event menu.

### 11.5.5.1 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.

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

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

Figure 47: Principle connection of the test set

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
11.5.6.1 Measuring the operate and time limit for set values

**Operation mode** $3I_0 \cdot \cos \phi$

**Procedure**

1. Set the polarizing voltage to $1.2 \cdot UNRel>$ 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 $INcosPhi>$ setting.
   The $I Dir (3I_0 \cdot \cos \phi)$ function activates the START and STDIRIN output.

3. Assume that $\phi’$ is the phase angle between injected voltage ($3U_0$) and current ($3I_0$) i.e. $\phi’ = RCADir - \phi$. Change $\phi’$ 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 $INcosPhi>$.
   Take the set characteristic into consideration, see Figure 48 and Figure 49.

5. Measure the operate time of the timer by injecting a current two times the set $INcosPhi>$ value and the polarizing voltage $1.2 \cdot UNRel>$.

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 $UNRel>$.

8. Continue to test another function or complete the test by setting the test mode to Off.

$$T_{inv} = \frac{kSN \cdot Sref}{3I_{0test} \cdot 3U_{0test} \cdot \cos(\phi)}$$

(Equation 81)
\[
-3U_0 = U_{ref}
\]

\[
3I_0 = \cos \varphi
\]

\[
RCADir = 0^\circ
\]

Operate area

Figure 48: Characteristic with ROADir restriction
Operation mode $3I_0 \cdot 3U_0 \cdot \cos \phi$

1. Set the polarizing voltage to $1.2 \cdot UNRel>$ 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 $SN>$ setting for the set directional element. Note that for operation, both the injected current and voltage must be greater than the set values $INRel>$ and $UNRel>$ respectively. The function activates the START and STDIRIN outputs.
3. Assume that $\phi'$ is the phase angle between injected voltage ($3U_0$) and current ($3I_0$) i.e. $\phi' = RCADir - \phi$. Change $\phi'$ 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 $3I_0 \cdot 3U_0 \cdot \cos \phi$ is equal to the setting $SN>$. Take the set characteristic into consideration, see figure 48 and figure 49.
5. Measure the operate time of the timer by injecting $1.2 \cdot UNRel>$ and a current to get two times the set $SN>$ operate value.

$$T_{inv} = kSN \cdot Sref \cdot 3I_{max} \cdot 3U_{max} \cdot \cos(\phi)$$

(Equation 82)

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 Off.
Operation mode $3I_0$ and $\phi$

1. Set the polarizing voltage to $1.2 \cdot UNRel>$ 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 $INDir>$ setting for the set directional element.

   Note that for operation, both the injected current and voltage must be greater than the set values $INRel>$ and $UNRel>$ respectively.

The function activates the START and STDIRIN output.
3. Measure with angles $\phi$ around $RCADir +/- ROADir$.
4. Compare the result with the set values, refer to figure 50 for example characteristic.
5. Measure the operate time of the timer by injecting a current to get two times the set $SN_>$ operate value.

   $$T_{inv} = kSN \cdot Sref / 3I_{max} \cdot 3U_{max} \cdot \cos (\phi)$$

   (Equation 83)

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 $Off$.

$RCADir = 0^\circ$

$ROADir = 80^\circ$

$3I_0$

$-3U_0$

Operate area

IEC06000652-3-en.vsd

Figure 50: Example characteristic

Non-directional earth fault current protection

Procedure

1. Measure that the operate current is equal to the $INNonDir>$ setting.
   The function activates the START and STDIRIN output.
2. Measure the operate time of the timer by injecting a current of 200% of the operate value.
3. Compare the result with the expected value.
The expected value depends on whether definite time $t_{INNonDir}$ or inverse time was selected.

4. Continue to test another function or complete the test by setting the test mode to Off.

Residual overvoltage release and protection

Procedure

1. Measure that the operate voltage is equal to the $UN>$ setting. The function activates the START and STUN signals.
2. Measure the operate time by injecting a voltage 1.2 times set $UN>$ operate value.
3. Compare the result with the set $tUN$ operate value.
4. Inject a voltage $0.8 \cdot UNRel>$ and a current high enough to operate 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 $UNRel>$ operate value.

11.5.6.2 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.

11.5.7 Thermal overload protection, one time constant, Celsius/Fahrenheit LCPTTR/LFPTTR

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

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

11.5.7.1 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 LCPTTR/LFPTTR 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, START and TRIP should disappear.
8. Reset the BLOCK binary input.
9. Check the reset limit (TdReset).
Monitor the signal START 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
Off.

11.5.7.2 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.

11.5.8 Thermal overload protection, two time constants TRPTTR
Prepare the IED for verification of settings as outlined in section “Requirements” and
section “Preparing for test” in this chapter.

11.5.8.1 Checking operate and reset values

1. Connect symmetrical three-phase currents to the appropriate current terminals of the
IED.
2. Set the Time constant 1 (Tau1) and Time Constant 2 (Tau2) temporarily to 1 minute.
3. Set the three-phase injection currents slightly lower than the set operate value of stage
IBase1, increase the current in phase L1 until stage IBase1 operates and note the operate
value.

Observe the maximum permitted overloading of the current circuits in the
IED.

4. Decrease the current slowly and note the reset value.
Check, in the same way, the operate and reset values of IBase1 for phases L2 and L3.
5. Activate the cooling input signal, thus switching to base current IBase2.
6. Check the operate and reset values (for all three phases) for IBase2 in the same way as
described above for stage IBase1.
7. Deactivate the input signal for stage IBase2.
8. Set the time constant for IBase1 in accordance with the setting plan.
9. Set the injection current for phase L1 to 1.50 · IBase1.
10. Connect a trip output contact to the timer and monitor the output of contacts ALARM1
and ALARM2 to digital inputs in test equipment.
Read the heat content in the thermal protection from the local HMI and wait until the
content is zero.
11. Switch on the injection current and check that ALARM1 and ALARM2 contacts operate at
the set percentage level and that the operate time for tripping is in accordance with the
set Time Constant 1 (Tau1).
With setting Itr = 101%IBase1 and injection current 1.50 · IBase1, the trip time from zero
content in the memory shall be 0.60 · Time Constant 1 (Tau1).
12. Check that all trip and alarm contacts operate according to the configuration logic.
13. Switch off the injection current and check from the service menu readings of thermal
status and LOCKOUT that the lockout resets at the set percentage of heat content.
14. Activate the cooling input signal to switch over to base current IBase2.
Wait 5 minutes to empty the thermal memory and set Time Constant 2 \((T_{au2})\) in accordance with the setting plan.

15. Test with injection current \(1.50 \cdot I_{Base2}\) the thermal alarm level, the operate time for tripping and the lockout reset in the same way as described for stage \(I_{Base1}\).

16. Finally check that start and trip information is stored in the event menu.

11.5.8.2 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.

11.5.9 Breaker failure protection, phase segregated activation and output CCRBRF

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

The Breaker failure protection, 3-phase activation and output function CCRBRF should normally be tested in conjunction with some other function that provides a start signal. An external START signal can also be used.

To verify the settings in the most common back-up trip mode 1 out of 3, it is sufficient to test phase-to-earth faults.

At mode 2 out of 4 the phase current setting, \(I_P>\) can be checked by single-phase injection where the return current is connected to the summated current input. The value of residual (earth fault) current \(I_N>\) set lower than \(I_N>\) is easiest checked in back-up trip mode 1 out of 4.

11.5.9.1 Checking the phase current operate value, \(I_P>\)

\(BuTripMode = 1\) out of 3 or 2 out of 4.

1. Apply the fault condition, including START of CCRBRF, with a current below the set \(I_P>\).
2. Repeat the fault condition and increase the current in steps until a trip occurs. Note that the START signal shall be re-applied for each new current value.
3. Compare the result with the set \(I_P>\).

If \(RetripMode = Off\) and \(FunctionMode = Current\) is set, only backup trip can be used to check set \(I_P>\).

11.5.9.2 Checking the residual (earth fault) current operate value \(I_N>\) set below \(I_P>\)

Check the low set \(I_N>\) current where setting \(FunctionMode = Current\) and setting \(BuTripMode = 1\) out of 4

1. Apply the fault condition, including START of CCRBRF, with a current just below set \(I_N>\).
2. Repeat the fault condition and increase the current in steps until trip appears. Note that the START signal shall be re-applied for each new current value.
3. Compare the result with the set \(I_N>\).
4. Disconnect AC and START input signals.
11.5.9.3 Checking the re-trip and back-up times

The check of the set times can be made in connection with the check of operate values above.

Choose the applicable function and trip mode, such as FunctionMode = Current and RetripMode = UseFunctionMode.

1. Apply the fault condition, including start of CCRBRF, well above the set current value. Measure the time from START of CCRBRF.
2. Check the re-trip t1 and back-up trip times t2 and t3. In applicable cases, the back-up trip for multi-phase start t2MPh and back-up trip 2, t2 and t3 can also be checked. To check t2MPh, a two-phase or three-phase start shall be applied.

11.5.9.4 Verifying the re-trip mode

Choose the mode below, which corresponds to the actual case.

In the cases below it is assumed that FunctionMode = Current is selected.

Checking the case without re-trip, RetripMode = Off

1. Set RetripMode = Off.
2. Apply the fault condition, including start of CCRBRF, well above the set current value.
3. Verify that no re-trip, but back-up trip is achieved after set time.

Checking the re-trip with current check, RetripMode = UseFunctionMode

1. Set RetripMode = UseFunctionMode.
2. Apply the fault condition, including start of CCRBRF, well above the set current value.
3. Verify that re-trip is achieved after set time t1 and back-up trip after time t2.
4. Apply the fault condition, including the start of CCRBRF, with the current below the set current value.
5. Verify that no re-trip, and no back-up trip is obtained.

Checking re-trip without current check

1. Set RetripMode = Always.
2. Apply the fault condition, including start of CCRBRF, well above the set current value.
3. Verify that re-trip is achieved after the set time t1, and the back-up trip after time t2.
4. Apply the fault condition, including start of CCRBRF, with current below set current value.
5. Verify that re-trip is achieved after set time t1, but no back-up trip is obtained.

11.5.9.5 Verifying the back-up trip mode

In the cases below it is assumed that FunctionMode = Current is selected.

Checking that back-up tripping is not achieved at normal CB tripping

Use the actual tripping modes. The case below applies to re-trip with current check.

1. Apply the fault condition, including start of CCRBRF, with phase current well above set value IP>.
2. Interrupt the current, with a margin before back-up trip time, t2. It may be made at issue of re-trip command.
3. Check that re-trip is achieved, if selected, but no back-up trip is obtained.
The normal mode $BuTripMode = 1$ out of 3 should have been verified in the tests above. In applicable cases the modes 1 out of 4 and 2 out of 4 can be checked. Choose the mode below, which corresponds to the actual case.

**Checking the case $BuTripMode = 1$ out of 4**

It is assumed that the earth-fault current setting $IN>$ is below phase current setting $IP>$.

1. Set $BuTripMode = 1$ out of 4.
2. Apply the fault condition, including start of CCRBRF, with one-phase current below set $IP>$ but above $IN>$. The residual earth-fault should then be above set $IN>$.
3. Verify that back-up trip is achieved after set time. If selected, re-trip should also appear.
4. Disconnect AC and START input signals.

**Checking the case $BuTripMode = 2$ out of 4**

The earth-fault current setting $IN>$ may be equal to or below phase-current setting $IP>$.

1. Set $BuTripMode = 2$ out of 4.
2. Apply the fault condition, including start of CCRBRF, with one-phase current above set $IP>$ and residual (earth fault) above set $IN>$. The current may be arranged by feeding three- (or two-) phase currents with equal phase angle ($I₀$-component) below $IP>$, but of such value that the residual (earth fault) current ($3I₀$) will be above set value $IN>$.
3. Verify that back-up trip is not achieved.
4. Apply the fault condition, including start of CCRBRF, with at least one-phase current below set $IP>$ and residual (earth fault) above set $IN>$. The current may be arranged by feeding three- (or two-) phase currents with equal phase angle ($I₀$-component) below $IP>$, but of such value that the residual (earth fault) current ($3I₀$) will be above set value $IN>$. The current may be arranged by feeding three- (or two-) phase currents with equal phase angle ($I₀$-component) below $IP>$, but of such value that the residual (earth fault) current ($3I₀$) will be above set value $IN>$.
5. Verify that back-up trip is not achieved.
6. Disconnect AC and START input signals.

### 11.5.9.6 Verifying instantaneous back-up trip at CB faulty condition

Applies in a case where a signal from CB supervision function regarding CB being faulty and unable to trip is connected to input CBFLT.

1. Repeat the check of back-up trip time. Disconnect current and START input signals.
2. Activate the input CBFLT. The output CBALARM (CB faulty alarm) should appear after set time $tCBAlarm$. Keep the input activated.
3. Apply the fault condition, including start of CCRBRF, with current above set current value.
4. Verify that back-up trip is obtained without intentional delay, for example within 20ms from application of start.

### 11.5.9.7 Verifying the case $FunctionMode = CB\ Pos$

It is assumed that re-trip without current check is selected, $RetripMode = UseFunctionMode$.

1. Set $FunctionMode = CB\ Pos$.
2. Apply input signal for CB closed to relevant input or inputs CBCLDL1, CBCLD2 or CBCDL3.
3. Apply the input signal, or signals for the start of CCRBRF.
4. Verify that phase selection re-trip and backup trip are achieved after set times.
5. Disconnect the start signal(s). Keep the CB closed signal(s).
6. Apply input signal(s), for start of CCRBRF.
7. Arrange disconnection of CB closed signal(s) well before set backup trip time $t2$.
8. Verify that backup trip is not achieved.

### 11.5.9.8 Verifying the case $RetripMode = Contact$

It is assumed that re-trip without current check is selected, $RetripMode = Contact$. 

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1. Set FunctionMode = Contact
2. Apply input signal for CB closed to relevant input or inputs CBCLDL1, CBCLD2 or CBCDL3.
3. Apply the input signal, or signals for the start of CCRBRF.
4. Verify that phase selection re-trip and back-up trip are achieved after set times.
5. Disconnect the start signal(s). Keep the CB closed signal(s).
6. Apply input signal(s), for start of CCRBRF.
7.
8. Arrange disconnection of CB closed signal(s) well before set back-up trip time \( t_2 \).
9. Verify that back-up trip is not achieved.

### 11.5.9.9 Verifying the case FunctionMode = Current or CB Pos

To be made only when FunctionMode = Current or CB Pos is selected. It is suggested to make the tests in one phase only, or at three-phase trip applications for just three-phase tripping.

#### Checking the case with fault current above set value \( I_{P}> \)

The operation shall be as in RetripMode = UseFunctionMode.

1. Set FunctionMode = Current or CB Pos.
2. Leave the inputs for CB close inactivated. These signals should not influence.
3. Apply the fault condition, including the start of CCRBRF, with the current above the set \( I_{P}> \) value.
4. Check that the re-trip, if selected, and back-up trip commands are achieved.

#### Checking the case with fault current below set value \( I_{>BlkCBPos} \)

The case shall simulate a case where the fault current is very low and operation will depend on CB position signal from CB auxiliary contact. It is suggested that retrip without current check is used, setting RetripMode = UseFunctionMode Check.

1. Set FunctionMode = Current or CB Pos.
2. Apply input signal for CB closed to the relevant input or inputs CBCLDL1 (2 or 3).
3. Apply the fault condition with input signal(s) for start of CCRBRF. The value of current should be below the set \( I_{>BlkCBPos} \) value.
4. Verify that phase selection re-trip (if selected) and back-up trip are achieved after set times. Failure to trip is simulated by keeping the signal(s) CB closed activated.
5. Disconnect the input signal and the START signal(s). Keep the CB closed signal(s).
6. Apply START signal, and after \( 1.5 \) s apply the current above the set \( I_{P}> \) value.
7. Arrange disconnection of CB closed signal(s) well before set back-up trip time \( t_2 \). It simulates a correct CB tripping.
8. Verify that back-up trip is not achieved. Re-trip can appear for example, due to selection RetripMode = Always.

### 11.5.9.10 Verifying the external start signal has timed out

1. Set StartMode = FollowStart.
2. Set FunctionMode = Current.
3. Use default value for \( t_{StartTimeout} = 1.0 \) s.
4. Use default value for time delay backup trip \( t_2 = 0.150 \) s.
5. Leave the inputs for CB close inactivated. These signals should not influence.
6. Apply START signal, and after \( 1.5 \) s apply the current above the set \( I_{P}> \) value.
7. Check that STALARM signal is set after \( 1.0 \) s and backup trip is blocked.
11.5.9.11 Verifying that backup signal is released when STALARM is reset

1. Set StartMode = FollowStart.
2. Set FunctionMode = Current.
3. Use default value for tStartTimeout = 1.0 s.
4. Use default value for time delay backup trip \( t_2 \) = 0.150 s.
5. Leave the inputs for CB close inactivated. These signals should not influence.
6. Apply START signal at \( t=0 \) s, and after 1.5 s apply the current above the set \( I_{Ph} > \) value.
7. Check that STALARM signal is set after 1.0 s and backup trip is blocked.
8. Reset START signal after 3.5 s, ensure that STALARM reset immediately.
9. Set START after 3.6 s, ensure that backup trip is set after \( t_2 \) backup trip delay has expired (3.750 s).

11.5.9.12 Test of FollowStart\&Mode behaviour

1. Set StartMode = FollowStart\&Mode.
2. Set FunctionMode = Current.
3. Set RetripMode = UseFunctionMode.
4. Use default value for tStartTimeout = 1.0 s.
5. Use default value for time delay backup trip \( t_2 \) = 0.150 s.
6. Use default value for time delay re-trip \( t_1 \) = 0.000 s.
7. Leave the inputs for CB close inactivated. These signals should not influence.
8. Apply START signal, and after 0.200 s apply the current above the set \( I_{Ph} > \) value.
9. Check that STALARM does not come and that re-trip TRRET is instantly set at 0.200 s while the backup trip TRBU set only when \( t_2 \) expires at 0.200 + 0.150 s.

11.5.9.13 Test of FollowStart behaviour

1. Set StartMode = FollowStart.
2. Set FunctionMode = Current.
3. Set RetripMode = UseFunctionMode.
4. Use default value for tStartTimeout = 1.0 s.
5. Use for example the default value for time delay backup trip \( t_2 \) = 0.150 s.
6. Use for example the default value for time delay re-trip \( t_1 \) = 0.000 s.
7. Leave the inputs for CB close inactivated. These signals should not influence.
8. Apply START signal, and after 0.200 s apply the current above the set \( I_{Ph} > \) value.
9. Check that STALARM does not come and that both re-trip TRRET and backup trip TRBU comes instantly at 0.200 s (that is, as soon as current is given to the function).

11.5.9.14 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.

11.5.10 Stub protection STBPTOC

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

Logical signals for STBPTOC protection are available on the local HMI under Main menu/ Settings/IED Settings/Current protection/Stub(PTOC,50STB)/STBPTOC:x
11.5.10.1 Measuring the operate limit of set values

1. Check that the input logical signals BLOCK and RELEASE and the output logical signal TRIP are all logical zero.
2. Activate the input RELEASE on the STBPTOC function block.
3. For a short while inject a current (fault current) in one phase to about 110% of the set operating current, and switch the current off. Observe to not exceed the maximum permitted overloading of the current circuits in the IED.
4. Switch the fault current on and measure the operating time of STBPTOC. Use the TRIP signal from the configured binary output to stop the timer. The operation should be instantaneously.
5. Activate the input BLOCK on the STBPTOC function block.
6. Switch on the fault current (110% of the setting). No TRIP signal should appear.
7. Switch off the fault current.
8. For a short while inject a current (fault current) in same phase to about 90% of the set operating current, and switch the current off.
9. Switch the fault current on. No TRIP signal should appear.
10. Switch off the fault current.
11. Reset the RELEASE binary input.
12. Switch the fault current on. No TRIP signal should appear.
13. Switch the fault current off.

11.5.10.2 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.

11.5.11 Pole discordance protection CCPDSC

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

11.5.11.1 Verifying the settings

1. External detection logic, Contact function selection = ContSel/setting equals CCPDSC signal from CB. Activate the EXTPDIND binary input, and measure the operating time of CCPDSC. Use the TRIP signal from the configured binary output to stop the timer.
2. Compare the measured time with the set value tTrip.
3. Reset the EXTPDIND input.
4. Activate the BLKDBYAR binary input. This test should be performed together with Autorecloser SMBRREC.
5. Activate the EXTPDIND binary input. No TRIP signal should appear.
6. Reset both BLKDBYAR and EXTPDIND binary inputs.
7. Activate the BLOCK binary input.
8. Activate EXTPDIND binary input. NO TRIP signal should appear.
9. Reset both BLOCK and EXTPDIND binary inputs.
10. If Internal detection logic Contact function selection = ContSel setting equals Pole position from auxiliary contacts. Then set inputs POLE1OPN...POLE3CL in a status that activates the pole discordance logic and repeats step 2 to step 6.

11. Unsymmetrical current detection with CB monitoring: Set measured current in one phase to 110% of current release level. Activate CLOSECMD and measure the operating time of the CCPDSC protection. Use the TRIP signal from the configured binary output to stop the timer.

12. Deactivate the CLOSECMD: Set measured current in one phase to 90% of Current Release level. Activate CLOSECMD. NO TRIP signal should appear.

13. Repeat the previous two steps using OPENCMD instead of CLOSECMD. Asymmetry current detection with CB monitoring: Set all three currents to 110% of Current Release level. Activate CLOSECMD. NO TRIP signal should appear due to symmetrical condition.

14. Deactivate the CLOSECMD. Decrease one current with 120% of the current unsymmetrical level compared to the other two phases. Activate CLOSECMD and measure the operating time of the CCPDSC protection. Use the TRIP signal from the configured binary output to stop the timer.

15. Deactivate the CLOSECMD. Decrease one current with 80% of the current unsymmetrical level compared to the other two phases. Activate CLOSECMD. NO TRIP signal should appear.

11.5.11.2 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.

11.5.12 Directional underpower protection GUPPDUP

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

11.5.12.1 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 38: Calculation modes

<table>
<thead>
<tr>
<th>Set value: Mode</th>
<th>Formula used for complex power calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1, L2, L3</td>
<td>$\tilde{S} = \tilde{U}<em>{L1} \cdot \tilde{T}</em>{L1} + \tilde{U}<em>{L2} \cdot \tilde{T}</em>{L2} + \tilde{U}<em>{L3} \cdot \tilde{T}</em>{L3}$</td>
</tr>
<tr>
<td></td>
<td>(Equation 84)</td>
</tr>
<tr>
<td>Arone</td>
<td>$\tilde{S} = \tilde{U}<em>{L1L2} \cdot \tilde{T}</em>{L1} - \tilde{U}<em>{L2L3} \cdot \tilde{T}</em>{L3}$</td>
</tr>
<tr>
<td></td>
<td>(Equation 85)</td>
</tr>
<tr>
<td>PosSeq</td>
<td>$\tilde{S} = 3 \cdot \tilde{U}<em>{\text{PosSeq}} \cdot \tilde{T}</em>{\text{PosSeq}}$</td>
</tr>
<tr>
<td></td>
<td>(Equation 86)</td>
</tr>
<tr>
<td>L1L2</td>
<td>$\tilde{S} = \tilde{U}<em>{L1L2} \cdot (\tilde{T}</em>{L1} - \tilde{T}_{L2})$</td>
</tr>
<tr>
<td></td>
<td>(Equation 87)</td>
</tr>
<tr>
<td>L2L3</td>
<td>$\tilde{S} = \tilde{U}<em>{L2L3} \cdot (\tilde{T}</em>{L2} - \tilde{T}_{L3})$</td>
</tr>
<tr>
<td></td>
<td>(Equation 88)</td>
</tr>
<tr>
<td>L3L1</td>
<td>$\tilde{S} = \tilde{U}<em>{L3L1} \cdot (\tilde{T}</em>{L3} - \tilde{T}_{L1})$</td>
</tr>
<tr>
<td></td>
<td>(Equation 89)</td>
</tr>
<tr>
<td>L1</td>
<td>$\tilde{S} = 3 \cdot \tilde{U}<em>{L1} \cdot \tilde{T}</em>{L1}$</td>
</tr>
<tr>
<td></td>
<td>(Equation 90)</td>
</tr>
<tr>
<td>L2</td>
<td>$\tilde{S} = 3 \cdot \tilde{U}<em>{L2} \cdot \tilde{T}</em>{L2}$</td>
</tr>
<tr>
<td></td>
<td>(Equation 91)</td>
</tr>
<tr>
<td>L3</td>
<td>$\tilde{S} = 3 \cdot \tilde{U}<em>{L3} \cdot \tilde{T}</em>{L3}$</td>
</tr>
<tr>
<td></td>
<td>(Equation 92)</td>
</tr>
</tbody>
</table>

2. Adjust the injected current and voltage to the set values in % of $I_{\text{Base}}$ and $U_{\text{Base}}$ (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 0°. Decrease the current slowly until the $\text{START1}$ signal, start of stage 1, is activated.

5. Increase the current to 100% of $I_{\text{Base}}$.

6. Switch the current off and measure the time for activation of $\text{TRIP1}$, trip of stage 1.

7. If a second stage is used, repeat steps 2 to 6 for the second stage.
11.5.12.2 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.

11.5.13 Directional overpower protection GOPPDOP

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

11.5.13.1 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 UBase (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° 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 Angle1 + 90°. 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 Angle1 value. Increase the current slowly from 0 until the START1 signal, start of stage 1, is activated. Check the injected power and compare it to the set value Power1, power setting for stage 1 in % of Sbase.
5. Increase the current to 100% of IBase 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.

11.5.13.2 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.

11.5.14 Broken conductor check BRCPTOC

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

11.5.14.1 Measuring the operate and time limit of set values
1. Check that the input logical signal BLOCK to the BRCPTOC function block is logical zero and note on the local HMI that the output signal TRIP from the BRCPTOC function block is equal to the logical 0.

2. Set the measured current (fault current) in one phase to about 110% of the set operating current \( IP > \). Observe to not exceed the maximum permitted overloading of the current circuits in the terminal.

3. Switch on the fault current and measure the operating time of BRCPTOC. TRIP is controlled by Gate 13 in the configuration. Use the TRIP signal from the configured binary output to stop the timer.

4. Compare the measured time with the set value \( t_{\text{Oper}} \).

5. Activate the BLOCK binary input.

6. Switch on the fault current (110% of the setting) and wait longer than the set value \( t_{\text{Oper}} \). No TRIP signal should appear.

7. Switch off the fault current.

8. Set the measured current (fault current) in same phase to about 90% of the set operating current \( IP > \). Switch off the current.

9. Switch on the fault current and wait longer than the set value \( t_{\text{Oper}} \). No TRIP signal should appear.

10. Switch off the fault current.

11.5.14.2 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.

11.5.15 Capacitor bank protection CBPGAPC

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

In this section it is shown how to test the capacitor bank protection function CBPGAPC for application on a 50Hz, 200MVAR, 400kV SCB with 500/1A ratio CT.

Note that such SCB is shown in the application manual for this function. The same procedure can be used to test SCB with some other rating and different CT ratio.

As calculated in the application manual the base current for this particular SCB will be 289A on the primary side and 0.578A on the CT secondary side. Before any testing is commenced make sure that setting /Base for this function is set to 289A (that is, setting for the base current corresponds to the rated current of the protected SCB). It will be also assumed that all other settings have values as shown in the setting example in the application manual for this SCB.

Test equipment

Connect the secondary test set to the CT inputs on the IED dedicated for the SCB currents. Single- or three-phase test equipment can be used but it may be required to have facility to vary the frequency of the injected current signal(s).

11.5.15.1 Verifying the settings and operation of the function

Reconnection inhibit feature
1. Inject SCB rated current (that is, 0.587A at 50Hz for this SCB) in at least one phase (preferably perform this test with three phase injection).
2. After couple of seconds stop injection of all currents (that is, set all currents back to 0A).
3. Check that function binary output signal RECNINH is set to logical 1 and that only resets after the set time under parameter tReconnInhibit (for example 300s for this SCB) has expired.
4. If this binary signal is used to prevent CB closing make sure that it is properly connected/wired into the CB closing circuit.

**Overcurrent feature**

- Note that during testing the overcurrent feature the harmonic voltage overload feature or reactive power overload feature may also give start and operate signals depending on their actual settings. Therefore it is best to switch them off during this test.

1. Inject current 20% bigger than the set overcurrent pickup level under setting parameter IOC> (for example, 1.2 · 1.35 · 0.587A = 0.951A at 50Hz for this SCB) in phase L1 only.
2. Check that function binary output signals STOCL1 and STOC are set to one.
3. Check that function binary output signals TROC and TRIP are set to one after the set time under parameter tOC (that is, 30s for this SCB) has expired.
4. If any of these signals are used for tripping, signaling and/or local/remote indication check that all relevant contacts and LEDs have operated and that all relevant GOOSE messages have been sent.
5. Check that service value from the function for current in phase L1, on the local HMI under **Main menu/Test** is approximately 476A (that is, 0.951A · (500/1) = 476A).
6. Stop injection of all currents (that is, set all currents back to 0A).
7. Check that all above mentioned function binary output signals now have logical value zero.
8. Repeat above steps 1-7 for phase L2 and phase L3.

- Note that the operation of this feature is based on current peak value. That means that this overcurrent function is also able to operate for the same current magnitude but for different injected frequencies. If required repeat this injection procedure for example for the 3rd harmonic by just simply injecting 3 · 50 = 150Hz currents with the same magnitude. Obtain results shall be the same.

**Undercurrent feature**

1. Inject SCB rated current (that is, 0.587A at 50Hz for this SCB) in all three phases.
2. Lower phase L1 current 10% under the set value for setting parameter IUC< (that is, 0.9 · 0.7 · 0.587A = 0.370A at 50Hz for this SCB).
3. Check that function binary output signals STUCL1 and STUC are set to one.
4. Check that function binary output signals TRUC and TRIP are set to one after the set time under parameter tUC (for example, 5s for this SCB) has expired.
5. If any of these signals are used for tripping, signaling and/or local/remote indication check that all relevant contacts and LEDs have operated and that all relevant GOOSE messages have been sent.
6. Check that service value from the function for current in phase L1, on the local HMI under **Main menu/Test** is approximately 185A (that is, 0.370A · (500/1) = 185A).
7. Stop injection of all currents (that is, set all currents back to 0A).
8. Check that all above mentioned function binary output signals now have logical value zero because they will be automatically blocked by operation of built-in reconnection inhibit feature.
9. Repeat above steps 1-8 for phase L2 and phase L3.

**Reactive power overload feature**

Note that during testing the reactive power overload feature the harmonic voltage overload feature or overcurrent feature may also give start and operate signals depending on their actual settings. Therefore it is recommended to switch them off during this test.

1. Inject current equal to the set reactive power overload pickup level under setting parameter \( QOL > \) (that is, \( 1.3 \cdot 0.587A = 0.763A \) at 50Hz for this SCB) in phase L1 only.
2. Check that function binary output signals STQOLL1 and STQOL are set to one.
3. Check that function binary output signals TRQOL and TRIP are set to one after the set time under parameter \( tQOL \) (for example, 60s for this SCB) has expired.
4. If any of these signals are used for tripping, signaling and/or local/remote indication check that all relevant contacts and LEDs have operated and that all relevant GOOSE messages have been sent.
5. Check that service value from the function for current in phase L1, on the local HMI under Main menu/Test is approximately 382A (that is, \( 0.763A \cdot (500/1) = 382A \)).
6. Check that service value from the function for reactive power in phase L1, on the local HMI under Main menu/Test is approximately 169% (that is, \( 1.3 \cdot 1.3 = 1.69pu = 169\% \)).
7. Stop injection of all currents (that is, set all currents back to 0A).
8. Check that all above mentioned function binary output signals now have logical value zero.
9. Repeat above steps 1 - 8 for phase L2 and phase L3.

Note that operation of this feature is based on injected current and internally calculated true RMS values. That means that this feature is also able to operate for current signals with varying frequency. However due to relatively complex calculation procedure it is recommended to do secondary tests only with fundamental frequency current signals.

The following formula can be used to calculate SCB reactive power in per-unit system when current with different frequency from the rated frequency is injected.

\[
Q[pu] = \frac{f_{rated}}{f_{injected}} \cdot I_p[pu]
\]

(Equation 93)

**Harmonic voltage overload feature**

Note that during testing the harmonic voltage overload feature the reactive power overload feature or overcurrent feature may also give start and operate signals depending on their actual settings. Therefore it is recommended to switch them off during this test.

Procedure to test inverse time delayed step:
The following points on the inverse curve are defined per relevant IEC/ANSI standards for time multiplier value set to $k_{HOLIDMT}=1.0$

<table>
<thead>
<tr>
<th>$U_{peakRMS \ [pu]}$</th>
<th>1.15</th>
<th>1.2</th>
<th>1.3</th>
<th>1.4</th>
<th>1.7</th>
<th>2.0</th>
<th>2.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time [s]</td>
<td>1800</td>
<td>300</td>
<td>60</td>
<td>15</td>
<td>1</td>
<td>0.3</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Note that operation of this feature is based on internally calculated voltage peak RMS value. That means that this feature is also able to operate for current signals with varying frequency.

Here will be shown how to test the fourth point from the above table. Other points can be tested in the similar way:

1. Inject 140% of the base current (that is, $1.4 \cdot 0.587A = 0.822A$ at 50Hz for this SCB) in phase L1 only.
2. Check that function binary output signals STHIDML1 and STHOL are set to one.
3. Check that function binary output signals TRHOL and TRIP are set to one after the expected time (for example, 15s for this voltage level in accordance with the above table) has expired.
4. If any of these signals are used for tripping, signaling and/or local/remote indication, check that all relevant contacts and LEDs have operated and that all relevant GOOSE messages have been sent.
5. Check that service value for current in phase L1, on the local HMI under Main menu/Test is approximately $411A$ (that is, $0.822A \cdot \frac{500}{1} = 411A$).
6. Check that service value for voltage across SCB in phase L1, on the local HMI under Main menu/Test is approximately 140%.
7. Stop injection of all currents (that is, set all currents back to 0A).
8. Check that all above mentioned function binary output signals now have logical value zero.
9. Repeat above steps 1 - 8 for phase L2 and phase L3.
10. Repeat above steps 1 - 8 to test different points from the above table.

Operation of this feature is based on internally calculated peak RMS voltage value. That means that this feature is also able to operate for current signals with varying frequency. Note that for the fundamental frequency injection, internally calculated voltage in percent corresponds directly to the injected current value given in percent. However if it is required to test IDMT characteristic with a varying frequency, the magnitude of the injected current must be adjusted accordingly. The following formula can be used to calculate required current RMS value in percent at the desired injection frequency in order to achieve voltage percentage value given in the above table:

$$I_{inj} \ [%] = \frac{f_{inj}}{f_{rated}} \cdot U \ [%]$$

(Equation 94)

Note that it is recommended to test IDMT operating times by injected current with the rated frequency.

Above procedure can also be used to test definite time step. Pay attention that IDMT step can also operate during such injection. Therefore make sure that appropriate settings are entered in order to insure correct test results for definite time step.
11.5.15.2 Completing the test

Continue to test another functions 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. Make sure that all built-in features for this function, which shall be in operation, are enabled and with correct settings.

11.5.16 Negative-sequence time overcurrent protection for machines NS2PTOC

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

11.5.16.1 Verifying settings by secondary injection

1. Connect the test set for injection of three-phase currents to the appropriate current terminals of the IED.
2. Go to Main menu/Settings/IED Settings/Current protection/NegSeqOverCurr2Step/NSOn/General and make sure that the function is enabled, that is Operation is set to On.
3. Inject current into IEDs in such a way that negative sequence component is created and then verify that negative sequence component of the injected currents is calculated correctly by the function. See example below for 1 A rated current transformer.
4. 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 start level. No output signals should be activated.
   Note: If it is difficult to obtain pure negative sequence current for the secondary injection test, a current corresponding to the two phase short-circuit condition can be used. A two phase short-circuit gives a negative sequence current of a magnitude: magnitude = (1/√3) · fault current.
5. Increase the injected current and note the value at which the step 1 of the function operates. Start signal ST1 must be activated when amplitude of the negative sequence current lies slightly above the start level I2-1>. Corresponding trip signals TR1 and TRIP is activated after the pre-set time delay has expired.
   Note: Block or disable operation of step 2 when testing step 1 if the injected current activates the step 2.
6. Decrease the current slowly and note the reset value.
7. Connect a trip output contact to a timer.
8. Set the current to 200% of the start level of the step 1, switch on the current and check the definite time delay for trip signals TR1 and TRIP. Once the measured negative sequence current exceeds the set start level I2-1>, the settable definite timer t1 starts to count and trip signals is released after the set time delay has elapsed. The same test must be carried out to check the accuracy of definite time delay for ALARM signal.
   Note: The output ALARM is operated by START signal.
9. If inverse time is selected the trip signals TR1 and TRIP operates after a time corresponding to the formula:
This means that if current jumps from 0 to 2 times start and negative sequence capability value of generator $K1$ is set to 10 s and current start level $I2-I1$ is set to 10% of rated generator current, then TR1 and TRIP signals operates at time equal to 250 sec ± tolerance.

10. Repeat the above-described tests for the step 2 of the function excluding the inverse time testing.

11. Finally check that start and trip information is stored in the event menu.

**Example**

\[
I[s] = \left[ \frac{1}{\left( \frac{I2-I1}{100} \right) \text{(Multiple of Start)}} \right] \cdot K
\]

The CT ratios $\frac{CT_{\text{prim}}}{CT_{\text{sec}}}$ for all three phases is 1000 A, $I_{\text{Base}}$ is 1000 A, and the following secondary currents are applied:

<table>
<thead>
<tr>
<th>Phase</th>
<th>Ampl</th>
<th>Angl</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL1</td>
<td>1.1 A</td>
<td>15 deg</td>
</tr>
<tr>
<td>IL2</td>
<td>0.6 A</td>
<td>97 deg</td>
</tr>
<tr>
<td>IL3</td>
<td>1.3 A</td>
<td>-135 deg</td>
</tr>
</tbody>
</table>

The service value output NSCURR indicating amplitude of negative sequence current in primary amperes should be 962A approximative.

**11.5.16.2 Completing the test**

Continue to test another functions 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. Make sure that all built-in features for this function, which shall be in operation, are enabled and with correct settings.

**11.5.17 Voltage-restrained time overcurrent protection VRPVOC**

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

**11.5.17.1 Verifying the settings**

Verifying settings by secondary injection

1. Connect the test set for three-phase current injection and three-phase voltage injection to the appropriate IED terminals.
2. Go to Main menu/Settings/IED Settings/Current protection/VoltageRestOverCurr (51V,2(I>/U<))/VRPVOC (51V,2(I>/U<)):1/General and make sure that the function is enabled, that is, Operation is set to On.
3. The test of the function may be performed by injecting restrain voltage and increasing the injected current(s). Note the value at which the START and STOC signals are set.
In the following equations, restrain voltage is the magnitude of the minimum phase-to-phase voltage in secondary volts.

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

First part of the characteristic (Restrain voltage ≤ 25% of $U_{Base}$):

$$\frac{StartCurr}{100} \times I_{Base} \times \frac{CT \text{ sec}}{CT_{prim}} \times \frac{V_{DepFact}}{100}$$

(Equation 95)

Second part of the characteristic (25% of $U_{Base}$ ≤ Restrain voltage ≤ $U_{HighLimit}/100 * U_{Base}$), valid when setting parameter $V_{DepMode} = \text{Slope}$:

$$\frac{StartCurr}{100} \times \frac{I_{Base} \times CT \text{ sec}}{CT_{prim}} \times \left( \frac{V_{DepFact}}{100} \right) \times \left( \frac{U_{HighLimit} - 25 \times U_{Base}}{100} \right) \times \left( \frac{V_{sec}}{VT_{prim}} \right) \times \left( \frac{StartCurr}{100} \times \frac{I_{Base} \times CT \text{ sec}}{CT_{prim}} \times \frac{V_{DepFact}}{100} \right)$$

(Equation 96)

Third part of the characteristic ($U_{HighLimit}/100 * U_{Base}$ ≤ Restrain voltage):

$$\frac{StartCurr}{100} \times I_{Base} \times \frac{CT \text{ sec}}{CT_{prim}}$$

(Equation 97)

Example (rated secondary current = 1A):

<table>
<thead>
<tr>
<th>CT ratio</th>
<th>10 000/1A</th>
</tr>
</thead>
<tbody>
<tr>
<td>VT ratio</td>
<td>10 kV/100 V</td>
</tr>
<tr>
<td>StartCurr</td>
<td>100%</td>
</tr>
<tr>
<td>VDepFact</td>
<td>25%</td>
</tr>
<tr>
<td>UHighLimit</td>
<td>100%</td>
</tr>
<tr>
<td>IBase</td>
<td>10 000 A</td>
</tr>
</tbody>
</table>

A test for each section of the characteristic of the function VRPVOC may be performed; that may be achieved by applying the following voltages:

First section of the characteristic:
If $V_{DepMode} = \text{Slope}$, the minimum measured phase-to-phase voltage is lower than 0,25* $U_{Base}$; if $V_{DepMode} = \text{Step}$, the minimum measured phase-to-phase voltage is lower than $U_{HighLimit}/100*U_{Base}$:

- UL1: Ampl = 10 / √3; Angle = 0°
- UL2: Ampl = 10 / √3; Angle = 240°
- UL3: Ampl = 100 / √3; Angle = 120°

Second section of the characteristic only:
If $V_{DepMode} = \text{Slope}$, the minimum measured phase-to-phase voltage is between 0,25*$U_{Base}$ and $U_{HighLimit}/100*U_{Base}$:

- UL1: Ampl = 50 / √3; Angle = 0°
- UL2: Ampl = 50 / √3; Angle = 240°
- UL3: Ampl = 100 / √3; Angle = 120°

Last section of the characteristic:
If $V_{DepMode} = \text{either Slope or Step}$, the minimum measured phase-to-phase voltage is higher than $U_{HighLimit}/100*U_{Base}$.
4. Inject the voltages that are related to the first part of the characteristic, and then slowly increase the phase current $I_{L1}$ from 0.0 A up to the value the function operates. The START and STOC signals must be activated when the amplitude of the phase current $I_{L1}$ is slightly above 0.25 A on the secondary side. The corresponding trip signals TROC and TRIP will be activated after the pre-set time delay has expired.

5. Decrease the current $I_{L1}$ slowly and note the reset value.

6. Repeat steps 4 and 5 applying voltages that are related to the second and the last section of the characteristic; the function operates when $I_{L1}$ is slightly higher than: 0.5 A in the second section; 1A in the last section.

7. Connect the trip output contact to the input channel of the test set in order to stop the injection and measure the trip time.

8. If definite time delay is used for the overcurrent step, set the setting Characterist = IEC Def. Time. Apply the voltages related to the last part of the characteristic and inject a current $I_{L1}$ 200% higher than the set operation level, and check the definite time delay for trip (the signals TROC and TRIP of the protection function VRPVOC are active in trip condition).

9. If inverse time delay is used for the overcurrent step, the parameter setting Characterist shall be properly set; we can refer, for example, to the setting IEC Very inv.; If the IEC Very inverse time characteristic is selected, the trip signals TROC and TRIP will operate after a time defined by the equation:

$$t_{s} = \frac{13.5 \times k}{I - \text{StartCurr}}$$

(Equation 98)

where:
- $t$ Operate time in seconds
- $I$ Measured value (for example, phase current)
- StartCurr Set operate value

This means that if the measured phase current jumps from 0 to 2 times the set operate level and time multiplier $k$ is set to 1.0 s (default value), then the TROC and TRIP signals will operate after a time delay equal to 13.5 s ± tolerance.

Taking into account the above explanation, inject the voltages related to the last part of the characteristic and inject a current $I_{L1}$ 200% higher than the set operation level, and check the trip time delay.

10. Check the start and operate information that are stored in the event menu.

11. The previous step 8 or 9 may be repeated also for the first and second section of the characteristic.

12. Supply the IED with symmetric three-phase voltages at their rated values. Go to Main menu/Settings/IED Settings/Current protection/VoltageRestOverCurr(51V,2(I>/U<))/VRPVOC(51V,2(I>/U<)):1/Undervoltage and set the setting Operation_UV = On to activate the undervoltage stage.

13. Slowly decrease the voltage in two phases simultaneously, until the STUV and START signals appear.

14. Note the operate value. The set operate value in secondary volts is calculated according to the following equation:

If $t_{Def\_OC}$ is set to a value different from 0 s, then this time delay is added to the one that is defined by the IDMT characteristic.
If the VRPVOC function is used as an overcurrent protection with undervoltage seal-in, it is necessary to first inject sufficient current to activate the STOC signal before the under-voltage step is allowed to operate. In order to achieve that, apply symmetric three-phase voltages at their rated value and then inject a current \( I_L1 \) that is 200% higher than the set operation level. Then slowly decrease the voltage in two phases simultaneously, until the STUV and START signals appear.

15. Increase slowly the applied voltages of the previous two phases and note the reset value.

16. Check that the trip output of the relay is connected to the input channel of the test in order to stop the injection and measure the trip time.

17. Inject symmetric three-phase voltages at their rated value and check that the STUV and START signals reset as well as the trip signals of the function block (TRIP and TRUV).

18. Instantaneously decrease the voltage in two phases simultaneously to a value 20% lower than the set operate value (take into account the previous note if VRPVOC is configured in ACT with the undervoltage seal-in feature).

19. Measure the definite time delay for the TRUV and TRIP signals and compare it with the set value \( t_{Def\_UV} \).

20. Check that start and operate information is stored in the event menu.

### 11.5.17.2 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.

### 11.6 Voltage protection

#### 11.6.1 Two step undervoltage protection UV2PTUV

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

#### 11.6.1.1 Verifying the settings

**Verification of start value and time delay to operate for Step 1**

1. Check that the IED settings are appropriate, especially the START 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 START 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-earth measurement:

\[ U_1 < \frac{U_{\text{Base}} \times VT \sec}{100 \times \sqrt{3} \times VT_{\text{prim}}} \]

(Equation 100)

For phase-to-phase measurement:

\[ U_1 < \frac{U_{\text{Base}}}{100} \times \frac{VT \sec}{VT_{\text{prim}}} \]

(Equation 101)

5. Increase the measured voltage to rated load conditions.
6. Check that the START 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 \( \times U_1 < \).

For example, if the inverse time curve A is selected, the trip signals TR1 and TRIP operate after a time corresponding to the equation:

\[ t(s) = \frac{k1}{1 - \frac{U}{U_1 <}} \]

(Equation 102)

where:

- \( t(s) \) Operate time in seconds
- \( k1 \) Settable time multiplier of the function for step 1
- \( U \) Measured voltage
- \( U_1 < \) Set start voltage for step 1

For example, if the measured voltage jumps from the rated value to 0.8 times the set start voltage level and time multiplier \( k1 \) is set to 0.05 s (default value), then the TR1 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.

### 11.6.1.2 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.

### 11.6.2 Two step overvoltage protection OV2PTOV

Prepare the IED for verification of settings as outlined in section "Requirements" and section "Preparing for test" in this chapter.
11.6.2.1 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 $U_1 >$.
2. Slowly increase the voltage until the ST1 signal appears.
3. Note the operate value and compare it with the set value $U_1 >$.

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

For phase-to-earth measurement:

$$U_1 > \frac{U_{Base}}{100} \times \sqrt{3} \times \frac{VT}{VT_{prim}} \times sec$$

(Equation 103)

For phase-to-phase measurement:

$$U_1 > \frac{U_{Base}}{100} \times \frac{VT}{VT_{prim}} \times sec$$

(Equation 104)

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 TR1 signal and compare it with the set value.
7. Check the inverse time delay by injecting a voltage corresponding to $1.2 \times U_1 >$.
8. Repeat the test to check the inverse time characteristic at different over-voltage levels.
9. Repeat the above described steps for Step 2 of the function.

11.6.2.2 Extended testing

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

11.6.2.3 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.

11.6.3 Two step residual overvoltage protection ROV2PTOV

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

11.6.3.1 Verifying the settings
1. Apply a single-phase voltage either to a single-phase voltage input or to a residual voltage input with the start value below the set value $U1>$. 
2. Slowly increase the value until ST1 appears. 
3. Note the operate value and compare it with the set value. 
4. Decrease the voltage slowly and note the reset value. 
5. Set and apply a 20% higher voltage than the measured operate voltage for one phase. 
6. Measure the time delay for the TR1 signal and compare it with the set value. 
7. Check the inverse time delay by injecting a voltage corresponding to $1.2 \times U1>$. 

For example, if the inverse time curve A is selected, the trip signals TR1 and TRIP operate after a time corresponding to the equation:

$$t(s) = \frac{k1}{\left(\frac{U}{U1> - 1}\right)}$$

(Equation 105)

where:

- $t(s)$ Operate time in seconds
- $k1$ Settable time multiplier of the function for step 1
- $U$ Measured voltage
- $U1>$ Set start voltage for step 1

8. Repeat the test for Step 2 of the function.

### 11.6.3.2 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.

### 11.6.4 Overexcitation protection OEXPVPH

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

#### 11.6.4.1 Verifying the settings

1. Enable function. 
2. Connect a symmetrical three-phase voltage input from the test set to the appropriate connection terminals of the overexcitation protection OEXPVPH is configured for a three-phase voltage input. 
   A single-phase injection voltage is applied if the function is configured for a phase-to-phase voltage input. 
   OEXPVPH is conveniently tested using rated frequency for the injection voltage and increasing the injection voltage to get the desired overexcitation level. 
3. Connect the alarm contact to the timer and set the time delay $tAlarm$ temporarily to zero. 
4. Increase the voltage and note the operate value $V/Hz>$. 
5. Reduce the voltage slowly and note the reset value. 
6. Set the alarm time delay to the correct value according to the setting plan and check the time delay, injecting a voltage corresponding to $1.2 \cdot V/Hz>$. 

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7. Connect a trip output contact to the timer and temporarily set the time delay \( t_{Min} \) to 0.5s.
8. Increase the voltage and note the \( V/Hz> \) operate value.
9. Reduce the voltage slowly and note the reset value.
10. Set the time delay to the correct value according to the setting plan and check the time delay \( t_{Min} \), injecting a voltage corresponding to \( 1.2 \cdot V/Hz> \).
11. Check that trip and alarm contacts operate according to the configuration logic.
12. Set the cooling time constant to min value (1min.) to quickly lower the thermal content.
13. Wait for a period equal to 6 times \( T_{cooling} \) switch 20 minutes on a voltage \( 1.15 \cdot V/Hz> \) and check the inverse operate time.
   Wait until the thermal memory is emptied, set the cooling time constant according to the setting plan and check another point on the inverse time curve injecting a voltage \( 1.3 \cdot V/Hz> \).
14. Finally check that START and TRIP information is stored in the event menu.

11.6.4.2 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.

11.6.5 Voltage differential protection VDCPTOV

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

11.6.5.1 Check of undervoltage levels

This test is relevant if the setting \( BlkDiffAtULow = Yes \).

Check of \( U1Low \)

Procedure

1. Connect voltages to the IED according to valid connection diagram and figure 51.
2. Apply voltage higher than the highest set value of \( UD_{trip}, U1_{Low} \) and \( U2_{Low} \) to the U1 three-phase inputs and to one phase of the U2 inputs according to figure 51. The voltage differential START signal is set.
Figure 51: Connection of the test set to the IED for test of U1 block level

where:
1 is three-phase voltage group1 (U1)
2 is three-phase voltage group2 (U2)

3. Decrease slowly the voltage in phase UL1 of the test set until the START signal resets.
4. Check U1 blocking level by comparing the voltage level at reset with the set undervoltage blocking U1Low.
5. Repeat steps 2 to 4 to check U1Low for the other phases.

The connections to U1 must be shifted to test another phase. (UL1 to UL2, UL2 to UL3, UL3 to UL1)

Check of U2Low

Procedure

1. Connect voltages to the IED according to valid connection diagram and figure 52.
2. Apply voltage higher than the highest set value of $UDTrip$, $U1Low$ and $U2Low$ to the U1 three-phase inputs and to one phase of the U2 inputs according to figure 52. The voltage differential START signal is set.
3. Decrease slowly the voltage in phase UL3 of the test set until the START signal resets.
4. Check U2 blocking level by comparing the voltage level at reset with the set undervoltage blocking $U2Low$.

11.6.5.2 Check of voltage differential trip and alarm levels

Procedure

1. Connect voltages to the IED according to valid connection diagram and figure 53.
Figure 53: Connection of the test set to the IED for test of alarm levels, trip levels and trip timer

where:

1. is three-phase voltage group1 (U1)
2. is three-phase voltage group2 (U2)

2. Apply 1.2 · Ur (rated voltage) to the U1 and U2 inputs.
3. Decrease slowly the voltage of in phase UL1 of the test set until the ALARM signal is activated.

The ALARM signal is delayed with timer $t_{Alarm}$

4. Check the alarm operation level by comparing the differential voltage level at ALARM with the set alarm level $U_{DAlarm}$.
5. Continue to slowly decrease the voltage until START signal is activated.
6. Check the differential voltage operation level by comparing the differential voltage level at START with the set trip level $U_{DTrip}$.
7. Repeat steps 1 to 6 to check the other phases. Observe that the connections to U1 must be shifted to test another phase. (UL1 to UL2, UL2 to UL3, UL3 to UL1)

11.6.5.3 Check of trip and trip reset timers

Procedure

1. Connect voltages to the IED according to valid connection diagram and figure 53.
2. Set Ur (rated voltage) to the U1 inputs and increase U2 voltage until differential voltage is 1.5 · operating level ($U_{DTrip}$).
3. Switch on the test set. Measure the time from activation of the START signal until TRIP signal is activated.
4. Check the measured time by comparing it to the set trip time $t_{Trip}$.
5. Increase the voltage until START signal resets. Measure the time from reset of START signal to reset of TRIP signal.
6. Check the measured time by comparing it to the set trip reset time $t_{Reset}$.

11.6.5.4 Final adjustment of compensation for VT ratio differences

Procedure

1. With the protection in test mode, view the differential voltage service values in each phase on the local HMI under Main menu/Test/Function status/Voltage protection/VoltageDiff(PTOV,60)/VDCPTOV:x.

   The IED voltage inputs should be connected to the VTs according to valid connection diagram.

2. Record the differential voltages.
3. Calculate the compensation factor $RFLx$ for each phase. For information about calculation of the compensation factor, see the application manual.
4. Set the compensation factors on the local HMI under Main menu/Settings_Settings group N/Voltage protection/VoltageDiff(PTOV,60)/VDCPTOV:x
5. Check that the differential voltages are close to zero.

11.6.5.5 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.

11.6.6 Loss of voltage check LOVPTUV

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

11.6.6.1 Measuring the operate limit of set values

1. Check that the input logical signals BLOCK, CBOPEN and VTSU are logical zero.
2. Supply a three-phase rated voltage in all three phases and note on the local HMI that the TRIP logical signal is equal to the logical 0.
3. Switch off the voltage in all three phases. After set $t_{Trip}$ time a TRIP signal appears on the corresponding binary output or on the local HMI.

   Note that TRIP at this time is a pulse signal, duration should be according to set $t_{Pulse}$.

4. Inject the measured voltages at rated values for at least set $t_{Restore}$ time.
5. Activate the CBOPEN binary input.
6. Simultaneously disconnect all the three-phase voltages from the IED. No TRIP signal should appear.
7. Inject the measured voltages at rated values for at least set $t_{Restore}$ time.
8. Activate the VTSU binary input.
9. Simultaneously disconnect all the three-phase voltages from the IED. No TRIP signal should appear.
10. Reset the VTSU binary input.
11. Inject the measured voltages at rated values for at least set \(t_{\text{Restore}}\) time.
12. Activate the BLOCK binary input.
13. Simultaneously disconnect all the three-phase voltages from the IED. No TRIP signal should appear.
14. Reset the BLOCK binary input.

11.6.6.2 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.

11.7 Frequency protection

11.7.1 Underfrequency protection SAPTUF

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

11.7.1.1 Verifying the settings

Verification of START value and time delay to operate

1. Check that the IED settings are appropriate, for example the start value and the time delay.
2. Supply the IED with three-phase voltages at their rated values and initial frequency. The initial frequency is calculated using Equation 106.

\[
\text{StartFrequency} + 0.02 + \frac{\text{floor} \left( f_r - \text{StartFrequency} \right)}{0.04} \times 0.04
\]

(Equation 106)

3. Slowly decrease the voltage frequency by steps of 40 mHz until the START signal appears; during each step apply the voltage signal for a time that is either at least 10% longer than \((t_{\text{Delay}}+100\text{ms})\) or a suitable time to monitor the function.
4. Note the frequency value at which the START signal appears and compare it with the set value \(\text{StartFrequency}\).
5. Increase the frequency until its rated value is reached.
6. Check that the START signal resets.
7. Supply the IED with three-phase voltages at their rated values and frequency 20 mHz over the set value \(\text{StartFrequency}\).
8. Decrease the frequency with a 40 mHz step, applying it for a time that is at least 10% longer than \((t_{\text{Delay}}+100\text{ms})\).
9. Measure the time delay of the \(TRIP\) signal, and compare it with the set value \(t_{\text{Delay}}\). Note that the measured time consists of the set value of the time delay plus the minimum operate time of the 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 StartFrequency, UMin, 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 UMin.
5. Slowly decrease the frequency of the applied voltage, to a value below StartFrequency.
6. Check that the START signal does not appear.
7. Wait for a time corresponding to tDelay, make sure that the TRIP signal does not appear.

### 11.7.2 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.

### 11.7.2 Overfrequency protection SAPTOF

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

### 11.7.2.1 Verifying the settings

#### Verification of START value and time delay to operate

1. Check that the IED settings are appropriate, for example the start value and the time delay.
2. Supply the IED with three-phase voltages at their rated values and initial frequency.
3. Slowly increase the frequency of the applied voltage with a 40 mHz step, applying it for a period that is 10% longer than tDelay.
4. Note the operate value and compare it with the set value.
5. Decrease the frequency to rated operating conditions.
6. Check that the START signal resets.
7. Set the frequency to 20 mHz under the operate value.
8. Increase the frequency with a 40 mHz step, applying it for a period that is 10% longer than tDelay.
9. 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 operate time of the start function (80 - 90 ms).

#### Extended testing

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

#### Verification of the low voltage magnitude blocking

1. Check that the settings in the IED are appropriate, for example the StartFrequency and the 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.
5. Slowly increase the frequency of the applied voltage, to a value above $StartFrequency$.
6. Check that the START signal does not appear.
7. Wait for a time corresponding to $tDelay$, make sure that the TRIP signal does not appear.

### 11.7.2.2 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.

### 11.7.3 Rate-of-change frequency protection SAPFRC

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

#### 11.7.3.1 Verifying the settings

**Verification of START value and time delay to operate**

1. Check that the settings in the IED are appropriate, especially the START value and the definite time delay. Set $StartFreqGrad$, 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 $StartFreqGrad$, and check that the START 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 START 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 $StartFreqGrad$.
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.

#### 11.7.3.2 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.

### 11.8 Multipurpose protection

#### 11.8.1 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 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.

### 11.8.1.1 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.
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 tMin.
8. Check that TRIP and START 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 START and TRIP information is stored in the event menu.

Information on how to use the event menu is found in the operator’s manual.

### 11.8.1.2 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.
11.8.1.3 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 START 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.

11.8.1.4 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 $I \cdot \cos(\theta)$ law (setting parameter DirPrinc_OC1 or DirPrinc_OC2 set to $I \cdot \cos(\theta)$). 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 CTstarpoint configuration parameter is set to ToObject.
   If reverse directional feature is selected or CTstarpoint 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.

11.8.1.5 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.

11.8.1.6 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.

11.9 Secondary system supervision

11.9.1 Current circuit supervision CCSSPVC

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

The Current circuit supervision function CCSSPVC 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 $I_{p>Block}$.

11.9.1.1 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 $1.5 \times I_{Base}$.
3. Inject a current $0.1 \times I_{Base}$ to the reference current input I5.
4. Increase slowly the current in one of the phases and check that FAIL output is obtained when the current is above $0.9 \times I_{Base}$.

11.9.1.2 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.

11.9.2 Fuse failure supervision FUFSPVC

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

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.
11.9.2.1 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 DISCPOS binary input.
   - The signal BLKU 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 DISCPOS binary input terminal.

4. Connect the nominal dc voltage to the MCBOP binary input.
   - The BLKU 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. Connect one of the phase voltages and observe the logical output signals on the binary outputs of the IED.
   BLKU and BLKZ signals should appear simultaneously whether the BLKU and BLKZ reset depends on the setting 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 BLKU 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 BLKU after about 50ms
   - Signal BLKZ after about 200ms

11.9.2.2 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 BLKU 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):

\[
3 \cdot U_2 = U_{L1} + a^2 \cdot U_{L2} + a \cdot U_{L3}
\]

(Equation 107)

Where:

\[ U_{L1}, U_{L2} \text{ and } U_{L3} \]

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 \(3U2\)) is in percentage of the base voltage \(U\text{Base}\).
5. Repeat steps 1 and 2. Then slowly increase the measured current in one phase until the BLKU 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):

$$3 \cdot \vec{I}_2 = \vec{I}_{1l} + a^2 \cdot \vec{I}_{2l} + a \cdot \vec{I}_{3l}$$

(Equation 108)

Where:

$\vec{I}_{1l}$, $\vec{I}_{2l}$, and $\vec{I}_{3l}$ 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 $3I_2<$ is in percentage of the base current $I_{Base}$.

11.9.2.3 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 BLKU 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):

$$3 \cdot \vec{U}_0 = \vec{U}_{L1} + \vec{U}_{L2} + \vec{U}_{L3}$$

(Equation 109)

Where:

$\vec{U}_{L1}$, $\vec{U}_{L2}$, and $\vec{U}_{L3}$ are the measured phase voltages

4. Compare the result with the set value of the zero-sequence operating voltage (consider that the set value $3U_0>$ is in percentage of the base voltage.)

5. Repeat steps 1 and 2. Then slowly increase the measured current in one phase until the BLKU 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):

$$3 \cdot \vec{I}_0 = \vec{I}_{1l} + \vec{I}_{2l} + \vec{I}_{3l}$$

(Equation 110)

Where:

$\vec{I}_{1l}$, $\vec{I}_{2l}$, and $\vec{I}_{3l}$ are the measured phase currents

7. Compare the result with the set value of the zero-sequence operate current. Consider that the set value $3I_0<$ is in percentage of the base current $I_{Base}$. 

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11.9.2.4 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 UDLD< (UDLD< is in percentage of the base voltage UBase).
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 IDLD< (IDLD< is in percentage of the base current IBase).

11.9.2.5 Checking the operation of the du/dt and di/dt based function

Check the operation of the du/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 DU> and the current change must be lower than the set value DI<.
   • The BLKU 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 UDLD< of the dead line detection function.
3. Apply normal conditions as in step 1.
The BLKU, 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 DU> and the current change must be higher than the set value DI<.
The BLKU, 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 BLKU, 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 DU> and DI<.
9. Check that the start output signals STDUL1 and STDIL1 and the general start signals STDU or STDI are activated.
10. Check that the start 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.

11.9.2.6 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.
11.9.3  Fuse failure supervision VDSPVC

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

Checking the operation of binary input and output

1. Simulate normal operation conditions with three-phase voltage on the main fuse group and the pilot fuse group. Ensure the values are equal to their rated values.
2. Disconnect one of the phase voltage from the main fuse group or the pilot fuse group. Observe the binary outputs of the IED. The MAINFUF or the PILOTFUF signals are simultaneously activated. Only the output circuit related to the open phase will be active i.e either MAINFUF or PILOTFUF.
3. Establish a normal voltage operating condition and observe the corresponding output signals. MAINFUF or PILOTFUF should change to 0 in about 27 ms.
4. Set normal conditions as mentioned in step 1.
5. Enable the BLOCK binary input and repeat step 2. MAINFUF or PILOTFUF should not appear.

Checking the operation of MAINFUF and PILOTFUF

1. Simulate normal operation conditions with three-phase voltage on the main fuse group and the pilot fuse group. Ensure the values are equal to their rated values.
2. Decrease one of the three-phase voltages on main fuse group or pilot fuse group. The voltage change must be greater than the set value for \( Ud>\text{MainBlock} \) or \( Ud>\text{PilotAlarm} \). MAINFUF or PILOTFUF signals are activated without any time delay.
3. Set normal conditions as mentioned in step 1. MAINFUF or PILOTFUF signals should reset.
4. Set \( \text{SealIn} \) to On, \( Ud>\text{MainBlock} \) to 20% of \( \text{UBase} \) and \( \text{USealIn} \) to 70% of \( \text{UBase} \).
5. Apply three-phase voltages with the value slightly below \( \text{USealIn} \) level.
6. Decrease one of the three-phase voltages on main fuse group. The voltage change must be greater than the set value for \( Ud>\text{MainBlock} \). MAINFUF signal is activated.
7. After more than 5 seconds increase the measured voltage back to the value slightly below \( \text{USealIn} \) level. MAINFUF signal should not reset.
8. Slowly increase measured voltage to the value slightly above \( \text{USealIn} \) until MAINFUF signal resets.
9. Record the measured voltage and compare with the set value \( \text{USealIn} \).

11.9.3.1 Completing the test

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

11.9.4  Voltage based delta supervision DELVSPVC

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

11.9.4.1 Verifying the signals and settings

Make sure that the function is connected to SMAI function with U3P signal.

Delta supervision function has 6 different modes of operation. Proceed as follows to test the function in a particular mode.
1. Set the following parameters:
   - Operation = On
   - MeasMode = Phase-to-ground
   - Umin = 10% of UBase
   - DelU> = 50% of UBase
   - DelUang> = 10°
   - DeltaT = 2
   - tHold = 100

2. Set the constant voltage input of UL1 = 63.5V at 0° and UL2 = 63.5V at 120° and UL3 at 63.5 -120° secondary at rated frequency.

3. Based on the mode of operation, carry out the following changes on input condition of Step 2 to detect start condition.
   Each mode is given for increase and decrease operation. (3-a and 3-b)

<table>
<thead>
<tr>
<th>Step No.</th>
<th>OpMode</th>
<th>Changes after step 2</th>
<th>Expected output</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-a</td>
<td>Instantaneous 1 cycle or Instantaneous 2 cycle</td>
<td>Change UL1 to 20V</td>
<td>STL1, STLOW, START signal should be TRUE for 100 ms</td>
</tr>
<tr>
<td>3-b</td>
<td>Instantaneous 1 cycle or Instantaneous 2 cycle</td>
<td>Change UL1 back to 63.5V</td>
<td>STL1, STRISE, START signal should be TRUE for 100 ms</td>
</tr>
<tr>
<td>3-a</td>
<td>RMS or DFT Mag</td>
<td>Change UL1 to 20V</td>
<td>STL1, STLOW, START signal should be TRUE for 100 ms</td>
</tr>
<tr>
<td>3-b</td>
<td>RMS or DFT Mag</td>
<td>Change UL1 back to 63.5V</td>
<td>STL1, STRISE, START signal should be TRUE for 100 ms</td>
</tr>
<tr>
<td>3-a</td>
<td>DFT Angle (vector shift)</td>
<td>Change UL1 to 63.5V at 15° without changing frequency</td>
<td>STL1, START signal will be TRUE for 100 ms</td>
</tr>
<tr>
<td>3-b</td>
<td>DFT Angle (Vector shift)</td>
<td>Change UL1 to 63.5V at 0° without changing frequency</td>
<td>STL1, START signal will be TRUE for 100 ms</td>
</tr>
</tbody>
</table>

4. Repeat Step 3 with UL2 changes for different mode.

11.9.4.2 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.

11.9.5 Current based delta supervision DELISPVC

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

11.9.5.1 Verifying the signals and settings

Make sure that the function is connected to SMAI function with I3P signal.

Delta supervision function has four different modes of operation. Proceed as follows to test the function in a particular mode.
1. Set the following parameters:
   - **Operation** = ON
   - **MeasMode** = Phase-to-ground
   - **Imin** = 10% of **IBase**
   - **DelI->** = 80% of **IBase**
   - **DeltaT** = 2
   - **tHold** = 100

2. Set the constant current input of **IL1** = 1A at 0° and **IL2** = 1A at 120° and **IL3** at -120° secondary at rated frequency.

3. Based on the mode of operation, carry out the following changes on input condition of Step 2 to detect start condition.
   Each mode is given for increase and decrease operation. (3-a and 3-b)

<table>
<thead>
<tr>
<th>Step No.</th>
<th>OpMode</th>
<th>Changes after step 2</th>
<th>Expected output</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-a</td>
<td>Instantaneous 1 cycle or Instantaneous 2 cycle</td>
<td>Change IL1 to 2 A</td>
<td>STL1, STRISE, START signal should be TRUE for 100 ms</td>
</tr>
<tr>
<td>3-b</td>
<td>Instantaneous 1 cycle or Instantaneous 2 cycle</td>
<td>Change IL1 back to 1A</td>
<td>STL1, STLOW, START signal should be TRUE for 100 ms</td>
</tr>
<tr>
<td>3-a</td>
<td>RMS or DFT Mag</td>
<td>Change IL1 to 2 A</td>
<td>STL1, STRISE, START signal should be TRUE for 100 ms</td>
</tr>
<tr>
<td>3-b</td>
<td>RMS or DFT Mag</td>
<td>Change IL1 back to 1A</td>
<td>STL1, STLOW, START signal should be TRUE for 100 ms</td>
</tr>
</tbody>
</table>

4. Repeat Step 3 with **IL2** changes for different mode.

11.9.5.2 **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.

11.9.6 **Delta supervision of real input DELSPVC**

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

11.9.6.1 **Verifying the signals and settings**

Make sure that the function is connected to any of the available real derived outputs, for example the **P** output signal of the CMMXU function.

1. Set the following parameters:
• Operation = ON
• MinStVal = 10
• DelSt\(>\) = 100
• DeltaT = 7
• tHold = 100

2. Set a constant voltage input of UL1 = 63.5 V at 0° and UL2 = 63.5 V at 180° secondary and
a current signal at IL1 = 1A at 0° and IL2 = 1A at 180°.

3. Ensure that the P output of CMMXU function has exceeded 10 MW and remains stable.

4. Change the current signal at IL1 = 2A at 0° and IL2 = 2A at 180°. Both START and STARTRISE
signals should be active for 100 ms.

5. Change the current signal at IL1 = 1A at 0° and IL2 = 1A at 180°. Both START and STARTLOW
signals should be active for 100 ms.

11.9.6.2 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.

11.10 Control

11.10.1 Synchrocheck, energizing check, and synchronizing SESRSYN

This section contains instructions on how to test the synchrocheck, energizing check, and
synchronizing function SESRSYN for single, double and 1½ breaker arrangements.

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

At commissioning and periodical checks, the functions shall be tested with the used settings.
To test a specific function, it might be necessary to change some setting parameters, for
example:

• AutoEnerg = Off/ DLLB/ DBLL/ Both
• ManEnerg = Off
• Operation = Off/ On
• Activation of the voltage selection function if applicable

The tests explained in the test procedures below describe the settings, which can be used as
references during testing before the final settings are specified. After testing, restore the
equipment to the normal or desired settings.

A secondary injection test set with the possibility to alter the phase angle and amplitude of
the voltage is needed. The test set must also be able to generate different frequencies on
different outputs.

The description below applies for a system with a nominal frequency of 50 Hz
but can be directly applicable to 60 Hz. SESRSYN can be set to use different
phases, phase to earth or phase to phase. Use the set voltages instead of what
is indicated below.

Figure 54 shows the general test connection principle, which can be used during testing. This
description describes the test of the version intended for one bay.
Figure 55 shows the general test connection for a 1½ breaker diameter with one-phase voltage connected to the line side.

![Diagram](IEC05000480-4-en.vsd)

**Figure 54:** General test connection with three-phase voltage connected to the line side

![Diagram](IEC05000481-5-en.vsd)

**Figure 55:** General test connection for a 1½ breaker diameter with one-phase voltage connected to the line side

### 11.10.1.1 Testing the synchronizing function

The voltage inputs used are:
Testing the frequency difference
The frequency difference test should verify that operation is achieved when the frequency difference between bus and line is less than set value of $FreqDiffMax$ and above set value of $FreqDiffMin$. The test procedure below will depend on the settings used. Input STARTSYN must be activated during the test.

$FreqDiffMax = 50.2 \text{ Hz}$

$FreqDiffMin = 50.01 \text{ Hz}$

$tBreaker = 0.080 \text{ s}$

1. Apply voltages
   1.1. U-Line = 100% $UBaseLine$ and f-Line = 50.0 Hz
   1.2. U-Bus = 100% $UBaseBus$ and f-Bus = 50.15Hz

2. Check that a closing pulse is submitted at a closing angle equal to calculated phase angle value from the formula below. Modern test sets will evaluate this automatically.

   Closing Angle = \(|( (f_{Bus} - f_{Line}) * tBreaker * 360 \text{ degrees}) |\)

   $f_{Bus}$ = Bus frequency
   $f_{Line}$ = Line frequency
   $tBreaker$ = Set closing time of the breaker

3. Repeat with
   3.1. U-Bus = 100% $UBaseBus$ and f-bus = 50.25 Hz, to verify that the function does not operate when frequency difference is above limit.

4. Verify that the closing command is not issued when the frequency difference is less than the set value $FreqDiffMin$.

11.10.1.2 Testing the synchrocheck functionality

During the test of SESRSYN for a single bay arrangement, these voltage inputs are used:

- U-Line: UL1, UL2 or UL3 line 1 voltage input on the IED according to the connection in SMT
- U-Bus: Bus voltage input on the IED according to the connection in SMT

Testing the voltage difference
Set the voltage difference to 0.15 p.u. on the local HMI, and the test should check that operation is achieved when the voltage difference $UDiffSC$ is lower than 0.15 p.u.

The settings used in the test shall be final settings. The test shall be adapted to site setting values instead of values in the example below.

Test with no voltage difference between the inputs.

Test with a voltage difference higher than the set $UDiffSC$. 

1. Apply voltages $U\text{Line} = 80\% \ Gbl\text{BaseSelLine}$ and $U\text{Bus} = 80\% \ Gbl\text{BaseSelBus}$ with the same phase-angle and frequency.

2. Check that the AUTOSYOK and MANSYOK outputs are activated.

3. The test can be repeated with different voltage values to verify that the function operates within the set $UDiffSC$. Check with both $U\text{Line}$ and $U\text{Bus}$ respectively lower than the other.

4. Increase the $U\text{Bus}$ to 110% $Gbl\text{BaseSelBus}$, and the $U\text{Line} = 90\% \ Gbl\text{BaseSelLine}$ and also the opposite condition.

5. Check that the two outputs for manual and auto synchronism are not activated.

**Testing the phase angle difference**

The phase angle differences $Phase\text{DiffM}$ and $Phase\text{DiffA}$ respectively are set to their final settings and the test should verify that operation is achieved when the phase angle difference is lower than this value both leading and lagging.

Test with no voltage difference.

1. Apply voltages $U\text{Line} = 100\% \ Gbl\text{BaseSelLine}$ and $U\text{Bus} = 100\% \ Gbl\text{BaseSelBus}$, with a phase difference equal to 0 degrees and a frequency difference lower than $Freq\text{DiffA}$ and $Freq\text{DiffM}$.

2. Check that the AUTOSYOK and MANSYOK outputs are activated. The test can be repeated with other phase difference values to verify that the function operates for values lower than the set ones, $Phase\text{DiffM}$ and $Phase\text{DiffA}$. By changing the phase angle on the voltage connected to $U\text{Bus}$, between $\pm \phi$ degrees, the user can check that the two outputs are activated for a phase difference lower than the set value. It should not operate for other values. See figure 56.

![Figure 56: Test of phase difference](en05000551.vsd)

3. Change the phase angle between $+\phi$ and $-\phi$ and verify that the two outputs are activated for phase differences between these values but not for phase differences outside, see figure 56.

**Testing the frequency difference**

The frequency difference test should verify that operation is achieved when the $Freq\text{DiffA}$ and $Freq\text{DiffM}$ frequency difference is lower than the set value for manual and auto synchronizing check, $Freq\text{DiffA}$ and $Freq\text{DiffM}$ respectively and that operation is blocked when the frequency difference is greater.

Test with frequency difference = 0 mHz

Test with a frequency difference outside the set limits for manual and auto synchronizing check respectively.
1. Apply voltages U-Line equal to 100% $GblBaseSelLine$ and U-Bus equal to 100% $GblBaseSelBus$, with a frequency difference equal to 0 mHz and a phase difference lower than the set value.
2. Check that the AUTOSYOK and MANSYOK outputs are activated.
3. Apply voltage to the U-Line equal to 100% $GblBaseSelLine$ with a frequency equal to 50 Hz and voltage U-Bus equal to 100% $GblBaseSelBus$, with a frequency outside the set limit.
4. Check that the two outputs are not activated. The test can be repeated with different frequency values to verify that the function operates for values lower than the set ones. If a modern test set is used, the frequency can be changed continuously.

**Testing the reference voltage**

1. Use the same basic test connection as in figure 54. The voltage difference between the voltage connected to U-Bus and U-Line should be 0%, so that the AUTOSYOK and MANSYOK outputs are activated first.
2. Change the U-Line voltage connection to U-Line2 without changing the setting on the local HMI. Check that the two outputs are not activated.

### 11.10.1.3 Testing the energizing check

During the test of the energizing check function for a single bay arrangement, these voltage inputs are used:

- **U-Line**: UL1, UL2 or UL3 line1 voltage inputs on the IED
- **U-Bus**: Bus voltage input on the IED

**General**

When testing the energizing check function for the applicable bus, arrangement shall be done for the energizing check functions. The voltage is selected by activation of different inputs in the voltage selection logic.

Live voltage level is fixed to 80% $UBase$ and dead voltage level to fixed 40% $UBase$.

The test shall be performed according to the settings for the station. Test the alternatives below that are applicable.

**Testing the dead line live bus (DLLB)**

The test should verify that the energizing check function operates for a low voltage on the U-Line and for a high voltage on the U-Bus. This corresponds to the energizing of a dead line to a live bus.

1. Apply a single-phase voltage 100% $GblBaseSelBus$ to the U-Bus, and a single-phase voltage 30% $GblBaseSelLine$ to the U-Line.
2. Check that the AUTOENOK and MANENOK outputs are activated after $tAutoEnerg$ respectively $tManEnerg$.
3. Increase the U-Line to 60% $GblBaseSelLine$ and U-Bus to be equal to 100% $GblBaseSelBus$. The outputs should not be activated.
4. The test can be repeated with different values on the U-Bus and the U-Line.

**Testing the dead bus live line (DBLL)**

The test should verify that the energizing check function operates for a low voltage on the U-Bus and for a high voltage on the U-Line. This corresponds to an energizing of a dead bus to a live line.

1. Apply voltages U-Line equal to 100% $GblBaseSelLine$ and U-Bus equal to 100% $GblBaseSelBus$, with a frequency difference equal to 0 mHz and a phase difference lower than the set value.
2. Check that the AUTOSYOK and MANSYOK outputs are activated.
3. Apply voltage to the U-Line equal to 100% $GblBaseSelLine$ with a frequency equal to 50 Hz and voltage U-Bus equal to 100% $GblBaseSelBus$, with a frequency outside the set limit.
4. Check that the two outputs are not activated. The test can be repeated with different frequency values to verify that the function operates for values lower than the set ones. If a modern test set is used, the frequency can be changed continuously.
1. Verify the settings AutoEnerg or ManEnerg to be DBLL.
2. Apply a single-phase voltage of 30% GblBaseSelBus to the U-Bus and a single-phase voltage of 100% GblBaseSelLine to the U-Line.
3. Check that the AUTOENOK and MANENOK outputs are activated after set tAutoEnerg respectively tManEnerg.
4. Decrease the U-Line to 60% GblBaseSelLine and keep the U-Bus equal to 30% GblBaseSelBus. The outputs should not be activated.
5. The test can be repeated with different values on the U-Bus and the U-Line.

**Testing both directions (DLLB or DBLL)**

1. Verify the local HMI settings AutoEnerg or ManEnerg to be Both.
2. Apply a single-phase voltage of 30% GblBaseSelLine to the U-Line and a single-phase voltage of 100% GblBaseSelBus to the U-Bus.
3. Check that the AUTOENOK and MANENOK outputs are activated after set tAutoEnerg respectively tManEnerg.
4. Change the connection so that the U-Line is equal to 100% GblBaseSelLine and the U-Bus is equal to 30% GblBaseSelBus. The outputs should still be activated.
5. The test can be repeated with different values on the U-Bus and the U-Line.

**Testing the dead bus dead line (DBDL)**

The test should verify that the energizing check function operates for a low voltage on both the U-Bus and the U-Line, that is, closing of the breaker in a non-energized system. Test is valid only when this function is used.

1. Verify the local HMI setting AutoEnerg to be Off and ManEnerg to be DBLL.
2. Set the parameter ManEnergDBDL to On.
3. Apply a single-phase voltage of 30% GblBaseSelBus to the U-Bus and a single-phase voltage of 30% GblBaseSelLine to the U-Line.
4. Check that the MANENOK output is activated after set tManEnerg.
5. Increase the U-Bus to 80% GblBaseSelBus and keep the U-Line equal to 30% GblBaseSelLine. The outputs should not be activated.
6. Repeat the test with ManEnerg set to DLLB with different values on the U-Bus and the U-Line voltage.

### 11.10.1.4 Testing the voltage selection

**Testing the voltage selection for single CB arrangements**

This test should verify that the correct voltage is selected for the measurement in the SESRSYN function used in a double-bus arrangement. Apply a single-phase voltage of 100% GblBaseSelLine to the U-Line and a single-phase voltage of 100% GblBaseSelBus to the U-Bus.

If the UB1/2OK inputs for the fuse failure are used, they must be activated, during tests below. Also verify that deactivation prevents operation and gives an alarm.

1. Connect the signals above to binary inputs and binary outputs.
2. Connect the voltage inputs to the analog inputs used for each bus or line depending of the type of busbar arrangement and verify that correct output signals are generated.

**Testing the voltage selection for double breaker**

This test should verify that correct voltage is selected for the measurement in the SESRSYN function used for a diameter in a One-and-a-half breaker arrangement. Apply a single-phase voltage of 100% GblBaseSelLine to the U-Line and a single-phase voltage of 100% GblBaseSelBus to the U-Bus. Verify that correct output signals are generated.
1. Connect the analog signals to the voltage inputs, in pair of two for U1 and U2. (Inputs U3PBB1, U3PBB2, U3PLN1, U3PLN2)
2. Activate the binary signals according to the used alternative. Verify the measuring voltage on the synchronizing check function SESRSYN. Normally it can be good to verify synchronizing check with the same voltages and phase angles on both voltages. The voltages should be verified to be available when selected and not available when another input is activated so connect only one voltage transformer reference at each time.
3. Record the voltage selection tests in a matrix table showing read values and AUTOSYOK/MANSYOK signals to document the test performed.

Testing the voltage selection for 1 1/2 CB arrangements

At test of the SESRSYN function for a 1½ CB diameter the following alternative voltage inputs can be used for the three SESRSYN (SESRSYN 1, SESRSYN 2, SESRSYN 3) functions. These three SESRSYN functions can either be in one, two or three different IEDs. Table 39 describes the scenario when SESRSYN 1, SESRSYN 2 and SESRSYN 3 all are in the same IED. If SESRSYN 3 is in another IED, WA1 will be considered as WA2 and LINE2 as LINE1. The voltage is selected by activation of different inputs in the voltage selection logic as shown in table 39 and figure 57.

Table 39: Voltage selection logic

<table>
<thead>
<tr>
<th>SESRSYN</th>
<th>CBConfig setting</th>
<th>Section to be synchroniz ed</th>
<th>Activated B1QCLD input on IED from</th>
<th>Activated B2QCLD input on IED from</th>
<th>Activated L1QCLD input on IED from</th>
<th>Activated L2QCLD input on IED from</th>
<th>Indication from SESRSYN on IED</th>
</tr>
</thead>
<tbody>
<tr>
<td>SESRSYN 1 (Operates on WA1_QA1)</td>
<td>1 1/2 bus CB</td>
<td>WA1 – LINE1</td>
<td>LINE1_QB</td>
<td>BISEL, LNISEL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WA1 – LINE2</td>
<td>TIE_QA1</td>
<td>LINE2_QB</td>
<td>BISEL, LNISEL</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WA1 – WA2</td>
<td>TIE_QA1</td>
<td>WA2_QA1</td>
<td>BISEL, B2SEL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SESRSYN 2 (Operates on TIE_QA1)</td>
<td>Tie CB</td>
<td>LINE1 – LINE2</td>
<td>LINE1_QB</td>
<td>BISEL, LNISEL, LN2SEL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WA1 – LINE2</td>
<td>WA1_QA1</td>
<td>LINE2_QB</td>
<td>BISEL, LN2SEL</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WA2 – LINE1</td>
<td>WA2_QA1</td>
<td>LINE1_QB</td>
<td>B2SEL, LNISEL</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WA1 – WA2</td>
<td>WA1_QA1</td>
<td>WA2_QA1</td>
<td>BISEL, B2SEL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SESRSYN 3 (Operates on WA2_QA1)</td>
<td>1 1/2 bus alt. CB (mirrored)</td>
<td>WA2 – LINE2</td>
<td>LINE2_QB</td>
<td>B2SEL, LN2SEL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WA2 – LINE1</td>
<td>TIE_QA1</td>
<td>LINE1_QB</td>
<td>B2SEL, LNISEL</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WA2 – WA1</td>
<td>TIE_QA1</td>
<td>WA1_QA1</td>
<td>BISEL, B2SEL</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
11.10.1.5 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.

11.10.2 Apparatus control APC

The apparatus control function consists of four types of function blocks, which are connected in a delivery-specific way between bays and to the station level. For that reason, test the total function in a system, that is, either in a complete delivery system as an acceptance test (FAT/SAT) or as parts of that system.

If a block/unblock command is sent from remote to function, while the IED is shut down, this command will not be recognized after the start up, thus the command that was sent prior to the shut down is used. In such cases, where there is a mismatch, the user is advised to make a complete cycle of block/unblock operations to align the statuses.

11.10.3 Voltage control TR1ATCC, TR8ATCC, TCMYLTC, TCLYLTC

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

The automatic voltage control for tap changer, single control TR1ATCC is based on a transformer configuration that consists of one tap changer on a single two-winding power transformer.
The automatic voltage control for tap changer, parallel control TR8ATCC, if installed, may be set to operate in Master Follower (MF) mode, or Minimise Circulating Current (MCC) mode. The commissioning tests for each parallel control mode are addressed separately in the following procedure.

Secondary injection of load current ($I_L$) and secondary bus voltage ($U_B$) equivalent quantities are required during installation and commissioning tests. The test consists mainly of:

1. Increasing or decreasing the injected voltage or current at the analogue inputs of the IED.
2. Checking that the corresponding commands (Lower or Raise) are issued by the voltage control function.

Setting confirmation is an important step for voltage control in the installation and commissioning phase to ensure consistency of power systems base quantities, alarm/blocking conditions and parallel control settings for each transformer control function.

Before starting any test, verify the following settings in PCM600 or the local HMI for TR1ATCC, TR8ATCC and TCMYLTC and TCLYLTC.

- Confirm power system base quantities $I_1Base$, $I_2Base$, $UBase$.

Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR1ATCC:x/TR8ATCC:x/General

and

Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR1ATCC:x

- Confirm that the setting for short circuit impedance $Xr2$ for TR1ATCC or TR8ATCC is in accordance with transformer data:
  - Short circuit impedance, available on the local HMI under Main menu/Settings/IED settings/Control/TransformerVoltageControl(ATCC,90)/TR1ATCC:x/TR8ATCC:x/Xr2.

- Confirm that the setting for TCMYLTC or TCLYLTC is in accordance with transformer data:
  - Tap change timeout duration - effectively the maximum transformer tap change time, $t_{TCTimeout}$, available on the local HMI under Main menu/Settings/IED Settings/Control/TransformerTapControl(YLTC,84)/TCMYLTC:x/TCLYLTC:x/tTCTimeout.
  - Load tap changer pulse duration - required length of pulse from IED to load tap changer, $t_{PulseDur}$, available on the local HMI under Main menu/Settings/IED Settings/Control/TransformerTapControl(YLTC,84)/TCMYLTC:x/TCLYLTC:x/tPulseDur.
  - Transformer tap range, $LowVoltTap$ and $HighVoltTap$, available on the local HMI under Main menu/Settings/IED Settings/Control/TransformerTapControl(YLTC,84)/TCMYLTC:x/TCLYLTC:x/HighVoltTap and
  - Load tap changer code type - method for digital feedback of tap position, $CodeType$, available on the local HMI under Main menu/Settings/IED settings/Control/TransformerTapControl(YLTC,84)/TCMYLTC:x/TCLYLTC:x/CodeType.
During the installation and commissioning, the behavior of the voltage control functions for different tests may be governed by a parameter group, available on the local HMI under **Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR1ATCC:x/TR8ATCC:x**. These parameter settings can cause a Total Block, Automatic Block or Alarm for a variety of system conditions including over and under voltage, over current and tap changer failure. It is important to review these settings and confirm the intended response of the voltage control function for different secondary injection tests.

**Terminology**

The busbar voltage $U_B$ is a shorter notation for the measured voltages $U_{L1}$, $U_{L2}$, $U_{L3}$ or $U_{ij}$, where $U_{ij}$ is the phase-phase voltage, $U_{ij} = U_i - U_j$, or $U_i$, where $U_i$ is one single-phase-to-earth voltage.

$I_L$ is a shorter notation for the measured load current; it is to be used instead of the three-phase quantities $I_{L1}$, $I_{L2}$, $I_{L3}$ or the two-phase quantities $I_i$ and $I_j$, or single-phase current $I_i$.

Also note that for simplicity, the Parameter Setting menu structures included in the following procedure are referred to universally as VCP1, for example, **Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR1ATCC:x/TR8ATCC:x/Time/t1 and t2l**.

For cases where single-mode voltage control is implemented, the Parameter Setting menu structure includes TR1ATCC:1 instead of the parallel designator TR8ATCC:1.

### 11.10.3.1 Secondary test

The voltage control function performs basic voltage regulation by comparing a calculated load voltage ($U_L$) against a voltage range defined by setting $U_{Deadband}$ (with upper and lower limits $U_2$ and $U_1$ respectively). The calculated load voltage $U_L$ represents the secondary transformer bus voltage $U_B$ adjusted for Load drop compensation (LDC) where enabled in settings.

**Note that when LDC is disabled, $U_B$ equals $U_L$.**

When the load voltage $U_L$ stays within the interval between $U_1$ and $U_2$, no action will be taken.

If $U_L < U_1$ or $U_L > U_2$, a command timer will start, which is constant time or inverse time defined by setting $t1$ and $t1Use$. The command timer will operate while the measured voltage stays outside the inner deadband (defined by setting $U_{DeadbandInner}$).

If $U_L$ remains outside of the voltage range defined by $U_{Deadband}$ and the command timer expires, the voltage control will execute a raise or lower command to the transformer tap changer. This command sequence will be repeated until $U_L$ is brought back within the inner deadband range.

### 11.10.3.2 Check the activation of the voltage control operation
1. Confirm Transformer Tap Control = On and Transformer Voltage Control = On
   - Direct tap change control
     **Main menu/Settings/IED Settings/Control/TransformerTapChanger(YLTC,84)/**
     **TCMYLTC:x/TCLYLTC:x/Operation**
   - Automatic transformer voltage control
     **Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/**
     **TR1ATCC:x/TR8ATCC:x/General/Operation**
   - Enable Tap Command
     **Main menu/Settings/IED Settings/Control/TransformerTapChanger(YLTC,84)/**
     **TCMYLTC:x/TCLYLTC:x/EnabTapCmd**

While the test set is connected to the IED but no voltage is applied, the voltage control functions will detect an undervoltage condition that may result in an alarm or blocking of the voltage-control operation. These conditions will be shown on the local HMI.

2. Apply the corresponding voltage
   Confirm the analog measuring mode prior to undertaking secondary injection (positive sequence, phase-to-phase, or phase-to-earth). This measuring mode is defined in the local HMI under **Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/**
   **TR1ATCC:x/TR8ATCC:x/General/MeasMode**
The application of nominal voltage $U_{Set}$ according to set $MeasMode$ to the IEDs should cause the alarm or blocking condition for undervoltage to reset.

### 11.10.3.3 Check the normal voltage regulation function

1. Review the settings for $U_{Deadband}$ (based on percentage of nominal bus voltage) and calculate the upper ($U_2$) and lower ($U_1$) voltage regulation limits for which a tap change command will be issued.
2. Review the expected time for first ($t_1$) and subsequent ($t_2$) tap change commands from the voltage control function on the local HMI under **Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/**
   **TR1ATCC:x/TR8ATCC:x/Time/t1 and t2**
3. Lower the voltage 1% below $U_1$ and wait for the issue of a Raise command from the voltage control after the expiry of a constant or inverse time delay set by $t_1$. Detection of this command will involve locating the allocated binary output for a raise pulse command in the Signal Matrix in PCM600 and monitoring a positive from this output.
4. After the issue of the raise command, return the applied voltage to $U_{Set}$ (nominal value).
5. Raise the voltage 1% above the upper deadband limit $U_2$ and wait for the issue of a lower command from the voltage control after the expiry of a constant or inverse time delay set by $t_2$. Detection of this command will involve locating the allocated binary output for a low pulse command in the Signal Matrix in PCM600 and monitoring a positive from this output.
6. Return the applied voltage to $U_{Set}$.

### 11.10.3.4 Check the undervoltage block function

1. Confirm the setting for $U_{block}$, nominally at 80% of rated voltage.
2. Confirm the voltage control function response to an applied voltage below $U_{block}$, by reviewing the setting in the local HMI under **Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/**
   **TR1ATCC:x/TR8ATCC:x/UVBk** that may cause an

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alarm, total or automatic block of the voltage control function to be displayed on the local HMI.

3. Apply a voltage slightly below $U_{\text{block}}$ and confirm the response of the voltage control function.

11.10.3.5 Check the upper and lower busbar voltage limit

1. Confirm the settings for $U_{\text{min}}$ and $U_{\text{max}}$ in the local HMI under Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR1ATCC:x/TR8ATCC:x/Voltage/Umax or Umin and Main menu/Settings/IED Settings/Control/TR8ATCC (90)/TR8ATCC:n/Voltage/Umax

2. Confirm the voltage control function response to an applied voltage below $U_{\text{min}}$ and above $U_{\text{max}}$, by reviewing the settings in the local HMI under Main menu/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR1ATCC:x/TR8ATCC:x/UVPartBk and Main menu/IED Settings/Control/TransformerVoltageControl/TR1ATCC:x/TR8ATCC:x/OVPartBk. These conditions may cause an alarm or total block of the voltage control function to be displayed on the local HMI.

3. Decrease the injected voltage slightly below the $U_{\text{min}}$ value and check for the corresponding blocking or alarm condition on the local HMI. For an alarm condition, the voltage regulation function is not blocked and a raise command should be issued from the IED.

4. Increase the applied voltage slightly above the $U_{\text{max}}$ value and check for the corresponding blocking or alarm condition on the local HMI. For an alarm condition, the voltage regulation function is not blocked and a lower command should be issued from the IED.

11.10.3.6 Check the overcurrent block function

1. Confirm the setting for $I_{\text{block}}$ in the local HMI under Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,91)/TR1ATCC:x/TR8ATCC:x/TCCtrl/Iblock

2. Confirm the voltage control function response to an applied current above $I_{\text{block}}$, by reviewing the settings in the local HMI under Main menu/IED Settings/Control/TransformerVoltageControl(ATCC,91)/TR1ATCC:x/TR8ATCC:x/OVPartBk. This condition may cause an alarm or total block of the voltage control function to be displayed on the local HMI.

3. Inject a current higher than the $I_{\text{block}}$ setting and confirm the alarm or blocking condition is present on the local HMI. If an automatic or total blocking condition occurs, change the applied secondary voltage and confirm that no tap change commands are issued from the associated binary outputs. This situation can also be confirmed through reviewing the disturbance and service reports on the local HMI.

11.10.3.7 Single transformer

Load drop compensation

1. Confirm that OperationLDC is set to On.

2. Confirm settings for $R_{\text{line}}$ and $X_{\text{line}}$.

3. Calculate the expected load voltage $U_L$ (displayed as a measured value on the local HMI) based on secondary injection of transformer secondary voltage ($U_B = U_{\text{Set}}$) and rated load current ($I_L = I_{1\text{Base}}$), in accordance with equation 111.
\[ U_L = U_b - (R_{\text{line}} + jX_{\text{line}}) \cdot I_L \]  
(Equation 111)

where:

\( U_L, I_L = \text{Re}(I_L) + j\text{Im}(I_L) \) are complex phase quantities

When all secondary phase-to-earth voltages are available, use the positive-sequence components of voltage and current. By separation of real and imaginary parts:

\[
\begin{align*}
ul, re &= ub, re - rline \cdot iL, re + xline \cdot iL, im \\
ul, im &= ub, im - xline \cdot iL, re - rline \cdot iL, im
\end{align*}
\]  
(Equation 112)

(Equation 113)

where:

\( ub \) is the complex value of the busbar voltage

\( iL \) is the complex value of the line current (secondary side)

\( rline \) is the value of the line resistance

\( xline \) is the value of the line reactance

For comparison with the set-point value, the modulus of \( U_L \) are according to equation 114.

\[ |U_L| = \sqrt{(ul, re)^2 + (ul, im)^2} \]  
(Equation 114)

4. Inject voltage for \( U_b \) equal to setting \( U\text{Set} \).
5. Inject current equal to rated current \( I_2\text{Base} \).
6. Confirm on the local HMI that service values for bus voltage and load current are equal to injected quantities.
7. Confirm that the calculated value for load voltage, displayed on the local HMI, is equal to that derived through hand calculations.
8. When setting \( \text{OperationLDC} \) set to \( \text{On} \), the voltage regulation algorithm uses the calculated value for load voltage as the regulating quantity to compare against \( U\text{Set} \) and the voltage deadband limits \( U\text{Deadband} \) and \( U\text{DeadbandInner} \).
9. While injecting rated current \( I_2\text{Base} \) into the IED, inject a quantity for \( U_b \) that is slightly higher then \( U\text{Set} + |(R_{\text{line}}+jX_{\text{line}}) \cdot I_L| \). This will ensure that the regulating voltage \( U_L \) is higher than \( U\text{Set} \), and hence no tap change command should be issued from the IED.
10. Reduce the injected voltage for \( U_b \) slightly below \( U\text{Set} + |(R_{\text{line}}+jX_{\text{line}}) \cdot I_L| \) and confirm that the calculated value for load voltage is below \( U\text{Set} \) and a tap change command is issued from the IED.

11.10.3.8 Parallel voltage regulation

Master follower voltage regulation
1. For the transformers connected in the parallel group, confirm that OperationPAR is set to MF.

2. For parallel operation, it is also recommended to confirm for parallel group membership, defined by setting TnRXOP in the local HMI under Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR8ATCC:x/ParCtrl. The general parallel arrangement of transformers are defined by setting TnRXOP to On or Off. The following rules are applicable on the settings T1RXOP – T4RXOP.
   If IED T1 and T2 are connected,
   • T1RXOP shall be set to On in instance 2 of TR8ATCC,
   • T2RXOP shall be set to On in instance 3 of TR8ATCC,
   • T2RXOP and T3RXOP shall be set to On in instance 1 of TR8ATCC, and so on.

   The parameter corresponding to the own IED must not be set. T1RXOP should thus not be set in IED T1, T2RXOP not in IED T2, and so on.

3. The lowest transformer number in the parallel group is by default set as the Master – confirm that this is the case by reviewing the setting in the local HMI.

4. Review the settings for UDeadband (based on percentage of nominal bus voltage) and calculate the upper (U2) and lower (U1) voltage regulation limits for which a tap change command will be issued from the master transformer in the group.

5. Review the expected time for first (t1) and subsequent (t2) tap change commands from the master transformer in the local HMI under Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR1ATCC:x/TR8ATCC:x/Time/t1 and t2.

6. Apply a voltage 1% below U1 and wait for the issue of a raise command from the voltage control after the expiry of a constant or inverse time delay set by t1. Detection of this command will involve locating the allocated binary output for a raise command in the Signal Matrix in PCM600 and monitoring a positive from this output. Confirm the timing of this command correlates with the setting t1.

7. After the issue of the raise command, confirm that all follower transformers in the group change tap in accordance with the command issued from the master transformer.

8. Inject a voltage U2 for the master transformer that is 1% above the upper deadband limit U2 and wait for the issue of a lower command from the voltage control after the expiry of a constant or inverse time delay set by t2.

9. Confirm that all follower transformers in the group change tap in accordance with this command.

Circulating current voltage regulation
This instruction for confirmation of circulating current voltage regulation assumes two transformers in the parallel group. Setting confirmation through secondary injection requires calculation of circulating currents for each transformer based on impedance values and respective compensating factors, and is therefore more complex for greater than two transformers.

1. Confirm that OperationPAR is set to CC for the transformers in the parallel group.

2. For parallel operation, it is also recommended that settings be confirmed for parallel group membership, governed by setting TnRXOP in the local HMI under Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR8ATCC:x/ParCtrl. The general parallel arrangement of transformers are defined by setting TnRXOP to On or Off. The following rules are applicable on the settings T1RXOP – T4RXOP.
   If IED T1 and T2 are connected,
   • T1RXOP shall be set to On in instance 2 of TR8ATCC, and
   • T2RXOP shall be set to On in instance 1 of TR8ATCC.

   If T1 - T3 are available,
• **T1RXOP** and **T2RXOP** shall be set to **On** in instance 3 of TR8ATCC,
• **T2RXOP** and **T3RXOP** shall be set to **On** in instance 1 of TR8ATCC and so on.

The parameter corresponding to the own IED **must not** be set. **T1RXOP** should thus **not** be set in IED **T1**, **T2RXOP** in IED **T2** and so on.

3. Review the settings for **UDeadband** (based on percentage of nominal bus voltage) and calculate the upper (U2) and lower (U1) voltage regulation limits for which a tap change command will be issued from the master transformer in the group.

4. Review the expected time for first (t1) and subsequent (t2) tap change commands from the master transformer in the local HMI under **Main menu/Settings/IED Settings/TransformerVoltageControl(ATCC,90)/TR1ATCC:x/TR8ATCC:x/Time/t1 and t2**

5. Inject a voltage **U_0** equal to **USet** for each transformer.

6. Inject a load current for Transformer 1 that is equal to rated load current **I2Base** and a load current for Transformer 2 that is equal to 95% of rated load current **I2Base**. This will have the effect of producing a calculated circulating current that flows from HV to LV side for Transformer 1 and LV to HV side for Transformer 2.

7. Confirm that a circulating current is measured on the local HMI that is equal in magnitude to 5% of **I2Base**, with polarity as discussed in step 6.

8. Confirm the settings for **C_i** (Compensation Factor) and **X_i** (Transformer Short Circuit Impedance). Using these setting values and the measured quantity of circulating current from the local HMI (**Icc_i**), calculate the value for circulating current voltage adjustment **Uci**.

\[
U_{di} = C_i \cdot I_{cc\_i} \cdot X_i
\]

(Equation 115)

The voltage regulation algorithm then increases (for transformer **T2**) or decreases (for transformer **T1**) the measured voltage by **Udi** and compares **Ui** against the voltage deadband limits U1 and U2 for the purposes of voltage regulation.

\[
U_i = U_2 + U_{di}
\]

(Equation 116)

9. To cause a tap change, the calculated value for circulating current voltage adjustment must offset the injected quantity for bus voltage **U_0** so that **Ui** is outside the voltage deadband created by setting **UDeadband**. Expressed by equation 117 and equation 118.

\[
U_{di} > U_2 - U_B
\]

(Equation 117)

\[
U_B = U_{set}
\]

(for the purposes of this test procedure)

(Equation 118)

Therefore:

\[
C_i \cdot I_{cc\_i} \cdot X_i > U_2 - U_{set}
\]

(Equation 119)
Using the settings for $U_{\text{Set}}$, $U_{\text{Deadband}}$, $C$ (Compensating factor) and $X_{r2}$ (transformer short circuit impedance) calculate the magnitude of $I_{\text{cc}_i}$ necessary to cause a tap change command.

11. Inject current equal to $I_{2\text{Base}}$ for Transformer 1 and $(I_{2\text{Base}} - |I_{\text{cc}_i}|)$ for Transformer 2 so that the magnitude of calculated circulating current will cause a raise command to be issued for Transformer 2 and a lower command for Transformer 1. Magnitude and direction of circulating currents measured for each transformer can be observed as service values on the local HMI and raise/lower commands detected from the binary output mapped in the Signal Matrix.

The voltage injection equal to $U_{\text{Set}}$ is required for both transformers during this test.

12. Confirm that a tap change command is issued from the voltage control function to compensate for the circulating current.

13. Injected currents can be reversed such that the direction of calculated circulating currents change polarity, which will cause a lower command for Transformer 2 and a raise command for Transformer 1.

**Circulating current limit**

1. Confirm that $\text{OperationPAR}$ is set to $\text{CC}$ for each transformer in the parallel group.
2. Confirm that $\text{OperCCBlock}$ is set to $\text{On}$ for each transformer in the parallel group.
3. Review the setting for $\text{CircCurrLimit}$.
4. Review the setting for $\text{CircCurrBk}$ to confirm whether a circulating current limit will result in an $\text{Alarm}$ state, $\text{Auto Block}$ or $\text{Auto&Man Block}$ of the automatic voltage control for tap changer, for parallel control function TR8ATCC.
5. Inject a voltage $U_B$ equal to $U_{\text{Set}}$ for each transformer.
6. Inject a load current for Transformer 1 that is equal to rated load current $I_{2\text{Base}}$ and a load current for Transformer 2 that is 1% less than $(I_{2\text{Base}} - (I_{2\text{Base}} \cdot \text{CircCurrLimit}))$
7. Confirm that the automatic voltage control for tap changer, for parallel control function TR8ATCC responds in accordance with the setting for $\text{CircCurrBk}$. Alarm and blocking conditions can be confirmed through interrogation of the event menu or the control menu on the local HMI.

**$V_{\text{Tmismatch}}$ during parallel operation**

1. Confirm that $\text{OperationPAR}$ is set to $\text{MF}$ for each transformer in the parallel group.
2. Review the setting for $\text{VTMismatch}$ and $t\text{VTmismatch}$.
3. Inject a voltage $U_B$ equal to $U_{\text{Set}}$ for Transformer 1 and a voltage less than $(U_{\text{Set}} - (V_{\text{Tmismatch}} \cdot U_{\text{Set}}))$ for Transformer 2.
4. This condition should result in a $\text{VTMismatch}$ which will mutually block the operation of the automatic voltage control for tap changer, parallel control function TR8ATCC for all transformers connected in the parallel group, which can be confirmed through interrogation of the local HMI.
5. Confirm that the automatic voltage control for tap changer, parallel control function TR8ATCC responds in accordance with the setting for $\text{CircCurrBk}$.

\[
|I_{\text{cc}_i}| > \frac{(U_{2} - U_{\text{Set}})}{(C \cdot X_i)}
\]
11.10.3.9 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.

11.10.4 Single command, 16 signals SINGLECMD

For the single command function block, it is necessary to configure the output signal to corresponding binary output of the IED. The operation of the single command function (SINGLECMD) is then checked from the local HMI by applying the commands with Mode = Off, Steady or Pulse, and by observing the logic statuses of the corresponding binary output. Command control functions included in the operation of different built-in functions must be tested at the same time as their corresponding functions.

11.10.5 Interlocking

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

Values of the logical signals are available on the local HMI under Main menu/Tests/Function status/Control/Apparatus control/Interlocking. The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.

The interlocking function consists of a bay-level part and a station-level part. The interlocking is delivery specific and is realized by bay-to-bay communication over the station bus. For that reason, test the function in a system, that is, either in a complete delivery system as an acceptance test (FAT/SAT) or as parts of that system.

11.11 Scheme communication

11.11.1 Scheme communication logic for distance or overcurrent protection ZCPSCH

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

Check the scheme logic during the secondary injection test of the impedance or overcurrent protection functions.

Activation of the different zones verifies that the CS signal is issued from the intended zones. The CS signal from the independent tripping zone must have a tSendMin minimum time.

Check the tripping function by activating the CR and CRG inputs with the overreaching zone used to achieve the CACC signal.

It is sufficient to activate the zones with only one type of fault with the secondary injection.

11.11.1.1 Testing permissive underreaching

1. Activate the receive (CR) signal in the IED.
2. Apply healthy normal load conditions to the IED for at least two seconds.
3. Apply a fault condition within the permissive zone.
4. Check that correct trip outputs, external signals, and indications are obtained for the actual type of fault generated.
5. Check that other zones operate according to their zone timers and that the send (CS) signal is obtained only for the zone configured to generate the actual signal.
6. Deactivate the receive (CR) signal in the IED.
7. Check that the trip time complies with the zone timers and that correct trip outputs, external signals, and indications are obtained for the actual type of fault generated.

11.11.1.2 Testing permissive overreaching

1. Activate the receive (CR) signal in the IED.
2. Apply healthy normal load conditions to the IED for at least two seconds.
3. Apply a fault condition within the permissive zone.
4. Check that correct trip outputs, external signals, and indication are obtained for the actual type of fault generated.
5. Check that the other zones operate according to their zone timer and that the send (CS) signal is obtained only for the zones that are configured to give the actual signal. Also the zone connected to CS underreach is giving CS in this mode.
6. Deactivate the IED receive (CR) signal.
7. Apply healthy normal load conditions to the IED for at least two seconds.
8. Apply a fault condition within the permissive zone.
9. Check that trip time complies with the zone timers and that correct trip outputs, external signals, and indications are obtained for the actual type of fault generated.

11.11.1.3 Testing blocking scheme

1. Deactivate the receive (CR) signal of the IED.
2. Apply healthy normal load conditions to the IED for at least two seconds.
3. Apply a fault condition within the forward directed zone used for scheme communication tripping.
4. Check that correct trip outputs and external signals are obtained for the type of fault generated and that the operate time complies with the $t_{Coord}$ timer (plus relay measuring time).
5. Check that the other zones operate according to their zone times and that a send (CS) signal is only obtained for the reverse zone.
6. Activate the IED receive (CR) signal.
7. Apply a fault condition in the forward directed zone used for scheme communication tripping.
8. Check that the no trip from scheme communication occurs.
9. Check that the trip time from the forward directed zone used for scheme communication tripping complies with the zone timer and that correct trip outputs, external signals, and indications are obtained for the actual type of fault generated.

11.11.1.4 Testing delta blocking scheme

1. Deactivate the receive (CR) signal of the IED.
2. Apply healthy normal load conditions to the IED for at least two seconds.
3. Apply a fault condition within the forward directed zone used for scheme communication tripping.
4. Check that correct trip outputs and external signals are obtained for the type of fault generated and that the operate time complies with the $t_{Coord}$ timer (plus relay measuring time).
5. Check that the other zones operate according to their zone times and that a send (CS) signal is only obtained for the reverse zone.
6. Check that for a forward fault, carrier send (CS) signal is first obtained from the delta based fault inception detection (as it is not directional), and immediately inhibited by the forward zone.
7. Activate the IED receive (CR) signal.
8. Apply a fault condition in the forward directed zone used for scheme communication tripping.
9. Check that the no trip from scheme communication occurs.
10. Check that the trip time from the forward directed zone used for scheme communication tripping complies with the zone timer and that correct trip outputs, external signals, and indications are obtained for the actual type of fault generated.

11.11.1.5 Checking of unblocking logic

Check the unblocking function (if the function is required) when checking the communication scheme.

Command function with continuous unblocking \((Unblock = 1)\)

Procedure

1. Activate the guard input signal (CRG) of the IED.
2. Using the scheme selected, check that a signal accelerated trip (TRIP) is obtained when the guard signal is deactivated.

11.11.1.6 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.

11.11.2 Phase segregated scheme communication logic for distance or overcurrent protection ZC1PPSCH

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

Check the scheme logic during the secondary injection test of the impedance protection functions.

Activating of the different zones and phases verifies that the CSLx signal are issued from the intended zones. The CSLx signal from the independent tripping zone must have a \(tSendMin\) minimum time.

Check the tripping function by activating the CRLx inputs with the overreaching zone used to achieve the CACCLx signals.

It is sufficient to activate the zones with all types of fault with the secondary injection.

11.11.2.1 Testing permissive underreaching

1. Activate the receive (CRLx) signal in the IED.
2. Apply healthy normal load conditions to the IED for at least two seconds.
3. Apply a fault condition within the permissive zone.
4. Check that correct trip outputs, external signals, and indications are obtained for all the actual types of fault generated.
5. Check that other zones operate according to their zone timers and that the send (CSLx) signal is obtained only for the zone and phase configured to generate the actual signal.
6. Deactivate the receive (CRLx) signal in the IED.
7. Check that the trip time complies with the zone timers and that correct trip outputs, external signals, and indications are obtained for the actual type of fault generated.

11.11.2.2 Testing permissive overreaching

1. Activate the receive (CRLx) signal in the IED.
2. Apply healthy normal load conditions to the IED for at least two seconds.
3. Apply a fault condition within the permissive zone.
4. Check that correct trip outputs, external signals, and indication are obtained for all actual types of fault generated.
5. Check that the other zones operate according to their zone timer and that the send (CSLx) signal is obtained only for the zones and phases that are configured to give the actual signal. Also the zone connected to CSLx underreach is giving CSLx in this mode.
6. Deactivate the IED receive (CRLx) signal.
7. Apply healthy normal load conditions to the IED for at least two seconds.
8. Apply a fault condition within the permissive zone.
9. Check that trip time complies with the zone timers and that correct trip outputs, external signals, and indications are obtained for the actual type of fault generated.

11.11.2.3 Testing blocking scheme

1. Deactivate the receive (CRLx) signal of the IED.
2. Apply healthy normal load conditions to the IED for at least two seconds.
3. Apply a fault condition within the forward directed zone used for scheme communication tripping.
4. Check that correct trip outputs and external signals are obtained for the type of fault generated and that the operate time complies with the tCoord timer (plus relay measuring time).
5. Check that the other zones operate according to their zone times and that a send (CSLx) signal is only obtained for the reverse zone.
6. Activate the IED receive (CRLx) signal.
7. Apply a fault condition in the forward directed zone used for scheme communication tripping.
8. Check that no trip from scheme communication occurs.
9. Check that the trip time from the forward directed zone used for scheme communication tripping complies with the zone timer and that correct trip outputs, external signals, and indications are obtained for the actual type of fault generated.

11.11.2.4 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.
11.11.3 Current reversal and Weak-end infeed logic for distance protection 3-phase ZCRWPSCH

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

Values of the logical signals for ZCRWPSCH are available on the local HMI under Main menu/Tests/Function status / Scheme communication / ZCRWPSCH(85) /ZCRWPSCH:1.

The Signal Monitoring in PCM600 shows signals that are available on the Local HMI.

The current reversal logic and the weak-end infeed functions are tested during the secondary-injection test of the impedance or overcurrent protection zones together with the scheme communication logic for the distance protection function ZCPSCH.

11.11.3.1 Current reversal logic

It is possible to check the delay of the CS send signal with tDelayRev by changing from a reverse to a forward fault.

By continuously activating the CR input and changing from a reverse to a forward fault, the delay tDelayRev can be checked.

Checking of current reversal

The reverse zone timer must not operate before the forward zone fault is applied. The user might need to block the reverse zone timer setting during testing of current reversal.

The forward zone timer must be set longer than the tDelayRev set value.

1. Set the healthy condition to an impedance at 50% of the reach of the reverse zone connected to IRV.
2. Activate the receive (CRL) signal.
3. After the start condition is obtained for reverse zone, apply a fault at 50% of the reach of the forward zone connected to WEIBLK2.
4. Check that correct trip outputs and external signals are obtained for the type of fault generated. The operation time should be about the tDelayRev setting longer than the carrier accelerated trip (TRIP) recorded for the permissive overreach scheme communication.
5. Restore the forward and reverse zone timer to its original setting.

11.11.3.2 Weak end infeed logic

Weak-end infeed logic at permissive overreach schemes
1. Check the blocking of the echo with the injection of a CRL signal >40ms after a reverse fault is applied.
2. Measure the duration of the echoed CS signal by applying a CRL receive signal.
3. Check the trip functions and the voltage level for trip by reducing a phase voltage and applying a CRL receive signal.

**Testing conditions**

Only one type of fault is sufficient, with the current reversal and weak-end infeed logic for distance protection function ZCRWPSCH. Apply three faults (one in each phase). For phase L1-N fault, set these parameters:

**Table 40: Phase L1-N parameter values**

<table>
<thead>
<tr>
<th>Phase</th>
<th>I (Amps)</th>
<th>Phase-angle (Deg)</th>
<th>V (Volts)</th>
<th>Phase-angle (Deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>0</td>
<td>0</td>
<td>Set less than $L_{UPN}$&lt; 0</td>
<td>0</td>
</tr>
<tr>
<td>L2</td>
<td>0</td>
<td>240</td>
<td>63</td>
<td>240</td>
</tr>
<tr>
<td>L3</td>
<td>0</td>
<td>120</td>
<td>63</td>
<td>120</td>
</tr>
</tbody>
</table>

If wanted, change all settings cyclically for other faults (L2-N and L3-N).

The setting parameter WEI is set to *Echo & Trip*.

1. Apply input signals according Table 40.
2. Activate the receive (CR) signal.
3. After the IED has operated, turn off the input signals.
4. Check that trip, send signal, and indication are obtained.

The ECHO output gives only a 200 ms pulse.

### 11.11.3.3 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.

### 11.11.4 Scheme communication logic for residual overcurrent protection ECPSCH

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

Before testing the communication logic for residual overcurrent protection function ECPSCH, the four step residual overcurrent protection function EF4PTOC has to be tested according to the corresponding instruction. Once this is done, continue with the instructions below.

If the current reversal and weak-end infeed logic for earth-fault protection is included, proceed with the testing according to the corresponding instruction after testing the communication logic for residual overcurrent protection. The current reversal and weak-end-infeed functions shall be tested together with the permissive scheme.
11.11.4.1 Testing the directional comparison logic function

Blocking scheme

1. Inject the polarizing voltage 3U0 at 5% of \( U_{\text{Base}} \) (EF4PTOC) where the current is lagging the voltage by 65°.
2. Inject current (65° lagging the voltage) in one phase at about 110% of the set operating current, and switch the current off with the switch.
3. Switch the fault current on and measure the operating time of the communication logic. Use the TRIP signal from the configured binary output to stop the timer.
4. Compare the measured time with the set value \( t_{\text{Coord}} \).
5. Activate the CR binary input.
6. Check that the CRL output is activated when the CR input is activated.
7. Switch the fault current on (110% of the set operating current) and measure the operating time of the communication logic. Use the TRIP signal from the configured binary output to stop the timer.
8. Compare the measured time with the set value \( t_{\text{Coord}} \).
9. Activate the CR binary input.
10. Check that the CRL output is activated when the CR input is activated.

11. Switch the fault current on (110% of the set operating current) and wait longer than the set value \( t_{\text{Coord}} \).

No TRIP signal should appear.

Permissive scheme

1. Inject the polarizing voltage 3U0, which is 5% of \( U_{\text{Base}} \) (EF4PTOC) where the current is lagging the voltage by 65°.
2. Inject current (65° lagging the voltage) into one phase at about 110% of the set operating current, and switch the current off with the switch.
3. Switch the fault current on, (110% of the set operating current) and wait longer than the set value \( t_{\text{Coord}} \).

No TRIP signal should appear, and the CS binary output should be activated.

4. Switch the fault current off.
5. Activate the CR binary input.
6. Switch the fault current on (110% of the set operating current) and measure the operating time of the ECPSC logic. Use the TRIP signal from the configured binary output to stop the timer.
7. Compare the measured time with the setting for \( t_{\text{Coord}} \).
8. Activate the BLOCK digital input.
9. Switch the fault current on (110% of the set operating current) and wait for a period longer than the set value \( t_{\text{Coord}} \).
No TRIP signal should appear.

10. Switch the fault current and the polarizing voltage off.
11. Reset the CR binary input and the BLOCK digital input.

11.11.4.2 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.

11.11.5 Current reversal and weak-end infeed logic for residual overcurrent protection ECRWPSCH

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

Values of the logical signals for ECRWPSCH are available on the Local HMI under Main menu/Tests/Function status/Scheme communication/ECRWPSCH(85)/ECRWPSCH:1.

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

First, test the four step residual overcurrent protection function EF4PTOC and then the current reversal and weak-end infeed logic according to the corresponding instructions. Then continue with the instructions below.

11.11.5.1 Testing the current reversal logic

1. Inject the polarizing voltage 3U0 to 5% of UBase and the phase angle between voltage and current to 155°, the current leads the voltage.
2. Inject current (180° — AngleRCA) in one phase to about 110% of the set operating current of the four step residual overcurrent protection (IN>Dir).
3. Check that the IRVL output is activated in the disturbance recorder after the set time tPickUpRev.
4. Abruptly reverse the current to AngleRCA setting lagging the voltage, to operate the forward directional element.
5. Check that the IRVL output still is activated after the reversal with a time delay that complies with the setting tDelayRev.
6. Switch off the polarizing voltage and the current.

11.11.5.2 Testing the weak-end infeed logic

If setting WEI = Echo

1. Inject the polarizing voltage 3U0 to (180° — AngleRCA) of UBase and the phase angle between voltage and current to 155°, the current leads the voltage.
2. Inject current (180° — AngleRCA) in one phase to about 110% of the setting operating current (IN>Dir).
3. Activate the CRL binary input.
4. Abruptly reverse the current to the setting of AngleRCA setup lagging the voltage, to operate the forward directional element.

No ECHO and CS should appear.

5. Switch off the current and check that the ECHO and CS appear on the corresponding binary output during 200ms after resetting the directional element.
6. Switch off the CRL binary input.
7. Activate the BLOCK binary input.
8. Activate the CRL binary input.

No ECHO and CS should appear.

9. Switch off the polarizing voltage and reset the BLOCK and CRL binary input.

If setting WEI = Echo & Trip

1. Inject the polarizing voltage 3U0 to about 90% of the setting (3U0>) operating voltage.
2. Activate the CRL binary input.

No ECHO, CS and TRWEI outputs should appear.

3. Increase the injected voltage to about 110% of the setting (3U0) operating voltage.
4. Activate the CRL binary input.
5. Check that the ECHO, CS and TRWEI appear on the corresponding binary output or on the local HMI.
6. Reset the CRL binary input.
7. Activate the BLOCK binary input.
8. Activate the CRL binary input.

No ECHO, CS and TRWEI outputs should appear.

9. Reset the CRL and BLOCK binary input.
10. Inject the polarizing voltage 3U0 to about 110% of the setting (3U0>) and adjust the phase angle between the voltage and current to (180° - AngleRCA) setting, the current leads the voltage.
11. Inject current in one phase to about 110% of the set operate current (IN>Dir).
12. Activate the CRL binary input.

No ECHO and TRWEI should appear.

13. Abruptly reverse the current to 65° lagging the voltage to operate the forward directional element.
14. Switch the current off and check that the ECHO, CS and TRWEI appear on the corresponding binary output during 200ms after resetting the directional element. If EF4PTOC also operates in forward direction, CS should be obtained.

15. Switch the polarizing voltage off and reset the CRL binary input.

11.11.5.3 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.

11.12 Logic

11.12.1 Tripping logic, common 3-phase output SMPPTRC

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, earth-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.

11.12.1.1 3 phase operating mode

1. Check that AutoLock and TripLockout are both set to Off.
2. Initiate a three-phase fault.
   An adequate time interval between the faults should be considered, to overcome a reclaim time caused by the possible activation of the autorecloser function SMBRREC. The function must issue a three-phase 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, TRL1, TRL2, TRL3 and TR3P.

11.12.1.2 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 Off.
2. Initiate different single-phase-to-earth faults one at a time.
   Single-phase tripping will only be allowed when an autoreclose attempt will follow. The autorecloser function SMBRREC has the functionality such as the long trip time, CB ready and so on, which can prevent a proper single-phase tripping and autoreclose. To by-pass this problem the fault initiation should be with a test set and with the autoreclose in full service with a test set connected to the distance protection function. Consider using an adequate time interval between faults, to overcome a reclaim time of which is activated by SMBRREC. Only a single-phase trip should occur for each separate fault and only one
of the trip outputs (TRLn) should be activated at a time. Functional outputs TRIP and TR1P should be active during each fault. No other outputs should be active.

3. Initiate different phase-to-phase and three-phase faults.
Consider using an adequate time interval between faults, to overcome a reclaim time, which is activated by SMBRREC. A three-phase trip should occur for each separate fault and all of the trips. Functional outputs TRIP, all TRLn and TR3P should be active at each fault.

No other outputs should be active.

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

5. Initiate a single phase-to-earth fault and switch it off immediately when the trip signal is issued for the corresponding phase. Initiate the second single phase-to-earth 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, when included in the protection scheme.
Check that the second trip is a three-phase trip and that a three-phase autoreclosing attempt is given after the three-phase dead time. Functional outputs TRIP, TRLn and TR1P should be active during the first fault. No other outputs should be active. Functional outputs TRIP, all TRLn and TR3P should be active during second fault.

11.12.1.3 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 Off.
2. Initiate different single-phase-to-earth faults one at a time.
Take an adequate time interval between faults into consideration, to overcome a reclaim time, which is activated by the autorecloser function SMBRREC. Only a single-phase trip should occur for each separate fault and only one of the trip outputs (TRLn) 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 reclaim time which is activated by SMBRREC. Only a two-phase trip should occur for each separate fault and only corresponding two trip outputs (TRLn) 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.
Take an adequate time interval between faults into consideration, to overcome a reclaim time, which may be activated by SMBRREC. Only a three-phase trip should occur for the fault and all trip outputs (TRLn) should be activated at the same time. Functional outputs TRIP and TR3P should be active at each fault. No other outputs should be active.

5. Initiate a single phase-to-earth fault and switch it off immediately when the trip signal is issued for the corresponding phase. Initiate the same fault once again within the reclaim time of the used SMBRREC.
A single-phase fault shall be given at the first fault. Check that the corresponding trip signals appear after both faults. Functional outputs TRIP, TRLn and TR1P should be active during first fault. No other outputs should be active. Functional outputs TRIP, all TRLn and TR3P should be active during second fault.

6. Initiate a single phase-to-earth fault and switch it off immediately when the trip signal is generated for the corresponding phase. Initiate the second single-phase-to-earth 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, when included in the protection scheme.

   Check that the second trip is a three-phase trip and that a three-phase autoreclosing attempt is given after the three-phase dead time. Functional outputs TRIP, TRLn and TR1P should be active during first fault. No other outputs should be active. Functional outputs TRIP, all TRLn and TR3P should be active during second fault.

7. Initiate a phase-to-phase fault and switch it off immediately when the trip signal is issued for the corresponding two phases. Initiate a second phase-to-phase fault between two other phases within the time interval, shorter than $t_{EvolvingFault}$ (default setting 2.0s).

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

11.12.1.4 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 Off.
   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-phase trip should occur and all trip outputs TRL1, TRL2, TRL3 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 = On 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 = On and repeat.

      All trip outputs (TRL1, TRL2, TRL3) and functional outputs TRIP and TR3P must be active and stay active after each fault, CLLUOUT should be set.

   10. Reset the lockout.

      All functional outputs should reset.

   11. Deactivate the trip signal lockout function, set TripLockout = Off and the automatic lockout function, set AutoLock = Off.

11.12.1.5 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.
11.13 Monitoring

11.13.1 Gas medium supervision SSIMG

Prepare the IED for verification of settings as outlined in Section "Preparing the IED to verify settings" in this chapter.

Values of logical signals for SSIMG protection are available on the local HMI under Main menu/Tests/Function status/Monitoring/InsulationGas(63)/SSIMG(63):x, where x = 1, 2,...,21.

The Signal Monitoring in PCM600 shows the same signals that are available on the local HMI.

Check that the input logical signal BLOCK is logical zero and that on the local HMI, the logical signals PRESALM, PRESLO, TEMPALM, TEMPLO, ALARM and LOCKOUT are logical zero.

Using service kit, prepare the IED for verification of settings as outlined in Section "Preparing the IED to verify settings" in this chapter.

11.13.1.1 Testing the gas medium supervision for pressure alarm and pressure lockout conditions

1. Connect binary inputs to consider gas pressure and gas density to initiate the alarms.
2. Consider the analogue pressure input SENPRES and set SENPRES to a value lower than PresAlmLimit or activate binary input signal SENPRESALM, check that outputs PRESALM and ALARM are activated after a set time delay of tPressureAlarm.
3. Gas pressure lockout input SETPLO can be used to set PRESLO.
4. Also, reduce further the pressure level input below PresLOLimit or activate the binary input signal SENPRESLO, check that PRESLO signal appears after a set time delay of tPressureLO.
5. Activate BLOCK binary input and check that the outputs PRESALM, PRESLO, ALARM and LOCKOUT disappear.
6. Reset the BLOCK binary input.
7. Make sure that pressure lockout condition exists and then activate the reset lock out input RESETLO and check that the outputs PRESLO and LOCKOUT reset.

11.13.1.2 Testing the gas medium supervision for temperature alarm and temperature lock out conditions

1. Consider the analogue temperature input SENTEMP and set SENTEMP to a value higher than TempAlarmLimit, check that outputs TEMPALM and ALARM are activated after a set time delay of tTempAlarm.
2. Temperature lockout input SETTLO can be used to set TEMPLO signal.
3. Also, increase further the temperature input above TempLOLimit, check that the outputs TEMPLO and LOCKOUT appears after a set time delay of tTempLockOut.
4. Activate BLOCK binary input and check that the outputs TEMPALM, TEMPLO, ALARM and LOCKOUT disappear.
5. Reset the BLOCK binary input.
6. Make sure that temperature lockout condition exists and then activate the reset lock out input RESETLO and check that the outputs TEMPLO and LOCKOUT reset.
**11.13.1.3 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.

**11.13.2 Liquid medium supervision SSIML**

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

Values of logical signals for SSIMG protection are available on the local HMI under Main menu/Tests/Function status/Monitoring/InsulationLiquid(71)/SSIML(71):x, where x = 1, 2,...,4.

Check that the input logical signal BLOCK is logical zero and that on the local HMI, the logical signals LVLALM, LVLLO, TEMPALM, TEMPLO, ALARM and LOCKOUT are logical zero.

**11.13.2.1 Testing the liquid medium supervision for level alarm and level lockout conditions**

1. Connect the binary inputs to consider liquid level to initiate the alarms.
2. Consider the analogue level input SENLEVEL and set SENLEVEL to a value lower than LevelAlmLimit or activate binary input signal SENLVLALM, check that outputs LVLALM and ALARM are activated after a set time delay of tLevelAlarm.
3. Liquid level lockout input SENLVLLO can be used to set LVLLO.
4. Also, reduce the liquid level input below LevelLOLimit or activate the binary input signal SENLVLLO, check that LVLLO signal after a set time delay of tLevelLockOut.
5. Activate BLOCK binary input and check that the outputs LVLALM, LVLLO, ALARM and LOCKOUT disappears.
6. Reset the BLOCK binary input.
7. Make sure that level lockout condition exists and then activate the reset lock out input RESETLO and check that the outputs PRESLO and LOCKOUT reset.

**11.13.2.2 Testing the liquid medium supervision for temperature alarm and temperature lock out conditions**

1. Consider the analogue temperature input SENTEMP and set SENTEMP to a value higher than TempAlarmLimit, check that outputs TEMPALM and ALARM are activated after a set time delay of tTempAlarm.
2. Temperature lockout input SETTLO can be used to set TEMPLO signal.
3. Also, increase further the temperature input above TempLOLimit, check that the outputs TEMPLO and LOCKOUT appears after a set time delay of tTempLockOut.
4. Activate BLOCK binary input and check that the outputs TEMPALM, TEMPLO, ALARM and LOCKOUT disappear.
5. Reset the BLOCK binary input.
6. Make sure that temperature lockout condition exists and then activate the reset lock out input RESETLO and check that the outputs TEMPLO and LOCKOUT reset.

**11.13.2.3 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.
11.13.3 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

11.13.3.1 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 AccStopCurr set value. Only for a current lower than set AccStopCurr should activate the output POSOPEN.
   5.4. Check the circuit breaker is in INVDPOS if auxiliary contacts read same value or CB is open and inject the current in selected phase more than AccStopCurr set value.
6. Test of remaining life of CB
   6.1. Test the set timing defined by RatedOperCurr, RatedFltCurr, OperNoRated, OperNoFault, DirCoef, CBLifeAlmLevel.
   6.2. Vary the phase current in the selected phase from below rated operated current, RatedOperCurr to above rated fault current, RatedFltCurr of a breaker.
   6.3. The remaining life of CB output CBLIFEPH is estimated when the CB is changed from closed to open position. Check that the output CBLIFEPH is decreased with a value that corresponds to the injected current.
   6.4. CBLIFEAL is activated as soon as CBLIFEPH is below the set CBLifeAlmLevel value.
7. Test of accumulated energy
   7.1. Test the actual set values defined by AccSelCal to Aux Contact, ContTrCorr and AlmAccCurPwr.
   7.2. Inject phase current in the selected phase such that its value is greater than set AccStopCurr value.
   7.3. When the breaker goes to open position, accumulated energy IPOWPH is calculated. The calculated value can be seen on the output IPOWPH.
7.4. Alarm signal IPOWALPH appears when IPOWPH is greater than set AlmAccCurrPwr value.
7.5. Lockout signal IPOWLOPH appears if IPOWPH exceeds further to the threshold value LOAccCurrPwr.
7.6. Calculation of accumulated energy IPOWPH is stopped when injected current is lower than set AccStopCurr value.

8. Test of CB operation cycles
8.1. Test the actual set values defined by OperAlmLevel and OperLOLevel.
8.2. The operation counter, NOOPER is updated for every close-open sequence of the breaker by changing the position of auxiliary contacts POSCLOSE and POSOPEN.
8.3. OPERALM is activated when NOOPER value exceeds the set OperAlmLevel value. The actual value can be read on the output NOOPER.
8.4. OPERLO is activated when NOOPER value exceeds the set 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.

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

11.13.4 Event function EVENT

Prepare the IED for verification of settings as outlined in 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.

11.13.5 Fault locator LMBRFLO

Prepare the IED for verification of settings as outlined in section "Requirements" and section "Preparing for test" in this chapter.
The Fault locator function LMBRFLO depends on other functions to work properly, that is, phase selection information from distance protection function and analog information supplied by the trip value recorder function. Check that proper binary start and phase selection signals are connected and voltage and current signals are configured (parameter settings).

The result is displayed on the local HMI or via PCM600. Distances to faults for the last 100 recorded disturbances can be found on the local HMI under **Main menu/Disturbance Records/Disturbance #n(n = 1–100)/General Information**

If PCM600 is used, the result is displayed on the recording list after upload, including loop selection information.

**Table 41: Test settings**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Higher than 30% Iₚ</td>
</tr>
<tr>
<td>Healthy conditions</td>
<td>U = 63.5 V, I = 0 A &amp; ZF = 0°</td>
</tr>
<tr>
<td>Impedance</td>
<td>Test point Note:</td>
</tr>
<tr>
<td></td>
<td>• (Z_x &lt; (X0 + 2 \cdot X1)/3) For single-phase faults</td>
</tr>
<tr>
<td></td>
<td>• (Z_x &lt; X1) For three and two phase faults</td>
</tr>
<tr>
<td></td>
<td>• (Z_x &lt; (X0 + 2 \cdot X1 \cdot XM)/3) For single-phase fault with mutual zero-sequence current</td>
</tr>
<tr>
<td>Impedance angle  (Z\Phi)</td>
<td>Test angle</td>
</tr>
<tr>
<td></td>
<td>• (Z\Phi = \arctan[(X0 + 2 \cdot X1) / (R0 + 2R1)]) For single-phase faults</td>
</tr>
<tr>
<td></td>
<td>• (Z\Phi = \arctan(X1/R1)) For two-phase faults</td>
</tr>
</tbody>
</table>

**11.13.5.1 Measuring the operate limit**

1. Set the test point (|Z| fault impedance and \(Z\Phi\) impedance phase angle) for a condition that meets the requirements in table 41.
2. Subject the IED to healthy normal load conditions for at least two seconds.
3. Apply a fault condition.
   Check that the distance-to-fault value displayed on the HMI complies with equations 121, 122 and 123

\[
p = \frac{Z_x}{X1} \cdot 100
\]

(Equation 121)

in % for two- and three-phase faults

\[
p = \frac{3 \cdot Z_x}{X0 + 2 \cdot X1} \cdot 100
\]

(Equation 122)

in % for single-phase-to-earth faults
\[
p = \frac{3 \cdot Z_x}{X_0 + 2 \cdot X_1 \pm X_M} \cdot 100
\]

(Equation 123)

in % for single-phase-to-earth faults with mutual zero sequence current.

Where:
- \( p \) = the expected value of a distance to fault in percent
- \( Z_x \) = set test point on the test set
- \( X_0 \) = set zero-sequence reactance of a line
- \( X_1 \) = set positive-sequence reactance of a line
- \( X_M \) = set mutual zero-sequence impedance of a line

11.13.5.2 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.

11.13.6 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. Trigger the function and check that the counter result corresponds to the number of operations.

11.13.6.1 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.

11.13.7 Estimation of transformer insulation life LOLSPTR

Prepare the IED for verification of settings outlined in Section “Preparing the IED to verify settings”.

11.13.7.1 Verifying the signals and settings

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

Verifying HPTMPMAX and TOTCALC outputs

1. Connect the test set for injection of three-phase currents to the appropriate current terminals of the IED.
2. Activate the TOTVALID input and set some temperature value in TOTEMP input.
3. Supply the IED with three-phase currents slightly more than the rated value.
4. Make sure that the hot spot temperature (HPTMPMAX) is more than the set value of TOTEMP.
5. Activate the AMBVALID input and set some temperature value in AMBTEMP input.
6. Make sure that the top oil temperature calculated (TOTCALC) is more than the set value of AMBTEMP.

Verifying WARNINGx and ALARMx outputs

1. Connect the test set for injection of three-phase currents to the appropriate current terminals of the IED.
2. Make sure that the settings in the IED are appropriate, especially the warning temperature levels (\textit{WrnHPTmpLevX}) and alarm time settings (\textit{tDelayToAlarmX}).
3. Supply three-phase currents nearly zero to the IED and take note of hot spot temperature (HPTMPMAX).
4. Make sure that the WARNINGx and ALARMx signals remains low.
5. Supply three-phase currents slightly more than the rated value to the IED and take note of hot spot temperature (HPTMPMAX).
6. Check the time until the warning limit has reached \textit{WrnHPTmpLev1} level during injection. Monitor the signal WARNING1 until it appears on the corresponding binary output.
7. Compare the measured temperature (HPTMPMAX) with \textit{WrnHPTmpLev1} setting.
8. Check the time until the warning limit has reached \textit{WrnHPTmpLev2} level during injection. Monitor the signal WARNING2 until it appears on the corresponding binary output.
9. Compare the measured temperature (HPTMPMAX) with \textit{WrnHPTmpLev2} setting.
10. Wait for a time corresponding to \textit{tDelayToAlarm1} from the appearance of WARNING1 signal. Make sure that the ALARM1 signal appears.
11. Note the time taken for the appearance of ALARM1 signal from the appearance of WARNING1 signal, and compare it with set value (\textit{tDelayToAlarm1}).
12. Wait for a time corresponding to \textit{tDelayToAlarm2} from the appearance of WARNING2 signal, and make sure that the ALARM2 signal appears.
13. Note the time taken for the appearance of ALARM2 signal from the appearance of WARNING2 signal, and compare it with set value (\textit{tDelayToAlarm2}).
14. Activate the BLKWRN binary input. The WARNING1 and WARNING2 signals should disappear.
15. Activate the BLKALM binary input. The ALARM1 and ALARM2 signals should disappear.
16. Reset the BLKWRN and BLKALM binary inputs. Once again warning and alarm signals should appear.
17. Reduce the three-phase currents suddenly to value lower than the rated current and take note of hot spot temperature.
18. Check the warnings reset limit (\textit{HystAbsHPT}). Monitor the WARNING1 and WARNING2 signals until they disappears on the corresponding binary outputs. Take the HPTMPMAX readings and compare with the reset level settings.

Verifying LOLINDAY and LOLINYRS outputs

1. Connect the test set for injection of three-phase currents to the appropriate current terminals of the IED.
2. Make sure that the settings in the IED are appropriate, especially set the \textit{EnaAgeCalc} setting as Enable, \textit{TimeToUpdate} setting as 1 hour and \textit{AgeingRateMeth} setting as IEC.
3. Activate the TOTVALID input and set some temperature value in TOTEMP input.
4. Supply the IED with three-phase currents slightly more than the rated value.
5. Note the hot spot temperature (HPTMPMAX) and maintain it for another 1 hour.
6. Check the LOLINDAY and LOLINYRS outputs after 1 hour and compare it with the calculated loss of life value using IEC standard method.
11.13.7.2 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.

11.13.8 Through fault monitoring PTRSTHR

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

11.13.8.1 Verifying the signals and settings

The voltage or current can be injected using a common test equipment.

Verifying the through fault detection

1. Supply the IED with three-phase current at rated value.
2. Ensure that the relevant settings for through fault detection such as $W1I>$, $W2I>$ and $W3I>$ are set correctly.
3. Ensure that the BLOCK and INHIBIT inputs are not activated.
4. Set $tMin$ as 0 s to check the start level of through fault detection.
5. Slowly increase any phase current of any winding until ALARM signal appears.
6. Compare the injected phase current value with the set threshold limit value.
7. Bring the injected three-phase currents at the rated value.
8. Change the $tMin$ setting to a particular value.
9. Slowly increase any phase current of any winding to the threshold limit and wait until the ALARM signal appears.
10. Compare the wait time with the set $tMin$ value.
11. Bring the injected three-phase currents to the rated value.

Verifying the fault $f^2t$ and cumulative $f^2t$ alarms

1. Supply the IED with three-phase current at rated value.
2. Ensure that the relevant settings for fault $f^2t$ alarm such as $MaxI2tW1$, $MaxI2tW2$ and $MaxI2tW3$ are set correctly.
3. Ensure that the BLOCK and INHIBIT inputs are not activated.
4. Slowly increase any phase current of any winding until ALARM signal appears.
5. Continue to inject the same level of current until the I2TALM signal appears.
6. Compute the time between the ALARM signal raise to I2TALM signal raise and multiply with the squared injected current.
7. Compare the calculated value with the set $MaxI2tWx$ value.
8. Bring the injected three-phase currents to the rated value.
9. Ensure that the relevant settings for fault cumulative $f^2t$ alarm such as $MaxI2tCmlW1$, $MaxI2tCmlW2$ and $MaxI2tCmlW3$ are set correctly.
10. Slowly increase any phase current of any winding to the threshold limit and wait until the ALARM signal appears.
11. Continue to inject the same level of current until the CMLI2TALM signal appears.
12. Compute the time between the ALARM signal raise to CMLI2TALM signal raise and multiply with the squared injected current.
13. Add the calculated value with previously calculated $f^2t$ value.
14. Compare the calculated value with the set $MaxI2tCmlWx$ value.
15. Bring the injected three-phase currents to the rated value.
11.13.8.2 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.

11.13.9 Current harmonic monitoring CHMMHAI

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

11.13.9.1 Verifying the signals and settings

The current can be injected using common test equipment.

Verifying the warning and alarm time limit of THD, WrnLimitTHD and tDelayAlmTHD

1. Supply the IED with current at rated value.
2. Apply harmonics at the numerical multiple of fundamental frequency along with the injected current signal.
3. Slowly increase the harmonic amplitudes until the THDWRN signal appears.
4. Compare the harmonic amplitude level value with the set warning limit value.
5. Continue to inject the same level of harmonics level until the THDALM signal appears and note down the time from THDWRN set to THDALM set.
6. Compare the noted time value with the set time limit value of alarm.

Verifying the warning and alarm time limit of TDD, WrnLimitTDD and tDelayAlmTDD

1. Supply the IED with current at rated value.
2. Apply harmonics at the numerical multiple of fundamental frequency along with the injected current signal.
3. Slowly increase the harmonic amplitudes until the TDDWRN signal appears.
4. Compare the harmonic amplitude level value with the set warning limit value.
5. Continue to inject the same level of harmonics level until the TDDALM signal appears and note down the time from TDDWRN set to TDDALM set.
6. Compare the noted time value with the set time limit value of alarm.

Verifying the warning and alarm time limit of individual harmonic distortions IHD, WrnLimit#HD and tDelayAlm#HD (where # = 2\textsuperscript{nd}, 3\textsuperscript{rd}...5\textsuperscript{th})

1. Supply the IED with current at rated value.
2. Apply 2\textsuperscript{nd} order harmonic along with injected current signal.
3. Slowly increase the harmonic amplitude until the 2NDHDWRN signal appears.
4. Compare the harmonic amplitude level value with the set warning limit value.
5. Continue to inject the same level of harmonics level until the 2NDHDALM signal appears and note down the time from 2NDHDWRN signal set to 2NDHDALM signal set.
6. Compare the noted time value with the set time limit value of alarm.
7. Repeat Steps 2 to 6 for the harmonics until 5\textsuperscript{th} order.

11.13.9.2 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.
11.13.10  Voltage harmonic monitoring VHMMHAI

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

11.13.10.1  Verifying the signals and settings

The voltage can be injected using common test equipment.

Verifying the warning and alarm time limit of \(THD, \text{WrnLimitTHD} \) and \(t\text{DelayAlmTHD} \)

1. Supply the IED with voltage at rated value.
2. Apply harmonics at the numerical multiple of fundamental frequency along with the injected voltage signal.
3. Slowly increase the harmonic amplitudes until the THDWRN signal appears.
4. Compare the harmonic amplitude level value with the set warning limit value.
5. Continue to inject the same level of harmonics level until the THDALM signal appears and note down the time from THDWRN set to THDALM set.
6. Compare the noted time value with the set time limit value of alarm.

Verifying the warning and alarm time limit of individual harmonic distortions \(I\text{HD}, \text{WrnLimit#HD} \) and \(t\text{DelayAlm#HD} \) (where \(\# = 2^{\text{nd}}, 3^{\text{rd}} \ldots 5^{\text{th}}\))

1. Supply the IED with voltage at rated value.
2. Apply \(2^{\text{nd}}\) order harmonic along with injected voltage signal.
3. Slowly increase the harmonic amplitude until the 2NDHDWRN signal appears.
4. Compare the harmonic amplitude level value with the set warning limit value.
5. Continue to inject the same level of harmonics level until the 2NDHDALM signal appears and note down the time from 2NDHDWRN signal set to 2NDHDALM signal set.
6. Compare the noted time value with the set time limit value of alarm.
7. Repeat Steps 2 to 6 for the harmonics until 5\(^{th}\) order.

11.13.10.2  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.

11.14  Metering

11.14.1  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 \(\text{Operation} = \text{On or Operation} = \text{Off} \) and the function blocked or unblocked. The pulse counter value is then checked in PCM600 or on the local HMI.
11.14.2 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.

11.14.2.1 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 $t_{Energy}$ 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 $EAFALM$ and $ERFALM$ outputs by changing the power inputs directions through direction settings.

11.14.2.2 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.

11.15 Station communication

11.15.1 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.

11.16 Remote communication

11.16.1 Binary signal transfer

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

To perform a test of the binary signal transfer functions, 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 the binary signal transfer:

- 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 58. 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 58: Test of RTC with I/O](image)

### 11.17 Basic IED functions

#### 11.17.1 Parameter setting group handling SETGRPS

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

#### 11.17.1.1 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**
The **ActiveGroup** menu is located on the PCM600 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.

### 11.17.1.2 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.

### 11.18 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 **On** setting to **Off**. Press the ‘E’ key and the left arrow key.
3. Answer **YES**, press the ‘E’ key and exit the menus.
Section 12  Primary injection testing

Whenever it becomes necessary to work on primary equipment, it is essential that all the necessary switching, locking, earthing and safety procedures are observed and obeyed in a rigid and formalized manner. Operating and testing procedures should be strictly followed in order to avoid exposure to live equipment.

A test with primary current through the protected zone is usually a final check that the current circuits are correctly connected to the IED protection scheme. It is important to have an appropriate source, which is able to inject sufficient current in the primary circuit in order to distinguish between noise and real injected current. Therefore it is recommended that the injection current should be at least 10% of rated CT primary current.

12.1 Transformer Voltage Control ATCC

12.1.1 Load drop compensation function, LDC

The load drop compensation function can be tested directly with operational currents, in other words, with the power transformer in service and loaded.

When the system is carrying load there is a difference between the busbar voltage (UB) and the voltage at the load point (UL). This difference is load dependent and can be compensated by the ATCC function.

The load current is fed into the ATCC function where parameters corresponding to the line data for resistance and inductance are set. The voltage drop calculated by the LDC is proportional to the voltage drop in the system up to the load point.

In the IED, this voltage is subtracted from the measured busbar voltage (UB) and the result, corresponding to the voltage at the load point (UL) is presented to the ATCC function for the purposes of voltage regulation. This voltage will be lower (if resistive or inductive load current is applied) than the Uset voltage and ATCC increases the voltage in order to achieve the correct system voltage at the load point.

1. Confirm the PST settings for $R_{line}$ and $X_{line}$.
   If the function LDC is set to Zero, this test is omitted.
2. Open the voltage control display on the LHMI in Main Menu/Control/Commands/TransformerVoltageControl (ATCC, 90).
3. In this view, check the following settings:

3.1. Check that Control Mode is set to Manual.

3.2. Operate the tap changer so that the Load Voltage corresponds to the Voltage Set Point.

3.3. Check that neither the Raise or the Lower command are operating. Voltage Deviation should be less than 100%.

3.4. Compare the values of Bus Voltage and Load Voltage. UL can be obtained by a vector calculation where IL is the load current and values for RL and XL are the settings given in primary system ohms.

For inductive load, the Bus Voltage should be higher than the Load Voltage. If not, current circuits are incorrect and must be reversed. Incorrect current polarity may be an issue with physical wiring or the current direction convention selected for the CT analogue input as part of the setting in the PST setting.

### 12.1.2 Voltage control of Parallel Transformers

In parallel operation, each transformer protection IED must be connected to the station communication bus for data exchange. The following procedure assumes that the necessary pre-configuration in the Parameter Setting tool and the Signal Matrix tool has been performed and tested to enable data exchange between IEDs or between instances of voltage control in the same IED.

For parallel operation, it is also recommended to confirm the setting for the general parallel arrangement of transformers in **Main menu/Settings/IED Settings/Control/**
TransformerVoltageControl(ATCC,90)/TR8ATCC:x/ParCtrl. General parallel arrangement of transformers are defined by setting \(TnRXOP\) to \textit{On} or \textit{Off}. The following rules are applicable for the settings of \(T1RXOP\) – \(T8RXOP\).

- In each instance of TR8ATCC, set all \(TnRXOP\) parameters corresponding to the connected IEDs to \textit{On} except the parameter corresponding to the IED itself. For example, do not set \(T1RXOP\) to \textit{On} in IED T1 or \(T2RXOP\) to \textit{On} in IED T2.

For example, if IEDs T1, T2 and T3 are connected,
- In instance 1 of TR8ATCC, set \(T2RXOP\) and \(T3RXOP\) to \textit{On}.
- In instance 2 of TR8ATCC, set \(T1RXOP\) and \(T3RXOP\) to \textit{On}.
- In instance 3 of TR8ATCC, set \(T1RXOP\) and \(T2RXOP\) to \textit{On}.

### 12.1.3 Minimum Circulating Current (MCC) method

Voltage control of parallel transformers with the circulating current method means minimizing the circulating current at a given voltage target value. The busbar voltage (UB) is measured individually for each transformer in the parallel group by its associated TR8ATCC function. These measured values are then exchanged between the transformers, and in each TR8ATCC block, the mean value of all UB values is calculated. The resulting value UBmean is then used in each IED instead of UB for the voltage regulation.

1. Check the overcurrent blocking level (\textit{Iblock}) in \textit{Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR8ATCC:x/TCCtrl/Iblock}.
2. Check that the circulating current blocking (\textit{OperCCBlock}) is set \textit{On}, and check the correct settings for circulating current limit (\textit{CircCurLimit}) in \textit{Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR8ATCC:x/ParCtrl/CircCurrLimit}.

<table>
<thead>
<tr>
<th>TransformerVoltageControl(ATCC,90)/TR8ATCC:90/Outputs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>TOPC</td>
<td>(0)</td>
</tr>
<tr>
<td>RAISE</td>
<td>(0)</td>
</tr>
<tr>
<td>LOWER</td>
<td>(0)</td>
</tr>
<tr>
<td>BUSVOLT</td>
<td>35.428 kV</td>
</tr>
<tr>
<td>VOLTDEV</td>
<td>12.159 %</td>
</tr>
<tr>
<td>TRL3CURR</td>
<td>998.996 A</td>
</tr>
<tr>
<td>USSETOUT</td>
<td>33.000 kV</td>
</tr>
<tr>
<td>ULORD</td>
<td>33.048 kV</td>
</tr>
<tr>
<td>(P)</td>
<td>57.089 NU</td>
</tr>
<tr>
<td>(Q)</td>
<td>36.651 MVAR</td>
</tr>
<tr>
<td>IPRIM</td>
<td>300.002 A</td>
</tr>
<tr>
<td>CCAvoit</td>
<td>33.048 kV</td>
</tr>
<tr>
<td>USETPAR</td>
<td>0.000 kV</td>
</tr>
<tr>
<td>ICIRCUL</td>
<td>0.000 A</td>
</tr>
</tbody>
</table>

1. Connect all transformers in the parallel group to the same busbar on the secondary side.
2. Open the test display for Transformer Voltage Control on the LHMI in \textit{Main menu/Test/Function status/Control/TransformerVoltageControl(ATCC,90)}.
3. Manually execute Raise commands to step up the tap changer for transformer T1 to two steps above the setting for the other transformers in the parallel group.
4. Check that the value of \(IPRIM\) is below the overcurrent blocking level (\textit{Iblock})
5. Check that the value of \(ICIRCUL\) is below the circulating current limit (\textit{CircCurLimit}).
6. Set the control mode to \textit{Automatic} for all transformers.
7. For transformer T1, adjust the parameter \textit{Comp} on the local HMI in \textit{Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR8ATCC:x/ParCtrl/Comp} so that the LOWER output is activated due to circulating current.
Comp is a setting for circulating current Compensating Factor, and it is effectively a multiplier value to change the sensitivity of the voltage regulation function to measured values of circulating current. A nominal value of 200 for Comp should be appropriate to achieve sensitive voltage regulation. Smaller values may lead to a normal state where tap changers for parallel transformers are well out of step, and values significantly higher will cause over-sensitivity in the voltage control function and tap changer hunting behavior. It is an important outcome of the testing process that the compensating factor is checked for each transformer to ensure sensitive but stable operation for circulating currents.

For example, if there are three transformers connected in parallel, and the tap changer of transformer T1 is two steps over the tap changer of T2 and T3, the circulating current detected by the VCTR for T1 will be the sum (with opposite sign) of the current measured at T2 and T3. The currents measured at T2 and T3 will ideally be about the same values. If the voltage is close to the upper limit of the UDeadband, the tap changer of T1 will try to decrease the controlled voltage. In the opposite case, that is, the voltage is close to the lower limit of UDeadband, the tap changer at T1 will not try to decrease the controlled voltage. The tap changer for T2 and T3 will not operate due to the fact that the detected circulating current will be half of the current detected at T1. The setting of the parameter Comp then might need to be increased a little. At least one tap changer step difference between the different transformers should be allowed in order to avoid the tap changers to operate too often. If the allowed difference is, for example, two steps, the tap changer shall be stepped up three steps when setting the parameter Comp.

10. Set the Comp parameter for T2 and T3 in the same manner as for T1. According to the described procedure when the tap changer of one transformer is two steps above the others, it shall automatically step down. When there are only two transformers in the group either shall one step down or the other step up depending on the voltage level at the ATCC.

### 12.1.4 Master Follower (MF) method

The Master Follower method requires a Master to be nominated in a parallel group. It is responsible for measuring secondary bus voltage and executing commands to raise and lower tap changers, which are repeated by Follower transformers in the group.

1. Confirm the voltage blocking levels OVPartBK and UVPartBK in Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR8ATCC:x/Voltage/Umax,Umin.
2. Check that MFMode is set to Follow Tap or Follow Cmd in Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR8ATCC:x/MFMode.
   - If this setting is Follow Tap, all Follower transformers shall match the actual tap setting of the Master, while Follow Cmd requires that Follower transformers follow the RAISE and LOWER commands executed by the Master.
3. Confirm the maximum difference in tap positions for parallel transformers. The number of taps is determined by the setting in the Parameter Setting tool under Main menu/Settings/IED Settings/Control/TransformerVoltageControl(ATCC,90)/TR8ATCC:x/ParCtrl/MFPosDiffLim
4. Connect all transformers in the parallel group to the same busbar on both the primary and secondary sides.
5. Set the control mode to Manual for each transformer in the parallel control group
6. Open the test display for Transformer Voltage Control on the LHMI in Main menu/Test/Function status/Control/TransformerVoltageControl (ATCC, 90).
7. Manually execute Raise commands to step up the tap changer one step for all transformers in the parallel group.

8. Check that the value of `BUSVOLT` is below overvoltage blocking level `OVPartBK` and above the undervoltage blocking level `UVPartBK`.

9. Set the control mode to `Auto` for each transformer in the parallel control group. The Master in the parallel group will issue a Lower command after time delay `t1`, which will also be repeated by the Follower transformers in the group.

10. Set Transformer 2 to Master of the parallel group and T1 to Follower (in that order) and repeat steps 7 to 10. Undertake this same test by setting each Transformer in turn to Master.

11. Note that voltage regulation will be mutually blocked if no transformer is set to Master in the parallel group. To confirm this function, set T1 as Master and the other transformers in the parallel grouper set as Follower. Without allocating a new Master, set T1 to Follower and note the `Automatic` block state on the local HMI for all parallel transformers.

12. Restore T1 to Master of the parallel transformer group and ensure that control mode for each transformer is `Automatic`.

### 12.1.5 Completing the test

After the test is completed and relevant disturbance records are saved to document the test, go to **Main menu/Clear** on the local HMI and clear all LEDs, the process eventlist and disturbances from the IED.
Section 13 Checking the directionality

13.1 Overview

Before starting this process, all individual devices that are involved in the fault clearance process of the protected object must have been individually tested and must be set in operation. The circuit breaker must be ready for an open-close-open cycle.

The directional test is performed when the protected object is energized and a certain amount of load current is available. It is also necessary to know the flow of the load current (import or export, i.e. forward or reverse) by help of the indication from an external instrument (energy-meter, or SCADA information).

The design of the test procedure depends on the type of protection function to be tested. Some items that can be used as guidelines are the following.

13.2 Testing the directionality of the distance protection

The test is performed by looking at the information given by the High speed distance protection ZMFPDIS, ZMFCPDIS or the directional function ZDRDIR or ZDMRDIR whichever is used.

Procedure:

1. Make sure that all control and protection functions that belong to the object that are going to be energized have been tested and are set to be in operation
2. Make sure that the primary load current fulfills the following conditions (by using an external equipment):
   • The magnitude of the primary load current must be higher than the minimum operating current set for the directional elements in the IED. In case of default settings this means:
     • load current > 5% of base current
     • Otherwise the settings IMinOpPE and IMinOpPP for ZDRDIR or ZDMRDIR are available under the HMI menu: Main menu/Settings/IED Settings/Impedance protection/DirectionalImpedance
   • The primary load impedance must have an angle (PHI) between the setting angles for the directional lines. In case of default settings this means:
     • for forward (exported) load: -15 deg < PHI < 115 deg
     • for reverse (imported) load: 165 deg < PHI < 295 deg
   • The settings for forward load: - ArgDir < PHI < ArgNegRes and the settings for reverse load: 180 deg - ArgDir < PHI < 180 deg + ArgNegRes included in the directional functions ZDRDIR or ZDMRDIR are available under the HMI menu: Main menu/Settings/IED Settings/Impedance protection/DirectionalImpedance
3. The directionality of the load current is shown by the High speed distance protection ZMFPDIS or ZMFCPDIS under the HMI menu: Main menu/Test/Function status/Impedance protection/HighSpeedDistance or by the directional function ZDRDIR or ZDMRDIR and it is available under the HMI menu: Main menu/Test/Function status/Impedance protection/DirectionalImpedance
   • The following will be shown if the load current flows in forward (exporting) direction:
• L1Dir = Forward
• L2Dir = Forward
• L3Dir = Forward

The following will be shown if the load current flows in the reverse direction (importing):
• L1Dir = Reverse
• L2Dir = Reverse
• L3Dir = Reverse

Compare this result with the information given by the external equipment, it must be the same. If the direction of the three phases is not the same, this is a sign of incorrect connection of the voltage or current transformers serving the distance protection function. It is also possible that there is a wrong setting for the earthing point for one or more of the CTs serving distance protection (the setting name is: CTStarPoint available under the HMI menu: Main menu/Configuration/Analog modules).

If the directional function shows forward when it should show reverse (or vice-versa) for all the three phases, this probably means a wrong connection of CTs and/or VTs serving the distance protection, or it can mean a wrong setting of earthing point (the setting name is: CTStarPoint) for all the three CTs, or it could mean a wrong setting for the pre-processing blocks (3PhaseAnalogGroup under the HMI menu: Main menu/Configuration/Analog modules) connected to the CTs/VTs and serving the distance protection (verify that no wrong negation has been set; the setting name is: Negation).

If the directional function shows "No direction" for all the three phases it can mean that the load current is below the minimum operating current or that the load impedance has an angle which is outside the above given valid angles for determining forward or reverse direction.

If the directional function shows "No direction" for only some of the three phases, this probably means a wrong CTs/VTs connection.

4. The measured impedance information is available under the same menu. These values are not affected by the minimum operating current setting of ZDRDIR or ZDMRDIR and the measured values are shown any time the load current is higher than 3% of the base current:
• L1R
• L1X
• L2R
• L2X
• L3R
• L3X

The measured impedance information can still be used to determine the direction of the load. A positive resistance measured in all phases indicates a forward (exporting) resistive load (active power), while a negative sign indicates a reverse (importing) resistive load (active power). Usually it is enough to look at the resistive values to get information of the load direction, that must anyway be compared with the indication given by external equipment measuring the same power flow.
Section 14 Commissioning and maintenance of the fault clearing system

14.1 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 green-lining 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 amplitudes 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.

14.2 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 praxis 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.

14.2.1 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.

14.2.2 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 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.

14.2.2.1 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

14.2.2.2 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.

14.2.2.3 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.

14.2.2.4 Alarm test

When inserting the test handle the alarm and event signalling is normally blocked. This is done in the IED by setting the event reporting to Off 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.

14.2.2.5 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.

14.2.2.6 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.

14.2.2.7 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 earth-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 earth-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.

### 14.2.8 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 15  Troubleshooting

15.1  Checking the self supervision signals

15.1.1  Checking the self supervision function

15.1.1.1  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.

15.1.2  Self supervision HMI data

15.1.2.1  General IED status

The following table shows the general IED status signals.

Table 42:  Signals from the General menu in the diagnostics tree.

<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.</td>
</tr>
<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>
</tbody>
</table>

Table continues on next page
### 15.2 Fault tracing

#### 15.2.1 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 43.

<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--APPERROR, 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>
</tbody>
</table>

Table continues on next page
<table>
<thead>
<tr>
<th>HMI Signal Name</th>
<th>Status</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<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 IEC 61850 stack did not succeed in some actions like reading IEC 61850 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 43. Loss of time synchronization can be considered as a warning only. The IED has full functionality without time synchronization.

When settings are changed in the IED, the protection and control applications restart in order to take effect of the changes. During restart, internal events get generated and Runtime App error will be displayed. These events are only indications and will be for short duration during the restart.

**IED will not be operational during applications restart.**

### 15.2.2 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 44: 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>IOm--Error</td>
<td>Off</td>
<td>IOm--Error (reset event)</td>
</tr>
<tr>
<td>IOm--Error</td>
<td></td>
<td>IOm--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>
<tr>
<td>MIM1--Error</td>
<td>Off</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>Off</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>Off</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--SETCHGD</td>
<td></td>
<td>INT--TSYNC (set event)</td>
</tr>
<tr>
<td>DRPC--CLEARED</td>
<td></td>
<td>INT--TSYNC (set event)</td>
</tr>
<tr>
<td></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.

### 15.2.3 Diagnosing the IED status via the LHMI hint menu

In order to help the user, there is an LHMI page labeled ‘Hints’. This page is located under **Main menu/Diagnostics/IED status/Hints**. For each activated hint there is a headline. From the headline view, an explanation page can be entered, giving the user more information and hints about the particular topic.

For example, if there is a configuration to use IEC 61850 9–2 analog data, but no data arrives on the access point, then the IED will use substituted data and most protection functions will be blocked. This condition will be indicated with a sub-menu under Hints, where details about this condition are shown. The Hint menu is a way to assist the user in troubleshooting.
The Hint menu is currently only available in English. All the entries are in English, regardless of which language is selected.

The supported list of hints are as follows:

Table 45: Hint menu

<table>
<thead>
<tr>
<th>Headline</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorrect setting of SyncLostMode</td>
<td>There are two explanations possible:</td>
</tr>
<tr>
<td></td>
<td>SyncLostMode is set to Block, no time source is configured to achieve the required accuracy. Unless a high accuracy time source is selected, the function dependent on high time accuracy will be blocked.</td>
</tr>
<tr>
<td></td>
<td>SyncLostMode is set to BlockOnLostUTC, but there is no UTC capable synch source (GPS, IRIG-B) used. Unless a UTC capable time source is selected, the function dependent on high time accuracy will be blocked.</td>
</tr>
<tr>
<td>Sampled value substituted</td>
<td>&lt;Access Point&gt;&lt;Hardware Module Identifier&gt;&lt;svID&gt;</td>
</tr>
<tr>
<td></td>
<td>Where the Hardware Module Identifier is the same as given in PCM600, e.g. AP1: MU1_9201 svID: &lt;ABB_MU0101&gt;</td>
</tr>
<tr>
<td>Time diff: IED vs Sampled value</td>
<td>&lt;Access Point&gt;&lt;Hardware Module Identifier&gt;&lt;svID&gt;</td>
</tr>
<tr>
<td></td>
<td>Where the Hardware Module Identifier is the same as given in PCM600, e.g. AP1: MU1_9201 svID: &lt;ABB_MU0101&gt;</td>
</tr>
<tr>
<td>Frequency diff: IED vs Sampled value</td>
<td>&lt;Access Point&gt;&lt;Hardware Module Identifier&gt;&lt;svID&gt;</td>
</tr>
<tr>
<td></td>
<td>Where the Hardware Module Identifier is the same as given in PCM600, e.g. AP1: MU1_9201 svID: &lt;ABB_MU0101&gt;</td>
</tr>
<tr>
<td>Wrong cycle time for PMU report</td>
<td>Wrong cycle time on SMAI or 3PHSUM block connected to Phasor Report block. The SMAI or 3PHSUM block should have the same cycle time as that of Phasor Report.</td>
</tr>
<tr>
<td>PMU not connected to 3ph output</td>
<td>The PMU phasor report input(s) must be connected to the 3ph output of SMAI or 3PHSU.</td>
</tr>
<tr>
<td>Invalid value set for PMU Parameters</td>
<td>There are two explanations possible:</td>
</tr>
<tr>
<td></td>
<td>Check if the following parameters are set correctly on PMUREPORT: ReportRate or SvcClass or parameter PRIMVAL.1.FrequencySel is not set as 50Hz / 60Hz.</td>
</tr>
<tr>
<td></td>
<td>Check if the following parameters are set correctly on PMUREPORT: ReportRate or SvcClass or RptTimetag or parameter PRIMVAL.1.FrequencySel is not set as 50Hz / 60Hz.</td>
</tr>
<tr>
<td>Invalid phase angle reference</td>
<td>The selected PhaseAngleRef corresponds to an analog channel that is not configured. Please configure a valid reference channel.</td>
</tr>
<tr>
<td>GOOSE is configured on a disabled port</td>
<td>At least one of the access points configured for GOOSE is disabled. The port can be disabled either through changing the access point operation to off or by unchecking the GOOSE protocol from the access point in the Ethernet configuration in PCM600 or LHMI. Please enable GOOSE on access points: AP_FRONT, AP_1</td>
</tr>
</tbody>
</table>

Table continues on next page
<table>
<thead>
<tr>
<th>Headline</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDCM not running the application image</td>
<td>&lt;slot number&gt; is running the factory image instead of the application image. The factory image is older and does not contain the latest updates and fixes. Please reboot the IED. If the problem persists update the LDCM firmware or replace the board.</td>
</tr>
<tr>
<td>LDCM version is not accepted</td>
<td>&lt;device name&gt; firmware version &lt;version string&gt; is not accepted. The minimum accepted version is &lt;version string&gt;. Please update the LDCM firmware or replace the board.</td>
</tr>
<tr>
<td>OEM not running the application image</td>
<td>OEM in slot &lt;slot number&gt; is running the factory image instead of the application image. The factory image is older and does not contain the latest updates and fixes. Please reboot the IED. If the problem persists, update the OEM firmware or replace the board.</td>
</tr>
<tr>
<td>SFP unplugged from the slot</td>
<td>SFP has been unplugged from the slot. Please check the connection. Corresponding hardware(s) is set to fail.</td>
</tr>
<tr>
<td>SFP replaced with other type</td>
<td>Configured and the detected SFP(s) are different. Corresponding hardware(s) is set to fail. Please restart IED and consider Reconfigure HW modules to get updated hardware list.</td>
</tr>
<tr>
<td>Non ABB vendor SFP detected</td>
<td>Non ABB vendor SFP detected. Corresponding hardware(s) is set to fail. Use ABB approved SFP's.</td>
</tr>
</tbody>
</table>

## 15.2.4 Hardware re-configuration

When adding, removing or moving a hardware modules in an IED (for example, I/O modules, communication modules or time synchronization modules) a set of procedures must be followed.

### Adding a new module in to an IED

Procedure:

1. Switch the IED off and insert the new module.
2. Switch the IED on, wait for it to start, and then perform a HW reconfig.
3. Perform a license update in PCM600.

The new module is now available in PCM600 and is ready to be configured.

### Removing a module from an IED

Procedure:

1. Remove all existing configuration for the module in PCM, and write that configuration to the IED.
2. Switch the IED off and remove the HW module.
3. Switch the IED on, wait for it to start, and then perform a HW reconfig.
4. Perform a license update in PCM 600.
If any configuration that makes the module needed remains, then the HW reconfig will not remove the module. The module will still be needed. An error indication for the module will appear, if the module is physically removed from the IED and the IED is restarted with some part of the configuration still requiring the module.

Moving a module in an IED from one position to another

Procedure:
1. Remove all existing configuration for the module in PCM, and write that configuration to the IED.
2. Switch the IED off and move the HW module.
3. Switch the IED on, wait for it to start, and then perform a HW reconfig.
4. Perform a license update in PCM600.

The new module is now available in PCM600 at the new position and is ready to be configured.

15.3 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 earth.

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.

15.4 Repair support

If an IED needs to be repaired, the whole IED must be removed and sent to an ABB Logistic Center. Before returning the material, an inquiry must be sent to the ABB Logistic Center.

e-mail: offer.selog@se.abb.com

15.5 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>Full Form</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 fiber optic connector</td>
</tr>
<tr>
<td>BFP</td>
<td>Breaker failure protection</td>
</tr>
<tr>
<td>BI</td>
<td>Binary input</td>
</tr>
<tr>
<td>BIM</td>
<td>Binary input module</td>
</tr>
<tr>
<td>BOM</td>
<td>Binary output module</td>
</tr>
<tr>
<td>BOS</td>
<td>Binary outputs status</td>
</tr>
<tr>
<td>BR</td>
<td>External bistable relay</td>
</tr>
<tr>
<td>BS</td>
<td>British Standards</td>
</tr>
<tr>
<td>BSR</td>
<td>Binary signal transfer function, receiver blocks</td>
</tr>
<tr>
<td>BST</td>
<td>Binary signal transfer function, transmit blocks</td>
</tr>
<tr>
<td>C37.94</td>
<td>IEEE/ANSI protocol used when sending binary signals between IEDs</td>
</tr>
<tr>
<td>CAN</td>
<td>Controller Area Network. ISO standard (ISO 11898) for serial communication</td>
</tr>
<tr>
<td>CB</td>
<td>Circuit breaker</td>
</tr>
<tr>
<td>CBM</td>
<td>Combined backplane module</td>
</tr>
<tr>
<td>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>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>--------------</td>
<td>------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>CO cycle</td>
<td>Close-open cycle</td>
</tr>
<tr>
<td>Codirectional</td>
<td>Way of transmitting G.703 over a balanced line. Involves two twisted pairs making it possible to transmit information in both directions</td>
</tr>
<tr>
<td>COM</td>
<td>Command</td>
</tr>
<tr>
<td>COMTRADE</td>
<td>Standard Common Format for Transient Data Exchange format for Disturbance recorder according to IEEE/ANSI C37.111, 1999 / IEC 60255-24</td>
</tr>
<tr>
<td>Contra-directional</td>
<td>Way of transmitting G.703 over a balanced line. Involves four twisted pairs, two of which are used for transmitting data in both directions and two for transmitting clock signals</td>
</tr>
<tr>
<td>COT</td>
<td>Cause of transmission</td>
</tr>
<tr>
<td>CPU</td>
<td>Central processing unit</td>
</tr>
<tr>
<td>CR</td>
<td>Carrier receive</td>
</tr>
<tr>
<td>CRC</td>
<td>Cyclic redundancy check</td>
</tr>
<tr>
<td>CROB</td>
<td>Control relay output block</td>
</tr>
<tr>
<td>CS</td>
<td>Carrier send</td>
</tr>
<tr>
<td>CT</td>
<td>Current transformer</td>
</tr>
<tr>
<td>CU</td>
<td>Communication unit</td>
</tr>
<tr>
<td>CVT or CCVT</td>
<td>Capacitive voltage transformer</td>
</tr>
<tr>
<td>DAR</td>
<td>Delayed autoreclosing</td>
</tr>
<tr>
<td>DARPA</td>
<td>Defense Advanced Research Projects Agency (The US developer of the TCP/IP protocol etc.)</td>
</tr>
<tr>
<td>DBDL</td>
<td>Dead bus dead line</td>
</tr>
<tr>
<td>DBLL</td>
<td>Dead bus live line</td>
</tr>
<tr>
<td>DC</td>
<td>Direct current</td>
</tr>
<tr>
<td>DFC</td>
<td>Data flow control</td>
</tr>
<tr>
<td>DFT</td>
<td>Discrete Fourier transform</td>
</tr>
<tr>
<td>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>ECT</td>
<td>Ethernet configuration tool</td>
</tr>
<tr>
<td>EHV network</td>
<td>Extra high voltage network</td>
</tr>
<tr>
<td>EIA</td>
<td>Electronic Industries Association</td>
</tr>
<tr>
<td>EMC</td>
<td>Electromagnetic compatibility</td>
</tr>
<tr>
<td>EMF</td>
<td>Electromotive force</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</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 fiber connector</td>
</tr>
<tr>
<td>FAN</td>
<td>Fault number</td>
</tr>
<tr>
<td>FCB</td>
<td>Flow control bit; Frame count bit</td>
</tr>
<tr>
<td>FOX 20</td>
<td>Modular 20 channel telecommunication system for speech, data and protection signals</td>
</tr>
<tr>
<td>FOX 512/515</td>
<td>Access multiplexer</td>
</tr>
<tr>
<td>FOX 6Plus</td>
<td>Compact time-division multiplexer for the transmission of up to seven duplex channels of digital data over optical fibers</td>
</tr>
<tr>
<td>FPN</td>
<td>Flexible product naming</td>
</tr>
<tr>
<td>FTP</td>
<td>File Transfer Protocol</td>
</tr>
<tr>
<td>FUN</td>
<td>Function type</td>
</tr>
<tr>
<td>G.703</td>
<td>Electrical and functional description for digital lines used by local telephone companies. Can be transported over balanced and unbalanced lines</td>
</tr>
<tr>
<td>GCM</td>
<td>Communication interface module with carrier of GPS receiver module</td>
</tr>
<tr>
<td>GDE</td>
<td>Graphical display editor within PCM600</td>
</tr>
<tr>
<td>GI</td>
<td>General interrogation command</td>
</tr>
<tr>
<td>GIS</td>
<td>Gas-insulated switchgear</td>
</tr>
<tr>
<td>GOOSE</td>
<td>Generic object-oriented substation event</td>
</tr>
<tr>
<td>GPS</td>
<td>Global positioning system</td>
</tr>
<tr>
<td>GSAL</td>
<td>Generic security application</td>
</tr>
<tr>
<td>GSE</td>
<td>Generic substation event</td>
</tr>
<tr>
<td>HDLC protocol</td>
<td>High-level data link control, protocol based on the HDLC standard</td>
</tr>
<tr>
<td>HFBR connector type</td>
<td>Plastic fiber connector</td>
</tr>
<tr>
<td>HLV circuit</td>
<td>Hazardous Live Voltage according to IEC60255-27</td>
</tr>
<tr>
<td>HMI</td>
<td>Human-machine interface</td>
</tr>
<tr>
<td>HSAR</td>
<td>High speed autoreclosing</td>
</tr>
<tr>
<td>HSR</td>
<td>High-availability Seamless Redundancy</td>
</tr>
<tr>
<td>HV</td>
<td>High-voltage</td>
</tr>
<tr>
<td>HVDC</td>
<td>High-voltage direct current</td>
</tr>
<tr>
<td>IDBS</td>
<td>Integrating deadband supervision</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electrical Committee</td>
</tr>
<tr>
<td>IEC 60044-6</td>
<td>IEC Standard, Instrument transformers – Part 6: Requirements for protective current transformers for transient performance</td>
</tr>
<tr>
<td>IEC 60870-5-103</td>
<td>Communication standard for protection equipment. A serial master/slave protocol for point-to-point communication</td>
</tr>
<tr>
<td>IEC 61850</td>
<td>Substation automation communication standard</td>
</tr>
<tr>
<td>IEC 61850–8–1</td>
<td>Communication protocol standard</td>
</tr>
<tr>
<td><strong>IEEE</strong></td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td><strong>IEEE 802.12</strong></td>
<td>A network technology standard that provides 100 Mbits/s on twisted-pair or optical fiber cable</td>
</tr>
<tr>
<td><strong>IEEE P1386.1</strong></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>
<tr>
<td><strong>IEEE 1686</strong></td>
<td>Standard for Substation Intelligent Electronic Devices (IEDs) Cyber Security Capabilities</td>
</tr>
<tr>
<td><strong>IED</strong></td>
<td>Intelligent electronic device</td>
</tr>
<tr>
<td><strong>IET600</strong></td>
<td>Integrated engineering tool</td>
</tr>
<tr>
<td><strong>I-GIS</strong></td>
<td>Intelligent gas-insulated switchgear</td>
</tr>
<tr>
<td><strong>IOM</strong></td>
<td>Binary input/output module</td>
</tr>
</tbody>
</table>

**Instance**

When several occurrences of the same function are available in the IED, they are referred to as instances of that function. One instance of a function is identical to another of the same kind but has a different number in the IED user interfaces. The word “instance” is sometimes defined as an item of information that is representative of a type. In the same way an instance of a function in the IED is representative of a type of function.

**IP**

1. Internet protocol. The network layer for the TCP/IP protocol suite widely used on Ethernet networks. IP is a connectionless, best-effort packet-switching protocol. It provides packet routing, fragmentation and reassembly through the data link layer.
2. Ingression protection, according to IEC 60529

**IP 20** | Ingression protection, according to IEC 60529, level 20 |
**IP 40** | Ingression protection, according to IEC 60529, level 40 |
**IP 54** | Ingression protection, according to IEC 60529, level 54 |
**IRF** | Internal failure signal |
**IRIG-B:** | InterRange Instrumentation Group Time code format B, standard 200 |
**ITU** | International Telecommunications Union |
**LAN** | Local area network |
**LIB 520** | High-voltage software module |
**LCD** | Liquid crystal display |
**LDCM** | Line data communication module |
**LDD** | Local detection device |
**LED** | Light-emitting diode |
**LNT** | LON network tool |
**LON** | Local operating network |
**MCB** | Miniature circuit breaker |
**MCM** | Mezzanine carrier module |
**MIM** | Milli-ampere module |
**MPM** | Main processing module |
**MVAL** | Value of measurement |
**MVB** | Multifunction vehicle bus. Standardized serial bus originally developed for use in trains.
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<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>PELV circuit</td>
<td>Protected Extra-Low Voltage circuit type according to IEC60255-27</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>PRP</td>
<td>Parallel redundancy protocol</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>PTP</td>
<td>Precision time protocol</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>
</tbody>
</table>
SCL  Short circuit location
SCS  Station control system
SCADA  Supervision, control and data acquisition
SCT  System configuration tool according to standard IEC 61850
SDU  Service data unit
SELV circuit  Safety Extra-Low Voltage circuit type according to IEC60255-27
SFP  Small form-factor pluggable (abbreviation)
      Optical Ethernet port (explanation)
SLM  Serial communication module.
SMA connector  Subminiature version A, A threaded connector with constant impedance.
SMT  Signal matrix tool within PCM600
SMS  Station monitoring system
SNTP  Simple network time protocol – is used to synchronize computer clocks on local area networks. This reduces the requirement to have accurate hardware clocks in every embedded system in a network. Each embedded node can instead synchronize with a remote clock, providing the required accuracy.
SOF  Status of fault
SPA  Strömberg Protection Acquisition (SPA), a serial master/slave protocol for point-to-point and ring communication.
SRY  Switch for CB ready condition
ST  Switch or push button to trip
Starpoint  Neutral point of transformer or generator
SVC  Static VAr compensation
TC  Trip coil
TCS  Trip circuit supervision
TCP  Transmission control protocol. The most common transport layer protocol used on Ethernet and the Internet.
TCP/IP  Transmission control protocol over Internet Protocol. The de facto standard Ethernet protocols incorporated into 4.2BSD Unix. TCP/IP was developed by DARPA for Internet working and encompasses both network layer and transport layer protocols. While TCP and IP specify two protocols at specific protocol layers, TCP/IP is often used to refer to the entire US Department of Defense protocol suite based upon these, including Telnet, FTP, UDP and RDP.
TEF  Time delayed earth-fault protection function
TLS  Transport Layer Security
TM  Transmit (disturbance data)
TNC connector  Threaded Neill-Concelman, a threaded constant impedance version of a BNC connector
TP  Trip (recorded fault)
TPZ, TPY, TPX, TPS  Current transformer class according to IEC
**TRM** Transformer Module. This module transforms currents and voltages taken from the process into levels suitable for further signal processing.

**TYP** Type identification

**UMT** User management tool

**Underreach** A term used to describe how the relay behaves during a fault condition. For example, a distance relay is underreaching when the impedance presented to it is greater than the apparent impedance to the fault applied to the balance point, that is, the set reach. The relay does not “see” the fault but perhaps it should have seen it. See also Overreach.

**UTC** Coordinated Universal Time. A coordinated time scale, maintained by the Bureau International des Poids et Mesures (BIPM), which forms the basis of a coordinated dissemination of standard frequencies and time signals. UTC is derived from International Atomic Time (TAI) by the addition of a whole number of “leap seconds” to synchronize it with Universal Time 1 (UT1), thus allowing for the eccentricity of the Earth's orbit, the rotational axis tilt (23.5 degrees), but still showing the Earth’s irregular rotation, on which UT1 is based. The Coordinated Universal Time is expressed using a 24-hour clock, and uses the Gregorian calendar. It is used for aeroplane and ship navigation, where it is also sometimes known by the military name, “Zulu time.” “Zulu” in the phonetic alphabet stands for “Z”, which stands for longitude zero.

**UV** Undervoltage

**WEI** Weak end infeed logic

**VT** Voltage transformer

**X.21** A digital signalling interface primarily used for telecom equipment

**3I₀** Three times zero-sequence current. Often referred to as the residual or the earth-fault current

**3U₀** Three times the zero sequence voltage. Often referred to as the residual voltage or the neutral point voltage