RELION® 650 SERIES
Bay control REC650
Version 2.1
Commissioning manual
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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 station which is not in service. The chapters are organized in the chronological order in which the IED should be commissioned. The relevant procedures may be followed also during the service and maintenance activities.

1.2  Intended audience

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

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

1.3.1 Product documentation set

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

The engineering manual contains instructions on how to engineer the IEDs using the various tools available within the PCM600 software. The manual provides instructions on how to set up a PCM600 project and insert IEDs to the project structure. The manual also recommends a sequence for the engineering of protection and control functions, LHMI functions as well as communication engineering for IEC 60870-5-103, IEC 61850, DNP3, LON and SPA.

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

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

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

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

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

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

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

### 1.3.2 Document revision history

<table>
<thead>
<tr>
<th>Document revision/date</th>
<th>History</th>
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<tbody>
<tr>
<td>January 2016</td>
<td>First Release</td>
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<tr>
<td>March 2019</td>
<td>Maintenance Release</td>
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### 1.3.3 Related documents

<table>
<thead>
<tr>
<th>Documents related to REC650</th>
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<tbody>
<tr>
<td>Application manual</td>
<td>1MRK 511 384-UEN</td>
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<tr>
<td>Commissioning manual</td>
<td>1MRK 511 386-UEN</td>
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<tr>
<td>Product guide</td>
<td>1MRK 511 387-BEN</td>
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<td>Technical manual</td>
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<thead>
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<th>650 series manuals</th>
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<tr>
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<td>1MRK 500 125-UEN</td>
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<td>1MRK 511 377-UEN</td>
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1.4 Document symbols and conventions

1.4.1 Symbols

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

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

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

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

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

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.
### Document conventions

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

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

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<thead>
<tr>
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</table>
Section 2  Safety information

2.1 Symbols on the product

All warnings must be observed.

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

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, station 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

### 3.1 Back-up protection functions

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<th>ANSI</th>
<th>Function description</th>
<th>Bay Control</th>
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<tbody>
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<td>PHPIOC</td>
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<td>Instantaneous phase overcurrent protection</td>
<td>REC650 (A02)</td>
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<td>OC4PTOC</td>
<td>51_67(^1)</td>
<td>Four step phase overcurrent protection</td>
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<td>50N</td>
<td>Instantaneous residual overcurrent protection</td>
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<td>Four step residual overcurrent protection</td>
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<td>67N(^2)</td>
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1) 67 requires voltage  
2) 67N requires voltage

### 3.2 Control and monitoring functions

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<td>AutomationBits, command function for DNP3.0</td>
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<tr>
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<td>SINGLECMD</td>
<td>Single command, 16 signals</td>
<td>4</td>
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<td></td>
<td>I103CMD</td>
<td>Function commands for IEC 60870-5-103</td>
<td>1</td>
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<tr>
<td></td>
<td>I103GENCMD</td>
<td>Function commands generic for IEC 60870-5-103</td>
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<td></td>
<td>I103POS CMD</td>
<td>IED commands with position and select for IEC 60870-5-103</td>
<td>50</td>
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<td></td>
<td>I103POS CMDV</td>
<td>IED direct commands with position for IEC 60870-5-503</td>
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<td>I103IEDCMD</td>
<td>IED commands for IEC 60870-5-103</td>
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<td></td>
<td>I103USRCMD</td>
<td>Function commands user defined for IEC 60870-5-103</td>
<td>4</td>
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<td>CCSSPVC</td>
<td>Current circuit supervision</td>
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<td></td>
<td>FUFS PVC</td>
<td>Fuse failure supervision</td>
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<tr>
<td></td>
<td>TMAGAPC</td>
<td>Trip matrix logic</td>
<td>12</td>
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<tr>
<td></td>
<td>ALMCALH</td>
<td>Logic for group alarm</td>
<td>5</td>
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<tr>
<td></td>
<td>WRNCALH</td>
<td>Logic for group warning</td>
<td>5</td>
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<td></td>
<td>INDICALH</td>
<td>Logic for group indication</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>AND, GATE, INV, LLD, OR, PULSETIMER, RSMEMORY, SRMEMORY, TIMERSET, XOR</td>
<td>Basic configurable logic blocks (see Table 2)</td>
<td>40–420</td>
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<tr>
<td></td>
<td>ANDQT, INDCOMBPQT, INDEXTSPQT, INVALIDQT, INVERTERQT, ORQT, PULSETIMERQT, RSMEMORYQT, SRMEMORYQT, TIMERSETQT, XORQT</td>
<td>Configurable logic blocks Q/T (see Table 3)</td>
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<td>FXDSIGN</td>
<td>Fixed signal function block</td>
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<td></td>
<td>B16I</td>
<td>Boolean 16 to Integer conversion</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>BTIGAPC</td>
<td>Boolean 16 to Integer conversion with Logic Node representation</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>IB16</td>
<td>Integer to Boolean 16 conversion</td>
<td>18</td>
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<tr>
<td></td>
<td>ITBGAPC</td>
<td>Integer to Boolean 16 conversion with Logic Node representation</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>TEIGAPC</td>
<td>Elapsed time integrator with limit transgression and overflow supervision</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>INTCOMP</td>
<td>Comparator for integer inputs</td>
<td>12</td>
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<tr>
<td></td>
<td>REALCOMP</td>
<td>Comparator for real inputs</td>
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Table continues on next page
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<thead>
<tr>
<th>IEC 61850</th>
<th>ANSI</th>
<th>Function description</th>
<th>Bay control</th>
</tr>
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<tbody>
<tr>
<td>Monitoring</td>
<td></td>
<td></td>
<td>REC650 (A02)</td>
</tr>
<tr>
<td>CVMMXN, VMMXU, CMSQI, VMSQI, VNMMXU</td>
<td>Measurements</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>CMMXU</td>
<td>Measurements</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>AISVBAS</td>
<td>Function block for service value presentation of secondary analog inputs</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>SSIMG</td>
<td>Gas medium supervision</td>
<td>21</td>
<td></td>
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<tr>
<td>SSIML</td>
<td>Liquid medium supervision</td>
<td>3</td>
<td></td>
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<tr>
<td>SSCBR</td>
<td>Circuit breaker condition monitoring</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>EVENT</td>
<td>Event function</td>
<td>20</td>
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<tr>
<td>DRPRDRE, A1RADR-A4RADR, B1RBDR-B8RBDR</td>
<td>Disturbance report</td>
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<tr>
<td>B9RBDR-B22RBDR</td>
<td>Disturbance report</td>
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<tr>
<td>SPGAPC</td>
<td>Generic communication function for Single Point indication</td>
<td>64</td>
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<tr>
<td>SP16GAPC</td>
<td>Generic communication function for Single Point indication 16 inputs</td>
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<tr>
<td>MVGAPC</td>
<td>Generic communication function for Measured Value</td>
<td>24</td>
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<td>BINSTATREP</td>
<td>Logical signal status report</td>
<td>3</td>
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<tr>
<td>RANGE_XP</td>
<td>Measured value expander block</td>
<td>66</td>
<td></td>
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<tr>
<td>LMBRFLO</td>
<td>Fault locator</td>
<td>1</td>
<td></td>
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<tr>
<td>I103MEAS</td>
<td>Measurands for IEC 60870-5-103</td>
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<tr>
<td>I103MEASUSR</td>
<td>Measurands user defined signals for IEC 60870-5-103</td>
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<tr>
<td>I103AR</td>
<td>Function status auto-recloser for IEC 60870-5-103</td>
<td>1</td>
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<tr>
<td>I103EF</td>
<td>Function status earth-fault for IEC 60870-5-103</td>
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<td></td>
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<tr>
<td>I103FLTPROT</td>
<td>Function status fault protection for IEC 60870-5-103</td>
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<td>I103IED</td>
<td>IED status for IEC 60870-5-103</td>
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<tr>
<td>I103SUPERV</td>
<td>Supervision status for IEC 60870-5-103</td>
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<tr>
<td>I103USRDEF</td>
<td>Status for user defined signals for IEC 60870-5-103</td>
<td>20</td>
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<tr>
<td>L4UFCNT</td>
<td>Event counter with limit supervision</td>
<td>30</td>
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<tr>
<td>TEILGAPC</td>
<td>Running hour-meter</td>
<td>6</td>
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</tr>
</tbody>
</table>

| Metering | | | |
| PCFCNT | Pulse-counter logic | 16 |
| ETPMMTR | Function for energy calculation and demand handling | 6 |

Table 2: Total number of instances for basic configurable logic blocks

<table>
<thead>
<tr>
<th>Basic configurable logic block</th>
<th>Total number of instances</th>
</tr>
</thead>
<tbody>
<tr>
<td>AND</td>
<td>280</td>
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<tr>
<td>GATE</td>
<td>40</td>
</tr>
<tr>
<td>INV</td>
<td>420</td>
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<tr>
<td>LLD</td>
<td>40</td>
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<td>OR</td>
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### Basic configurable logic block

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<tr>
<th>Logic Block</th>
<th>Total number of instances</th>
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<td>RSMEMORY</td>
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<tr>
<td>SRMEMORY</td>
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<tr>
<td>TIMERSET</td>
<td>60</td>
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<tr>
<td>XOR</td>
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**Table 3: Total number of instances for configurable logic blocks Q/T**

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<th>Configurable logic blocks Q/T</th>
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<td>ANDQ</td>
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<tr>
<td>INDCOMBSQQT</td>
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<tr>
<td>INDEXTSQQT</td>
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<tr>
<td>INVALIDQ</td>
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<tr>
<td>INVERTERQ</td>
<td>120</td>
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<tr>
<td>ORQ</td>
<td>120</td>
</tr>
<tr>
<td>PULSETIMERSQQT</td>
<td>40</td>
</tr>
<tr>
<td>RSMEMORIESQQT</td>
<td>40</td>
</tr>
<tr>
<td>SRMEMORIESQQT</td>
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</tr>
<tr>
<td>TIMERSETQ</td>
<td>40</td>
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<tr>
<td>XORQ</td>
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### 3.3 Communication

<table>
<thead>
<tr>
<th>IEC 61850</th>
<th>ANSI</th>
<th>Function description</th>
<th>Bay control</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>REC650 (A02)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Station communication</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>LONSPA, SPA</td>
<td></td>
<td>SPA communication protocol</td>
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<tr>
<td>ADE</td>
<td></td>
<td>LON communication protocol</td>
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</tr>
<tr>
<td>HORZCOMM</td>
<td></td>
<td>Network variables via LON</td>
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<td>PROTOCOL</td>
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<td>Operation selection between SPA and IEC 60870-5-103 for SLM</td>
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<tr>
<td>RS485PROT</td>
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<td>Operation selection for RS485</td>
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</tr>
<tr>
<td>RS485GEN</td>
<td></td>
<td>RS485</td>
<td>1</td>
</tr>
<tr>
<td>DNPGEN</td>
<td></td>
<td>DNP3.0 communication general protocol</td>
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<tr>
<td>DNPGENTCP</td>
<td></td>
<td>DNP3.0 communication general TCP protocol</td>
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<td>CHSERRS485</td>
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<td>DNP3.0 for EIA-485 communication protocol</td>
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<tr>
<td>CH1TCP, CH2TCP, CH3TCP, CH4TCP</td>
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<td>DNP3.0 for TCP/IP communication protocol</td>
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<td>CHSEROPT</td>
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<td>DNP3.0 for TCP/IP and EIA-485 communication protocol</td>
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<td>MSTSER</td>
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<td>DNP3.0 for serial communication protocol</td>
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<tr>
<td>MST1TCP, MST2TCP, MST3TCP, MST4TCP</td>
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<td>DNP3.0 for TCP/IP communication protocol</td>
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<tr>
<td>DNPFREC</td>
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<td>DNP3.0 fault records for TCP/IP and EIA-485 communication protocol</td>
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### 3.4 Basic IED functions

#### Table 4: Basic IED functions

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<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>
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<tr>
<td>SELF SUPEVLST</td>
<td>Self supervision with internal event list</td>
</tr>
<tr>
<td>TIMESYNCHGEN</td>
<td>Time synchronization module</td>
</tr>
<tr>
<td>BININPUT, SYNCHCAN, SYNHGPS, SYNCHCMPPS, SYNCHLON, SYNCHPPH, SYNCHPPS, SNTP, SYNCHSPA, SYNCHCMPPS</td>
<td>Time synchronization</td>
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<table>
<thead>
<tr>
<th>IEC 61850 or function name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIMEZONE</td>
<td>Time synchronization</td>
</tr>
<tr>
<td>DSTBEGIN, DSTENABLE, DSTEND</td>
<td>GPS time synchronization module</td>
</tr>
<tr>
<td>IRIG-B</td>
<td>Time synchronization</td>
</tr>
<tr>
<td>SETGRPS</td>
<td>Number of setting groups</td>
</tr>
<tr>
<td>ACTVGRP</td>
<td>Parameter setting groups</td>
</tr>
<tr>
<td>TESTMODE</td>
<td>Test mode functionality</td>
</tr>
<tr>
<td>CHNGLCK</td>
<td>Change lock function</td>
</tr>
<tr>
<td>SMBI</td>
<td>Signal matrix for binary inputs</td>
</tr>
<tr>
<td>SMBO</td>
<td>Signal matrix for binary outputs</td>
</tr>
<tr>
<td>SMAI1 - SMAI12</td>
<td>Signal matrix for analog inputs</td>
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<tr>
<td>3PHSUM</td>
<td>Summation block 3 phase</td>
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<tr>
<td>ATHSTAT</td>
<td>Authority status</td>
</tr>
<tr>
<td>ATHCHCK</td>
<td>Authority check</td>
</tr>
<tr>
<td>AUTHMAN</td>
<td>Authority management</td>
</tr>
<tr>
<td>FTPACCS</td>
<td>FTP access with password</td>
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<tr>
<td>SPACOMMMAP</td>
<td>SPA communication mapping</td>
</tr>
<tr>
<td>SPATD</td>
<td>Date and time via SPA protocol</td>
</tr>
<tr>
<td>DOSFRNT</td>
<td>Denial of service, frame rate control for front port</td>
</tr>
<tr>
<td>DOSLANAB</td>
<td>Denial of service, frame rate control for OEM port AB</td>
</tr>
<tr>
<td>DOSLANCD</td>
<td>Denial of service, frame rate control for OEM port CD</td>
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<tr>
<td>DOSSCKT</td>
<td>Denial of service, socket flow control</td>
</tr>
<tr>
<td>GBAVAL</td>
<td>Global base values for settings</td>
</tr>
<tr>
<td>PRIMVAL</td>
<td>Primary system values</td>
</tr>
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<td>ALTMS</td>
<td>Time master supervision</td>
</tr>
<tr>
<td>ALTIM</td>
<td>Time management</td>
</tr>
<tr>
<td>MSTSER</td>
<td>DNP3.0 for serial communication protocol</td>
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Table 5: Local HMI functions

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<thead>
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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>
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<tr>
<td>LANGUAGE</td>
<td></td>
<td>Local human machine language</td>
</tr>
<tr>
<td>SCREEN</td>
<td></td>
<td>Local HMI Local human machine screen behavior</td>
</tr>
<tr>
<td>FNKEYTY1–FNKEYTY5 FNKEYMD1– FNKEYMD5</td>
<td></td>
<td>Parameter setting function for HMI in PCM600</td>
</tr>
<tr>
<td>LEDGEN</td>
<td></td>
<td>General LED indication part for LHMI</td>
</tr>
<tr>
<td>OPENCLOSE_LED</td>
<td></td>
<td>LHMI LEDs for open and close keys</td>
</tr>
<tr>
<td>GRP1_LED1–GRP1_LED15</td>
<td></td>
<td>Basic part for CP HW LED indication module</td>
</tr>
<tr>
<td>GRP2_LED1–GRP2_LED15</td>
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<td></td>
</tr>
<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.
Figure 2: Typical IED start-up sequence

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

If the upper row in the window indicates ‘Fail’ instead of ‘Ready’ and the green LED flashes, an internal failure in the IED has been detected.

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 station or to the NCC.

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

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

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

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

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

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

The communication procedures are the same in both cases.

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

Setting up IP addresses

The IP address and the corresponding communication subnetwork mask must be set via the LHMI for each available Ethernet interface in the IED. Each Ethernet interface has a default factory IP address when the IED is delivered. The IP address and the subnetwork mask might have to be reset when an additional Ethernet interface is installed or an interface is replaced.
• The default IP address for the IED front port is 10.1.150.3 and the corresponding subnetwork mask is 255.255.255.0, which can be set via the local HMI path **Main menu/Configuration/Communication/Ethernet configuration/Front:1**.

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

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.

![Diagram](image.png)

**Figure 3: Point-to-point link between IED and PCM600**

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

Administrator rights are required to change the PC communication setup. It is automatically detected that Tx signals from the IED are received on the Tx pin on the PC. Thus, a straight (standard) Ethernet cable can be used.

1. Select **Search programs and files** in the **Start menu** in Windows.
Figure 4: Select: Search programs and files

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

4. Select the TCP/IPv4 protocol from the list of configured components using this connection and click Properties.
5. Select **Use the following IP address** and define **IP address** and **Subnet mask** if the front port is used and if the **IP address** is not set to be obtained automatically by the IED, see Figure 8. The IP address must be different from the IP address chosen for the IED.

![Figure 7: Select the TCP/IPV4 protocol and open Properties](image1)

**Figure 7: Select the TCP/IPV4 protocol and open Properties**

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 a 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>
<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>CTPrimn</td>
<td>from 0 to 99999</td>
<td>3000</td>
</tr>
</tbody>
</table>

This parameter defines the primary rated current of the CT. For two 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/IEC port, the SPA/IEC port has to be set either for SPA or IEC use.

6.1.1  Entering SPA settings

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

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

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

Procedure

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

2. Set the slave number and baud rate for the rear SPA port
   The slave number and baud rate can be found on the local HMI under Main menu/Configuration/Communication/Station communication/SPA/SPA:1
   Set the same slave number and baud rate as set in the SMS system for the IED.

6.1.2  Entering IEC settings

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

Two types of interfaces can be used:

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

Procedure

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

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

Set the same slave number and baud rate as set in the IEC master system for the IED.

6.2 Verifying the communication

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

6.2.1 Verifying SPA communication

Procedure

1. Use a SPA-emulator and send “RF” to the IED. The answer from the IED should be the type and version of it, for example, “REL650 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 Fibre optic loop

The SPA communication is mainly used for SMS. It can include different numerical IEDs with remote communication possibilities. The fibre optic loop can contain < 20-30 IEDs depending on requirements on response time. Connection to a personal computer (PC) can be made directly (if the PC is located in the station) or by telephone modem through a telephone network with ITU (CCITT) characteristics.
Table 7: Max distances between IEDs/nodes

<table>
<thead>
<tr>
<th>Material</th>
<th>Distance</th>
<th>According to Optical Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>glass</td>
<td>&lt; 1000 m</td>
<td></td>
</tr>
<tr>
<td>plastic</td>
<td>&lt; 25 m (inside cubicle)</td>
<td></td>
</tr>
</tbody>
</table>

6.4 Optical budget calculation for serial communication with SPA/IEC

Table 8: Example

<table>
<thead>
<tr>
<th>Distance</th>
<th>Glass</th>
<th>Plastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 km</td>
<td>-11 dB</td>
<td>-7 dB</td>
</tr>
<tr>
<td>4 dB/km</td>
<td>4 dB</td>
<td>-</td>
</tr>
<tr>
<td>0.16 dB/m</td>
<td>-</td>
<td>4 dB</td>
</tr>
<tr>
<td>5 dB</td>
<td>1 dB</td>
<td>-</td>
</tr>
<tr>
<td>1 dB</td>
<td>-</td>
<td>2 dB</td>
</tr>
<tr>
<td>11 dB</td>
<td>7 dB</td>
<td></td>
</tr>
</tbody>
</table>

Maximum total attenuation
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 station 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.

![Diagram of LON communication structure](IEC05000663-1-en.vsd)

*Figure 9: Example of LON communication structure for a station automation system*

An optical network can be used within the station automation system. This enables communication with the IEDs through the LON bus from the operator's workplace, from the control center and also from other IEDs via bay-to-bay horizontal communication.

The fibre optic LON bus is implemented using either glass core or plastic core fibre optic cables.

<table>
<thead>
<tr>
<th>Table 9: Specification of the fibre optic connectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable connector</td>
</tr>
<tr>
<td>Cable diameter</td>
</tr>
<tr>
<td>Max. cable length</td>
</tr>
</tbody>
</table>

Table continues on next page
### 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.

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Glass fibre</th>
<th>Plastic fibre</th>
</tr>
</thead>
<tbody>
<tr>
<td></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>

### 7.1.3 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 setting parameters for the LON communication are set via the local HMI. Refer to the technical manual for setting parameters specifications.

The path to LON settings in the local HMI is `Main menu/Configuration/Communication/SLM configuration/Rear optical LON port`
If the LON communication from the IED stops, caused by setting of illegal communication parameters (outside the setting range) or by another disturbance, it is possible to reset the LON port of the IED.

Path in the local HMI under **Main menu/Configuration/Communication/SLM configuration/Rear optical LON port**

These parameters can only be set with the LON Network Tool (LNT).

**Table 10: Setting parameters for the LON communication**

<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 - 255</td>
<td>0</td>
<td>-</td>
<td>Domain identification number</td>
</tr>
<tr>
<td>SubnetID*</td>
<td>0 - 255, Step: 1</td>
<td>0</td>
<td>-</td>
<td>Subnet identification number</td>
</tr>
<tr>
<td>NodeID*</td>
<td>0 - 127, Step: 1</td>
<td>0</td>
<td>-</td>
<td>Node identification number</td>
</tr>
</tbody>
</table>

*Can be viewed in the local HMI

Path in the local HMI under **Main menu/Configuration/Communication/SLM configuration/Rear optical LON port**

These parameters can only be set with the LON Network Tool (LNT).

**Table 11: LON node information 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 in the local HMI

Path in the local HMI under **Main menu/Configuration/Communication/SLM configuration/Rear optical LON port**

**Table 12: ADE Non group settings (basic)**

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

Path in the local HMI under **Main menu/Configuration/Communication/SLM configuration/Rear optical LON port**

**Table 13: LON commands**

<table>
<thead>
<tr>
<th>Command</th>
<th>Command description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ServicePinMsg</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 14: 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 - 1mm</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 (1dB/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 OEM ports are used for:

- station bus (IEC 61850-8-1) communication.

For IEC 61850-8-1 redundant communication, both rear OEM ports are utilized.

8.2 Setting the station communication

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

To enable IEC 61850 station communication:

1. Enable IEC 61850-8-1 (station bus) communication for port AB.
   1.1. Set values for the rear ports AB.
       Navigate to: Main menu/Configuration/Communication/Ethernet configuration/ LANAB:1
       Set values for Mode, IPAddress and IPMask. Mode must be set to Normal. Check that the correct IP address is assigned to the port.
   1.2. Enable IEC 61850-8-1 communication.
       Navigate to: Main menu/Configuration/Communication/Station communication/ IEC61850-8-1/IEC61850–8–1:1
       Set Operation to On, PortSelGOOSE and PortSelMMS to the port used (for example LANAB).

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

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 both port AB and CD. Browse in the local HMI to **Main menu/Diagnostics/Communication/Redundant PRP** and check that both signals LAN-A-STATUS and LAN-B-STATUS are shown as *Ok*. Remove the optical connection to one of the ports AB or CD. Verify that either signal LAN-A-STATUS or LAN-B-STATUS (depending on which connection that was removed) are shown as *Error* and the that other signal is shown as *Ok*. Be sure to re-connect the removed connection after completed verification.
Section 9  Testing IED operation

9.1  Preparing for test

9.1.1  Requirements

IED test requirements:

- Calculated settings
- Application configuration diagram
- Signal matrix (SMT) configuration
- Terminal connection diagram
- Technical manual
- Three-phase test equipment
- 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.

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

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

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

9.1.2 Preparing the IED to verify settings

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

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

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

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

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

For information about the functions to test, for example signal or parameter names, see the technical manual. The correct initiation of the disturbance recorder is made on 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.

9.2 Activating the test mode

Put the IED into the test mode before testing. The test mode blocks all protection functions and some of the control functions in the IED, and the individual functions to be tested can be unblocked to prevent unwanted operation caused by other functions. In this way, it is possible to test slower back-up measuring functions without the interference from faster measuring functions. The test switch should then be connected to the IED. Test mode is indicated when the yellow StartLED flashes.

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

9.3 Preparing the connection to the test equipment

The IED can be equipped with a test switch of type RTXP8, RTXP18 or RTXP24. 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.
9.4 Connecting the test equipment to the IED

Connect the test equipment according to the IED specific connection diagram and the needed input and output signals for the function under test. An example of a connection is shown in figure 10.

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.

![Diagram showing connection example of test equipment to IED](IEC09000652-1-en.vsd)

**Figure 10:** Connection example of the test equipment to the IED when test equipment is connected to the transformer input module

9.5 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.

### 9.6 Verifying analog primary and secondary measurement

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

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**

### 9.7 Testing the protection functionality

Each protection function must be tested individually by secondary injection.

- Verify operating levels (trip) and timers.
- Verify alarm and blocking signals.
- Use the disturbance handling tool in PCM600 to evaluate that the protection function has received the correct data and responded correctly (signaling and timing).
- Use the event viewer tool in PCM600 to check that only expected events have occurred.
9.8 Forcing of binary input/output signals for testing

9.8.1 Forcing concept

Forcing of binary inputs and outputs is a convenient way to test wiring in stations 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) 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.

9.8.2 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.

9.8.2.1 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.

9.8.2.2 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.

### 9.8.3 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.

#### 9.8.3.1 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 11.
  2. Press the Enter key to edit the value.

![Figure 11: Value line of the desired signal](image)

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 12

![Example of LHMI menu using BIM3](image)

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.

9.8.3.2 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*.

![Read Latest Values from IED](IEC15000023-1-en)

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

![IEC15000024-1-en](IEC15000024-1-en)

The Signal Monitoring menu changes and indicates the forcing values that can be edited.

<table>
<thead>
<tr>
<th>Index</th>
<th>Module Name</th>
<th>Module Type</th>
<th>Channel Name</th>
<th>Channel Type</th>
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<th>Signal Value</th>
<th>Signal Unit</th>
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</table>

5. Select and edit the values.
6. Click *Acknowledge and send*.

![IEC15000026-1-en](IEC15000026-1-en)

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.

![IEC15000032-1-en](IEC15000032-1-en)
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.

### 9.8.4 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.

![Warning symbol]

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.

#### 9.8.4.1 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.

#### 9.8.4.2 Undo forcing by using LHMI

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

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

#### 9.8.4.3 Undo forcing by using PCM600

1. Uncheck *Forcing Session* under the menu *IED*.

![ PCM600 menu screenshot with forcing session deselected ]

2. Click *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 10  Testing functionality by secondary injection

10.1 Testing disturbance report

10.1.1 Introduction

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

- Disturbance recorder
- Event list
- Event recorder
- Fault locator
- 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.

10.1.2 Disturbance report settings

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

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

10.1.3 Disturbance recorder (DR)

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

The Manual Trig can be started in two ways:

1. From the local HMI under Main menu/Disturbance records.
   1.1. Enter on the row at the bottom of the HMI called Manual trig. A new recording begins. The view is updated if you leave the menu and return.
   1.2. Navigate to General information or to Trip values to obtain more detailed information.

2. Open the Disturbance handling tool for the IED in the plant structure in PCM600.
   2.1. Right-click and select Execute manual Trig in the window Available recordings in IED.
   2.2. Read the required recordings from the IED.
   2.3. Refresh the window Recordings and select a recording.
   2.4. Right-click and select Create Report or Open With to export the recordings to any disturbance analyzing tool that can handle Comtrade formatted files.
Evaluation of the results from the disturbance recording function requires access to a PC either permanently connected to the IED or temporarily connected to the Ethernet port (RJ-45) on the front. The PCM600 software package must be installed in the PC.

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

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

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

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

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

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

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

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

The internal FIFO register of all events will appear when the event viewer is launched.

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

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

10.2 Identifying the function to test in the technical reference manual

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

10.3 Differential protection

10.3.1 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.
10.3.1.1 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.

10.3.1.2 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.

10.4 Current protection

10.4.1 Instantaneous phase overcurrent protection 3-phase output PHPIOC

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

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.

### 10.4.1.1 Measuring the operate limit of set values

1. Inject a phase current into the IED with an initial value below that of the setting.
2. Set the operation mode to 1 out of 3.
3. Increase the injected current in the Ln phase until the TRL (n=1–3) signal appears.
4. Switch the fault current off.

   ![Information icon] 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. Check - no operation.

### 10.4.1.2 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.

### 10.4.2 Four step phase overcurrent protection 3-phase output OC4PTOC

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

#### 10.4.2.1 Verifying the settings

Verification of the non-directional phase overcurrent function is done as instructed below, 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 for operation is chosen: Connect the injection current to phases L1 and neutral.
   If 2 out of 3 currents for operation is chosen: Connect the injection current into phase L1 and out from phase L2.
   If 3 out of 3 currents for operation is chosen: 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 slightly 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 for operation is chosen: The voltage angle of phase L1 is the reference. If 2 out of 3 currents for operation is chosen: The voltage angle of phase L1 – the voltage angle of L2 is the reference. If 3 out of 3 currents for operation is chosen: 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 matrices).

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 for operation is chosen: 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.

10.4.2.2 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.

10.4.3 Instantaneous residual overcurrent protection EFPIOC

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

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.

10.4.3.1 Measuring the operate limit of set values
1. Inject a phase current into the IED with an initial value below that of the setting.
2. Increase the injected current in the Ln or in the neutral (summated current input) phase until the TRIP signal appears.
3. Switch the fault current off.
   Observe to not exceed the maximum permitted overloading of the current circuits in the IED.
4. Compare the measured operating current with the set value.

10.4.3.2 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.

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

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

10.4.4.1 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 (default 5% of Ur) and set the injection current to lag the voltage by an angle equal to the set reference characteristic angle (AngleRCA), if the forward directional function is selected.
   If reverse directional function is selected, set the injection current to lag the polarizing voltage by an angle equal to RCA+ 180°.
3. Increase the injected current and note the value at which the studied step of the function operates.
4. Decrease the current slowly and note the reset value.
5. If the test has been performed by injection of current in phase 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 txMin.
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.

10.4.4.2 Four step non-directional earth fault protection

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

10.4.4.3 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.

10.4.5 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 txmin.

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.
10.4.5.1 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.

10.4.6 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 13: 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

10.4.6.1 Measuring the operate and time limit for set values

Operation mode 3i₀ · cosϕ

Procedure

1. Set the polarizing voltage to 1.2 · 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. \(\phi' = RCADir\cdot\phi\). 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 14 and Figure 15.

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

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

(Equation 1)

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.

\(RCADir = 0^\circ\)

Operate area

\(-3U_0 = U_{ref}\)

\(3I_0 \cdot \cos\phi\)

Figure 14: Characteristic with \(ROADir\) restriction
1. Set the polarizing voltage to 1.2·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 φ' is the phase angle between injected voltage (3U0) and current (3I0) i.e. φ' = RCADir·φ. Change φ' to for example 45 degrees. Increase the injected current until the function operates.
4. Compare the result with the set value and make sure that the new injected 3I0·3U0·cos φ is equal to the setting SN>. Take the set characteristic into consideration, see figure 14 and figure 15.
5. Measure the operate time of the timer by injecting 1.2·UNrel> and a current to get two times the set SN> operate value.

\[ T_{inv} = kSN \cdot Sref / 3I_{test} \cdot 3U_{test} \cdot \cos (\phi) \]

(Equation 2)

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 16 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 3)

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.

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. 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.

10.4.6.2 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.

10.4.7 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.

10.4.7.1 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(PTTR,26)/LFPTTR:x, Main menu/Reset/Reset temperature/ThermalOverload1TimeConst(PTTR,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(PTTR,26)/LFPTTR:x/TEMP, Main menu/Test/Function status/Current protection/ThermOverLoad1TimeConst(PTTR,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.

### 10.4.7.2 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.

### 10.4.8 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.

#### 10.4.8.1 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 (\(\text{Tau}_1\)) and Time Constant 2 (\(\text{Tau}_2\)) temporarily to 1 minute.
3. Set the three-phase injection currents slightly lower than the set operate value of stage \(i_{\text{Base1}}\), increase the current in phase L1 until stage \(i_{\text{Base1}}\) 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 \(i_{\text{Base1}}\) for phases L2 and L3.
5. Activate the cooling input signal, thus switching to base current \(i_{\text{Base2}}\).
6. Check the operate and reset values (for all three phases) for \(i_{\text{Base2}}\) in the same way as described above for stage \(i_{\text{Base1}}\).
7. Deactivate the input signal for stage \(i_{\text{Base2}}\).
8. Set the time constant for \(i_{\text{Base1}}\) in accordance with the setting plan.
9. Set the injection current for phase L1 to 1.50 · \(i_{\text{Base1}}\).
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 (\(\text{Tau}_1\)).
    With setting \(\text{Itr} = 101\%i_{\text{Base1}}\) and injection current 1.50 · \(i_{\text{Base1}}\), the trip time from zero content in the memory shall be 0.60 · Time Constant 1 (\(\text{Tau}_1\)).
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 \(i_{\text{Base2}}\).
Wait 5 minutes to empty the thermal memory and set Time Constant 2 (\( \text{Tau2} \)) in accordance with the setting plan.

15. Test with injection current \( 1.50 \cdot \text{IBase2} \) the thermal alarm level, the operate time for tripping and the lockout reset in the same way as described for stage \( \text{IBase1} \).

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

### 10.4.8.2 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.

### 10.4.9 Breaker failure protection, phase segregated activation and output CCRBRF

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

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 \( 1 \text{ out of 3} \), it is sufficient to test phase-to-earth faults.

At mode \( 2 \text{ out of 4} \), the phase current setting, \( \text{IP}> \) 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 \( \text{IN}> \) set lower than \( \text{IP}> \) is easiest checked in back-up trip mode \( 1 \text{ out of 4} \).

#### 10.4.9.1 Checking the phase current operate value, \( \text{IP}> \)

The check of the \( \text{IP}> \) current level is best made in FunctionMode = Current and BuTripMode = \( 1 \text{ out of 3 or 2 out of 4} \).

1. Apply the fault condition, including START of CCRBRF, with a current below the set \( \text{IP}> \).
2. Repeat the fault condition and increase the current in steps until a trip occurs.
3. Compare the result with the set \( \text{IP}> \).

Note! If No CBPos Check or Retrip off is set, only back-up trip can be used to check set \( \text{IP}> \).

#### 10.4.9.2 Checking the residual (earth fault) current operate value \( \text{IN}> \) set below \( \text{IP}> \)

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

1. Apply the fault condition, including START of CCRBRF, with a current just below set \( \text{IN}> \).
2. Repeat the fault condition and increase the current in steps until trip appears.
3. Compare the result with the set \( \text{IN}> \).
4. Disconnect AC and START input signals.
10.4.9.3 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 = CB Pos Check.

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 $t_1$ and back-up trip times $t_2$ and $t_3$. In applicable cases, the back-up trip for multi-phase start $t_{2MPH}$ and back-up trip 2, $t_2$ and $t_3$ can also be checked. To check $t_{2MPH}$, a two-phase or three-phase start shall be applied.

10.4.9.4 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 = Retrip Off

1. Set RetripMode = Retrip 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 = CB Pos Check

1. Set RetripMode = CB Pos Check.
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 $t_1$ and back-up trip after time $t_2$.
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 = No CBPos Check.
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 $t_1$, and the back-up trip after time $t_2$.
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 $t_1$, but no back-up trip is obtained.

10.4.9.5 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 $I_P$.
2. Interrupt the current, with a margin before back-up trip time, $t_2$. 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 \( BuTripMode = 1 \text{ out of } 3 \) should have been verified in the tests above. In applicable cases the modes \( 1 \text{ out of } 4 \) and \( 2 \text{ out of } 4 \) can be checked. Choose the mode below, which corresponds to the actual case.

**Checking the case \( BuTripMode = 1 \text{ out of } 4 \)**
It is assumed that the earth-fault current setting \( IN> \) is below phase current setting \( IP> \).

1. Set \( BuTripMode = 1 \text{ out of } 4 \).
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 \( BuTripMode = 2 \text{ out of } 4 \)**
The earth-fault current setting \( IN> \) may be equal to or below phase-current setting \( IP> \).

1. Set \( BuTripMode = 2 \text{ out of } 4 \).
2. Apply the fault condition, including start of CCRBRF, with one-phase current above set \( IP> \) and residual (earth fault) above set \( IN> \).
3. Verify that back-up trip is achieved after set time. If selected, re-trip should also appear.
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 \((3I_0)\) will be above set value \( IN> \).
5. Verify that back-up trip is not achieved.
6. Disconnect AC and START input signals.

### 10.4.9.6 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.

### 10.4.9.7 Verifying the case \( RetripMode = Contact \)

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

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 \( t2 \).
9. Verify that back-up trip is not achieved.
10.4.9.8 **Verifying the function mode** *Current&Contact*

To be made only when *FunctionMode = Current&Contact* 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** *IP>*

The operation shall be as in *FunctionMode = Current*.

1. Set *FunctionMode = Current&Contact*.
2. Leave the inputs for CB closed inactivated. These signals should not influence.
3. Apply the fault condition, including the start of CCRBRF, with the current above the set *IP>* 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>BlkCont*

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 re-trip without current check is used, setting *RetripMode = No CBPos Check*.

1. Set *FunctionMode = Current&Contact*.
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 value *I>BlkCont*.
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 the fault and the start again. The value of current should be below the set value *I>BlkCont*.
7. Arrange disconnection of BC closed signal(s) well before set back-up trip time *t2*. It simulates a correct CB tripping.
8. Verify that back-up trip is not achieved. Re-trip can appear for example, due to selection “Re-trip without current check”.

10.4.9.9 **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.

10.4.10 **Stub protection STBPTOC**

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

Logical signals for STBPTOC protection are available on the local HMI under **Main menu/Settings/Setting group N/Current protection/Stub(PTOC,50STB)/STBPTOC:x**

10.4.10.1 **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.

10.4.10.2 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.

10.4.11 Pole discordance protection CCPDSC

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

10.4.11.1 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.

10.4.11.2 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.

10.4.12 Directional underpower protection GUPPDUP

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

10.4.12.1 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>
<thead>
<tr>
<th>Set value: Mode</th>
<th>Formula used for complex power calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1, L2, L3</td>
<td>( \bar{S} = \bar{U}<em>{L1} \cdot \bar{T}</em>{L1}^* + \bar{U}<em>{L2} \cdot \bar{T}</em>{L2}^* + \bar{U}<em>{L3} \cdot \bar{T}</em>{L3}^* ) (Equation 4)</td>
</tr>
<tr>
<td>Arone</td>
<td>( \bar{S} = \bar{U}<em>{L1L2} \cdot \bar{T}</em>{L1}^* - \bar{U}<em>{L2L3} \cdot \bar{T}</em>{L3}^* ) (Equation 5)</td>
</tr>
<tr>
<td>PosSeq</td>
<td>( \bar{S} = 3 \cdot \bar{U}<em>{PosSeq} \cdot \bar{T}</em>{PosSeq}^* ) (Equation 6)</td>
</tr>
</tbody>
</table>

Table continues on next page
2. Adjust the injected current and voltage to the set values in % of \( I_{Base} \) and \( U_{Base} \) (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 \( \text{Angle1} + 90° \). 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 START1 signal, start of stage 1, is activated.

5. Increase the current to 100% of \( I_{Base} \).

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

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

### 10.4.12.2 Completing the test

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

### 10.4.13 Directional overpower protection GOPPDOP

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

### 10.4.13.1 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 $I_{Base}$ and $U_{Base}$ (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 $S_{base}$.

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

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

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

10.4.13.2 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.

10.4.14 Broken conductor check BRCPTOC

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

10.4.14.1 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 $I_{P}$.

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 $t_{Oper}$.

5. Activate the BLOCK binary input.

6. Switch on the fault current (110% of the setting) and wait longer than the set value $t_{Oper}$. 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 $I_{P}$. Switch off the current.

9. Switch on the fault current and wait longer than the set value $t_{Oper}$.
10 TRIP signal should appear.
10. Switch off the fault current.

10.4.14.2 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.

10.5 Voltage protection

10.5.1 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.

10.5.1.1 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:

\[
U_1 < \frac{U_{Base} \times V_{T sec}}{100 \times \sqrt{3} \times V_{Tprim}}
\]

(Equation 13)

For phase-to-phase measurement:

\[
\frac{U_1}{100} \times U_{Base} \times \frac{V_{T sec}}{V_{Tprim}}
\]

(Equation 14)

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 × 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:
\[ t(s) = \frac{k_1}{1 - \frac{U}{U_{1<}}} \]  

(Equation 15)

where:

- \( t(s) \) Operate time in seconds
- \( k_1 \) 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 \( k_1 \) 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.

**10.5.1.2 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.

**10.5.2 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.

**10.5.2.1 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:

\[ U_{1>} \times \frac{U_{\text{Base}} \times VT \text{ sec}}{100 \times \sqrt{3} \times V_{\text{prim}}} \]  

(Equation 16)

For phase-to-phase measurement:
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 × U1>.
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.

10.5.2.2 Extended testing

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

10.5.2.3 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.

10.5.3 Two step residual overvoltage protection ROV2PTOV

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

10.5.3.1 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 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 × 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:

\[
t(s) = \frac{k1}{\left(\frac{U}{U1>}\right)^{-1}}
\]

(Equation 18)

where:
- \(t(s)\) Operate time in seconds
- \(k1\) Settable time multiplier of the function for step 1
8. Repeat the test for Step 2 of the function.

10.5.3.2 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.

10.5.4 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.

10.5.4.1 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 tTrip 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 tPulse.

4. Inject the measured voltages at rated values for at least set tRestore 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 tRestore 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 tRestore 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.

10.5.4.2 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.
10.6 **Multipurpose protection**

10.6.1 **General current and voltage protection CVGAPC**

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

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

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

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

10.6.1.1 **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 \( \text{CurrentInput} \)) 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.
10.6.1.2 Overcurrent feature with current restraint

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

Procedure

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

10.6.1.3 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.

10.6.1.4 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.

10.6.1.5 Over/Undervoltage feature

Procedure

1. Connect the test set for injection three-phase voltages to the appropriate voltage terminals of the IED.
2. Inject voltage(s) in a way that relevant measured (according to setting parameter VoltageInput) voltages are created from the test set.
3. Overall check in principal as above (non-directional overcurrent feature) and correspondingly for the undervoltage feature.

10.6.1.6 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.

10.7 Secondary system supervision

10.7.1 Current circuit supervision CCSSPVC

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

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 IMinOp is lower than the setting of Ip>Block.

10.7.1.1 Verifying the settings

1. Check the input circuits and the operate value of the IMInOp 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 · IBase.
3. Inject a current 0.1 · IBase to the reference current input I5.
4. Increase slowly the current in one of the phases current input and check that FAIL output is obtained when the current is about 0.9 · IBase.

10.7.1.2 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.
10.7.2  Fuse failure supervision FUFSVPC

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.

10.7.2.1  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 BLKUand BLKZ signals should appear without any time delay.
   • All undervoltage-dependent functions must be blocked.
5. Disconnect the dc voltage from the MCBOP binary input terminal.
6. Disconnect one of the phase voltages and observe the logical output signals on the binary outputs of the IED.
   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

10.7.2.2  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):
\[ 3 \cdot \overline{U_2} = \overline{U_{L1}} + a^2 \cdot \overline{U_{L2}} + a \cdot \overline{U_{L3}} \]

(Equation 19)

Where:
\[ \overline{U_{L1}}, \overline{U_{L2}} \text{ and } \overline{U_{L3}} \]
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 \(3U2^\circ\) is in percentage of the base voltage \(U_{Base}\)).
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):
\[ 3 \cdot \overline{I_2} = \overline{I_{L1}} + a^2 \cdot \overline{I_{L2}} + a \cdot \overline{I_{L3}} \]

(Equation 20)

Where:
\[ \overline{I_{L1}}, \overline{I_{L2}} \text{ and } \overline{I_{L3}} \]
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 \(3I2^\circ\) is in percentage of the base current \(I_{Base}\).

10.7.2.3 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):
\[ 3 \cdot \overline{U_0} = \overline{U_{L1}} + \overline{U_{L2}} + \overline{U_{L3}} \]

(Equation 21)

Where:
\[ \overline{U_{L1}}, \overline{U_{L2}} \text{ and } \overline{U_{L3}} \]
are the measured phase voltages

4. Compare the result with the set value of the zero-sequence operating voltage (consider 
   that the set value \(3U0^\circ\) 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):

\[ 3 \cdot I_0 = I_{L1} + I_{L2} + I_{L3} \]

(Equation 22)

Where:

- \( I_{L1}, I_{L2}, \text{and } I_{L3} \)

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 \( I_{Base} \).

10.7.2.4 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 \( U_{Base} \)).
4. Apply three-phase currents with their rated value and zero voltages.
5. Decrease the measured current in one phase until the DLD1PH signal appears.
6. This is the point at which the dead line condition is detected. Check the value of the decreased current with the set value \( IDLD < \) (\( IDLD < \) is in percentage of the base current \( I_{Base} \)).

10.7.2.5 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.

### 10.7.2.6 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.

### 10.8 Control

#### 10.8.1 Synchrocheck, energizing check, and synchronizing SESRSYN

This section contains instructions on how to test the synchrocheck, energizing check, and synchronizing function SESRSYN for single 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 17 shows the general test connection principle, which can be used during testing. This description describes the test of the version intended for one bay.
10.8.1.1 Testing the synchronizing function

The voltage inputs used are:

- **UP3LN1**: UL1, UL2 or UL3 line 1 voltage inputs on the IED
- **UP3BB1**: Bus1 voltage input on the IED

**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.

   \[
   \text{Closing Angle} = |( (f_{Bus} - f_{Line}) \times tBreaker \times 360\text{ degrees}) |
   \]

   - **$f_{Bus}$**: Bus frequency
   - **$f_{Line}$**: Line frequency
   - **$tBreaker$**: Set closing time of the breaker

3. Repeat with
3.1. U-Bus = 100% U$BaseBus$ 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 $FreqDiffMin$.

10.8.1.2 Testing the synchrocheck check

During the test of SESRSYN for a single bay arrangement, these voltage inputs are used:

<table>
<thead>
<tr>
<th>U-Line</th>
<th>U-L1, U-L2 or U-L3 line 1 voltage input on the IED according to the connection in SMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-Bus</td>
<td>Bus voltage input on the IED according to the connection in SMT</td>
</tr>
</tbody>
</table>

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-Line (for example) = 80% $GblBaseSelLine$ and U-Bus = 80% $GblBaseSelBus$ 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-Line and U-Bus respectively lower than the other.
4. Increase the U-Bus to 110% $GblBaseSelBus$, and the U-Line = 90% $GblBaseSelLine$ 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 $PhaseDiffM$ and $PhaseDiffA$ 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-Line (for example) = 100% $GblBaseSelLine$ and U-Bus = 100% $GblBaseSelBus$, with a phase difference equal to 0 degrees and a frequency difference lower than $FreqDiffA$ and $FreqDiffM$.
2. Check that the AUTOSYOK and MANSYOK outputs are activated.

The test can be repeated with other phase angle differences to verify that the function operates for values lower than the set ones, $PhaseDiffM$ and $PhaseDiffA$. By changing the phase angle on the voltage connected to U-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 18.
3. Change the phase angle between +dφ and -dφ and verify that the two outputs are activated for phase differences between these values but not for phase differences outside, see figure 18.

**Testing the frequency difference**

The frequency difference test should verify that operation is achieved when the FreqDiffA and FreqDiffM frequency difference is lower than the set value for manual and auto synchronizing check, FreqDiffA and FreqDiffM 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 17. 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.

**10.8.1.3 Testing the energizing check**

During the test of the energizing check function for a single bay arrangement, these voltage inputs are used:

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-Line</td>
<td>UL1, UL2 or UL3 line1 voltage inputs on the IED</td>
</tr>
<tr>
<td>U-Bus</td>
<td>Bus voltage input on the IED</td>
</tr>
</tbody>
</table>
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% $U_{Base}$ and dead voltage level to fixed 40% $U_{Base}$.

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% $G_{blBaseSelBus}$ to the U-Bus, and a single-phase voltage 30% $G_{blBaseSelLine}$ to the U-Line.
2. Check that the AUTOENOK and MANENOK outputs are activated after set $t_{AutoEnerg}$ respectively $t_{ManEnerg}$.
3. Increase the U-Line to 60% $G_{blBaseSelLine}$ and U-Bus to be equal to 100% $G_{blBaseSelBus}$. 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. Verify the settings AutoEnerg or ManEnerg to be DBLL.
2. Apply a single-phase voltage of 30% $G_{blBaseSelBus}$ to the U-Bus and a single-phase voltage of 100% $G_{blBaseSelLine}$ to the U-Line.
3. Check that the AUTOENOK and MANENOK outputs are activated after set $t_{AutoEnerg}$ respectively $t_{ManEnerg}$.
4. Decrease the U-Line to 60% $G_{blBaseSelLine}$ and keep the U-Bus equal to 30% $G_{blBaseSelBus}$. 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% $G_{blBaseSelLine}$ to the U-Line and a single-phase voltage of 100% $G_{blBaseSelBus}$ to the U-Bus.
3. Check that the AUTOENOK and MANENOK outputs are activated after set $t_{AutoEnerg}$ respectively $t_{ManEnerg}$.
4. Change the connection so that the U-Line is equal to100% $G_{blBaseSelLine}$ and the U-Bus is equal to 30% $G_{blBaseSelBus}$. 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.

10.8.1.4 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.

10.8.1.5 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.

10.8.2 Autorecloser for 1/2/3-phase operation SMBRREC

Verification of the Autorecloser for 1/2/3-phase operation function SMBRREC for single-phase, two-phase or three-phase reclosing attempts can be considered to consist of two parts.

• One part to verify the internal logic and timing of the function
• One part to verify its interaction with the protection system

This section deals with verification of SMBRREC itself. However, it is practical to start SMBRREC by activating a protection function, for example, by secondary injection tests.

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

The purpose of verification before commissioning is to check that entered selections, setting parameters and configuration render the intended result. The function is flexible with many options and facilities. At commissioning only the selections and settings intended for use are verified. If one chooses to reduce some time settings in order to speed up verification, be careful to set the parameters at intended operational values at the end of the verification procedure. One such parameter is the tReclaim time that must be timed out before a new test sequence can be performed.

The verification test is performed together with protection and trip functions. Figure 19 illustrates a suggested testing arrangement, where the circuit-breaker (CB) is simulated by an
external bi-stable relay (BR), for example a relay type RXMVB2 or RXMD or Breaker Simulator of ABB. The following manual switches are used:

- Switch or push-button to close (SC)
- Switch or push-button to trip (ST)
- Switch for CB ready condition (SRY)

If no bi-stable relay or breaker simulator is available, replace it with two self-reset auxiliary relays and use a self-holding connection.

Use a secondary injection IED test set to operate the protection function. The test set shall be switched off when a trip signal is given or when the BR comes to open position to simulate real conditions.

The CB simulation can be made more elaborate, including simulation of the operating gear condition, CBREADY of either the type ready for a Close-Open (CO) cycle, or the type ready for an Open-Close -Open (OCO) cycle.

The CB condition CBREADY of a type, CO, shall be high (true) until a closing operation is performed. It then goes low (false) for a recharging time of about 5 - 10s. After that it is high again.

A CB condition CBREADY of a type, OCO shall be high (true) before and during tripping (Start reclosing). During tripping it goes low for a recharging time, for example, 10s. It may thus be low at the instant of reclosing. After each Open or Close operation it may need a recharging period before it goes high again.

In the example of CB simulation arrangement, the CBREADY condition is simulated by a manual switch, SRY.

Information and material for the verification:

- Protection or control unit, IED, configured and with settings entered.
- Configuration diagram for the IED
- Terminal diagram for the IED, or plant circuit diagram including the IED
- Technical reference manual for the IED
- IED test set for secondary injection
- Means to indicate, measure and record operation and times, for example an event recording facility
- A bi-stable relay (BR) or two auxiliary relays to simulate a CB
- Two push-buttons (SC, ST) to operate the BR and a change-over switch (SRY) to simulate CBREADY
- Possibly a switch simulation the synchronizing check SESRSYN condition
10.8.2.1 Preparation of the verification

1. Check the function settings on the local HMI under **Main menu/Settings/Setting group N/Control/Autorecloser79,5(0–→1)/SMBRREC:x**
   If any timer settings are reduced to speed up or facilitate the testing, they shall be set to normal after testing. A temporary label on the IED can be a reminder to restore normal settings after which a verification test should be performed.
2. Decide if a synchronizing check function SESRSYN shall be included in the test.
   If SESRSYN as an internal function or external device is not operated by the injection, input signal SYNC must be connected as a permanent high signal or controlled by a switch.
3. Read and make notes of the reclosing operation counters on the local HMI under **Main menu/Test/Function status/Control/AutoRecloser79,5(0–→1)/SMBRREC:x**
   Possibly reset the counters to Zero. Counters are reset in the reset menu.
4. Make arrangements for the simulation of the CB, for example as in figure 19.
5. Make arrangements for indication, recording and time measurements.
   The signals for CBPOS, START, CLOSECB, READY and other relevant signals should preferably be arranged for event recording with time tagging. If that is not possible, other means of time measurement and recording should be arranged.

10.8.2.2 Switching the autorecloser for 1/2/3-phase operation function to **On** and **Off**

1. Set the **Operation** setting to **Off** and check the state.
2. Set the **Operation** setting to **On** and check the state, including SETON and READY.
The CB should be closed and ready.

3. If external control inputs OFF/ON are used, check that they work. Set ExternalCtrl = On and use the control inputs to switch On and Off, and check the state of the function.

10.8.2.3 Verifying the autorecloser function SMBRREC

Select the test cases to be run according to what is applicable to the particular application. It can be, for example,

- three-phase single-shot reclosing
- two-shot reclosing
- single-phase and three-phase single-shot reclosing

Below, a case with single-phase and three-phase single-shot reclosing is described.

1. Set Operation = On.
2. If the synchronizing check SESRSYN is not to be operated, ensure that the signal SYNC input is activated. If SESRSYN is to be included, ensure that it is supplied with the appropriate AC quantities.
3. Simulate CB closed position by closing switch SC to make the BR relay start.
4. Simulate CBREADY by closing the switch SRY, and leave it closed.
5. Inject AC quantities to give a trip, for example, a one-phase trip, to the BR and to the START input.
Observe and preferably record the operation. The BR relay shall trip and reclose (start). After reclosing, the SRY switch can be opened for about 5s and then closed again. The autoreclosing open time and the sequence should be checked, for example in the event recording. Check also the operation indications (disturbance report) and the operation counters on the local HMI under Main menu/Test/Function status/Control/AutoRecloser79,5(0→1)/SMBRREC:x
Should the operation not be as expected, this should be investigated. It could be caused by an inappropriate setting or missing condition such as CBREADY.
6. Repeat the sequence by simulating a permanent fault.
Shortly after the reclosing shot, a new fault is applied. If a single-shot reclosing program is selected, there shall be one reclosing operation and then blocking of SMBRREC for the set Reclaim time.
Before a new reclosing sequence can be run, the CBREADY and CBPOS (CB closed) must be set manually.
7. Repeat the sequence by simulating a three-phase transient and permanent faults, and other applicable cases, such as signal to STARTHS and high-speed reclosing.
If just single-phase reclosing is selected, FirstShot = 1ph, a check can be run to make sure that a three-phase trip does not result in any reclosing. Other similar cases can be checked as required.

10.8.2.4 Checking the reclosing conditions

When checking the influence of a releasing condition it is suggested to first run a sequence with the condition fulfilled. When the condition signal is removed, and a new sequence is run, it indicates that the result was due to the changed condition. In case of a blocking signal the procedure should be similar. Start without the blocking or inhibit signal, and then run a sequence with the blocking or inhibit signal added.

Checking the influence of the INHIBIT signal
1. Check that the autorecloser function SMBRREC is operative, for example, by making a reclosing shot without the INHIBIT signal.
2. Apply a fault and thereby a START signal. At the same time, or during the open time, apply a signal to the input INHIBIT.
3. Check that the reclosing sequence is interrupted and no reclosing takes place.

**Check closing onto a fault**

1. Check that the autorecloser function SMBRREC is operative, for example by making a reclosing shot.
   - Keep the CBREADY signal high.
2. Set the breaker simulating relay BR in Open position.
3. Close the BR relay and apply immediately a fault and thereby a START signal.
4. Check that no reclosing takes place.

**Checking the influence of CB not ready for reclosing**

1. Check that the autorecloser function SMBRREC is operative, for example by making a reclosing shot.
   - Keep the CB simulator BR closed. Remove the CBREADY signal by opening SRY.
2. Apply a fault and thereby a START signal.
3. Check that no reclosing takes place.

**Checking the influence of synchronizing check (at three-phase reclosing)**

1. Check that the autorecloser function SMBRREC is operative, for example, by making a three-phase reclosing shot with the SESRSYN synchronizing check condition.
   - Set the SESRSYN function to Off to eliminate the signal connected to input signal SYNC.
2. Apply a fault causing three-phase trip and thereby a START and a TR3P signal.
3. Wait for the tSync time-out limit.
   - Check that no reclosing is made.

**Checking the response when autoreclosing is Off**

**Procedure**

1. Check that the autorecloser function SMBRREC is operative, for example by making a reclosing shot.
   - Set the autoreclosing operation to Off, for example by external control.
   - The output READY shall be low, and PREP3P shall be high.
2. Apply a single phase fault and thereby a START signal.
3. Check that a definitive three phase trip and no reclosing takes place.

**Restoring equipment**

After the tests, restore the equipment to normal or desired state. Check the following items in particular:

1. Check the operation counters.
   - Reset the counters to zero, if that is the user's preference. The counter reset function is found on the local HMI under *Main menu/Reset/Reset counters/AutoRecloser79.5(0–1)/SMBRREC:x*
2. Restore settings that may have been modified for the tests back to normal.
3. Disconnect the test switch, CB simulating arrangement and test circuits.
4. Reconnect any links or connection terminals, which may have been opened for the tests.
5. Reset indications, alarms and disturbance recordings.
   - Clearing of the disturbance report can be done via the Disturbance Handling in PCM600 or the local HMI.
10.8.2.5 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.

10.8.3 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.

10.8.4 Single command, 16 signals SINGLECMD

For the single command function block, it is necessary to configure the output signal to correspond to the 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.

10.8.5 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.

10.9 Scheme communication

10.9.1 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.

10.9.1.1 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.

10.9.1.2 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.

10.9.1.3 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 tCoord 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.

10.9.1.4 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.

10.9.1.5 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.

10.9.1.6 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.

10.9.2 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.

### 10.9.2.1 Current reversal logic

It is possible to check the delay of the CS send signal with $t_{\text{DelayRev}}$ 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 $t_{\text{DelayRev}}$ 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 $t_{\text{DelayRev}}$ set value.

1. Activate the receive (CRL) signal.
2. Set the healthy condition to an impedance at 50% of the reach of the reverse zone connected to IRV.
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 $t_{\text{DelayRev}}$ 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.

### 10.9.2.2 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 16: 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 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 16.
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.

10.9.2.3 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.

10.10 Logic

10.10.1 Tripping logic, common 3-phase output SMPPTRC

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

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. The instances of SMPPTRC are identical except for the name of the function block SMPPTRC. The testing is preferably done in conjunction with the protection system and autoreclosing function.

10.10.1.1 Three-phase operating mode

1. Check that \( AutoLock \) and \( TripLockout \) are both set to \( Off \).
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.

### 10.10.1.2 1ph/3ph operating mode

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

**Procedure**

1. Make sure that TripLockout and AutoLock are both set to 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 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.

### 10.10.1.3 1ph/2ph/3ph operating mode

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

1. Make sure that AutoLock and TripLockout are both set to 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 during 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. 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.
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 tEvolvingFault (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 tEvolvingFault (default setting 2.0s). Check, that the output signals, issued for the first fault, correspond to a two-phase trip for included phases. The output signals generated by the second fault must correspond to the three-phase tripping action.

10.10.1.4 Circuit breaker lockout

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

1. Check that AutoLock and TripLockout are both set to 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 CLLKOUT should not be set.

7. Activate the automatic lockout function, set AutoLock = On and repeat. Besides the TRIP outputs, CLLKOUT 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, CLLKOUT 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.

10.10.1.5 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.

10.11 Monitoring

10.11.1 Gas medium supervision SSIMG

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

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

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

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

10.11.1.2 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.
10.11.2 Liquid medium supervision SSIML

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

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

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

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

10.11.2.2 Completing the test

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

10.11.3 Breaker monitoring SSCBR

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

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

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

10.11.3.1 Verifying the settings

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

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

4. Test of CB contact travel time
4.1. Test the set timing defined by \textit{OpenTimeCorr}, \textit{CloseTimeCorr}, \textit{tTrOpenAlm} and \textit{tTrCloseAlm}.

4.2. Change the status of the auxiliary contacts such that travel time to open \textit{TTRVOP} and travel time to close \textit{TTRVCL} exceed the respective set values (\textit{tTrOpenAlm} and \textit{tTrCloseAlm}). The measured travel time for opening and closing is shown on \textit{TTRVOP} and \textit{TTRVCL} respectively.

4.3. Check that \textit{TRVTOPAL} and \textit{TRVTCLAL} are activated.

5. Test of CB status

5.1. Test the set current level defined by \textit{AccStopCurr}.

5.2. Check the \textit{CLOSEPOS} output by changing the \textit{POSOPEN} to 0 and \textit{POSCLOSE} to 1.

5.3. Check the \textit{OPENPOS} output by changing the \textit{POSOPEN} to 1 and \textit{POSCLOSE} to 0 and also inject the current in the selected phase slightly lower and higher than \textit{AccStopCurr} set value. Only for a current lower than set \textit{AccStopCurr} should activate the output \textit{POSOPEN}.

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

6. Test of remaining life of CB


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

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

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

7. Test of accumulated energy

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

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

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

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

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

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

8. Test of CB operation cycles

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

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

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

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

9. Test of CB spring charge monitoring

9.1. Test the actual set value defined by \textit{SpChAlmTime}.

9.2. Enable \textit{SPRCHRST} input. Also activate \textit{SPRCHRD} after a time greater than set time \textit{SpChAlmTime}.

9.3. At this condition, \textit{SPCHALM} is activated.

10. Test of CB gas pressure indication
10.1. Test the actual set value defined by $tD\text{GasPresAlm}$ and $tD\text{GasPresLO}$. 

10.2. The output $GPRES\text{ALM}$ is activated after a time greater than set time of $tD\text{GasPresAlm}$ value if the input $PRES\text{ALM}$ is enabled. 

10.3. The output $GPRES\text{LO}$ is activated after a set time of $tD\text{GasPresLO}$ value if the input $PRES\text{LO}$ is enabled.

10.11.3.2 Completing the test

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

10.11.4 Event function EVENT

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

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

- Use event masks
- Report no events
- Report all events

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

10.11.5 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 17: Test settings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Higher than 30% Ir</td>
</tr>
<tr>
<td>Healthy conditions</td>
<td></td>
</tr>
</tbody>
</table>

**U = 63.5 V, I = 0 A & ZF = 0°**

#### Impedance |Z|

**Test point**

**Note:**

- \( Z_x \leq \frac{(X_0 + 2 \cdot X_1)}{3} \) for single-phase faults
- \( Z_x \leq X_1 \) for three and two phase faults
- \( Z_x \leq \frac{(X_0 + 2 \cdot X_1 \cdot X_M)}{3} \) for single-phase fault with mutual zero-sequence current

#### Impedance angle Z

**Test angle**

- \( \Phi = \text{arctan}\left[\frac{X_0 + 2 \cdot X_1}{R_0 + 2R_1}\right] \) for single-phase faults
- \( \Phi = \text{arctan}\left[\frac{X_1}{R_1}\right] \) for two-phase faults

### 10.11.5.1 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 17.
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 23, 24 and 25

\[
p = \frac{Z_x}{X_1} \cdot 100
\]

(Equation 23)

in % for two- and three-phase faults

\[
p = \frac{3 \cdot Z_x}{X_0 + 2 \cdot X_1} \cdot 100
\]

(Equation 24)

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 25)

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

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Commissioning manual
10.11.5.2 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.

10.11.6 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. Trig the function and check that the counter result corresponds to the number of operations.

10.11.6.1 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.

10.12 Metering

10.12.1 Pulse-counter logic PCFCNT

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

10.12.2 Function for energy calculation and demand handling ETPMMTR

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

10.12.2.1 Verifying the settings

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

Verification of EAFACC & ERFACC output

1. Connect the test set for injection of three-phase currents and three phase voltage to the appropriate current and voltage terminals of the IED.
2. Ensure the instantaneous values of active and reactive power from CVMMXN function block are connected to ETPMMTR function block active and reactive power inputs.
3. Enable the EnaAcc setting and set tEnergy as 1 minute.
4. Activate the STARTACC input and supply the IED with three phase currents and voltages at their rated value.
5. Check that the ACCINPRG signal appears continuously.
6. Note the EAFACC and ERFACC value after 1 minute and compare it with calculated energy value.

7. Similarly check after each 1 minute whether the calculated integrated energy value and EAFACC and ERFACC outputs are matching.

8. After some time (multiple of minute) remove the current and voltage input from CVMMXN function block.

9. Check the EAFACC and ERFACC output in the next 1 minute cycle for the retaining the same value.

10. Activate STOPACC input after some time and supply the IED with same current and voltage.

11. Check that the ACCINPRG signal disappears immediately and EAFACC and ERFACC outputs also stop updating.

12. Similarly the testing can be done for EAFACC and ERFACC outputs by changing the power inputs directions through direction settings.

Verification of MAXPAFD & MAXPRFD outputs

1. Repeat the above test steps 1 to 2.

2. Set tEnergy setting as 1 minute and supply the IED with three phase currents and voltages at their rated value till 1 minute.

3. Check the MAXPAFD and MAXPRFD outputs after 1 minute and compare it with last 1 minute average power values.

4. Increase either three phase current or voltage above the last 1 minute value.

5. After 1 minute check the MAXPAFD and MAXPRFD whether it is showing the last 1 minute average power value as maximum.

6. Next 1 minute cycle reduce the current or voltage below previous value.

7. Check after 1 minute whether the MAXPAFD and MAXPRFD outputs are retaining the old maximum value.

8. Similarly the testing can be done for MAXPAFD and MAXPRFD outputs by changing the power inputs directions through direction settings.

Verification of EAFALM & ERFALM outputs

1. Repeat the above test steps 1 to 2.

2. Set tEnergy setting as 1 minute and supply the IED with three phase currents and voltages at their rated value till 1 minute.

3. Ensure that the active and reactive energy values are less than the EALim and ERLim setting default values respectively.

4. Check that EAFALM and ERFALM are low.

5. Increase the supply currents or voltage in next 1 minute cycle such that the active or reactive energy values are greater than the EALim and ERLim setting default values respectively.

6. Check that EAFALM and ERFALM are high after 1 minute.

7. Similarly the testing can be done for EARALM and ERRALM outputs by changing the power inputs directions through direction settings.

10.12.2.2 Completing the test

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

10.13.1 Multiple command and transmit MULTICMDRCV / MULTICMDSND

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

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

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

10.14 Basic IED functions

10.14.1 Parameter setting group handling SETGRPS

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

10.14.1.1 Verifying the settings

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

10.14.1.2 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.

10.15 Exit test mode

The following procedure is used to return to normal operation.
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 11 Commissioning and maintenance of the fault clearing system

11.1 Commissioning tests

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

11.2 Periodic maintenance tests

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

The normal maintenance 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.

### 11.2.1 Visual inspection

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

Make sure that all IEDs are equipped with covers.

### 11.2.2 Maintenance tests

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

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

ABB protection IEDs are preferably tested by aid of components from the COMBITEST testing system 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.

### 11.2.2.1 Preparation

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

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

### 11.2.2.2 Recording

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

### 11.2.2.3 Secondary injection

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

11.2.2.4 Alarm test

When inserting the test handle 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.

11.2.2.5 Self supervision check

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

11.2.2.6 Trip circuit check

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

Note that the breaker must be closed.

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

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

Remember to close the circuit directly after the test and tighten the terminal carefully.

11.2.2.7 Measurement of service currents

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

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

The zero-sequence current to 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.

### 11.2.8 Restoring

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

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

12.1  Checking the self supervision signals

12.1.1  Checking the self supervision function

12.1.1.1  Determine the cause of an internal failure

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

Procedure

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

12.1.2  Self supervision HMI data

12.1.2.1  General IED status

The following table shows the general IED status signals.

Table 18:  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. If the problem persists, contact your ABB representative for service.</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
### 12.2 Fault tracing

#### 12.2.1 Internal fault indications

If an internal fault has occurred, the local HMI displays information under **Main menu/Diagnostics/IED status/General**

Under the Diagnostics menus, indications of a possible internal failure (serious fault) or internal warning (minor problem) are listed.

Indications regarding the faulty unit are outlined in table 19.

**Table 19: Self-supervision signals on the local HMI**

<table>
<thead>
<tr>
<th>HMI Signal Name:</th>
<th>Status</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>INT Fail</td>
<td>OFF / ON</td>
<td>This signal will be active if one or more of the following internal signals are active; INT--LMDERROR, INT--WATCHDOG, INT--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>
</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 19. 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.

### 12.2.2 Using front-connected PC

When an internal fault has occurred, extensive information about the fault can be retrieved from the list of internal events available in the SMS part:

**TRM-STAT TermStatus - Internal Events**

The list of internal events provides valuable information, which can be used during commissioning and fault tracing.

The internal events are time tagged with a resolution of 1ms and stored in a list. The list can store up to 40 events. The list is based on the FIFO principle, when it is full, the oldest event is overwritten. The list cannot be cleared and its content cannot be erased.

The internal events in this list not only refer to faults in the IED, but also to other activities, such as change of settings, clearing of disturbance reports, and loss of external time synchronization.
The information can only be retrieved from the Parameter Setting software package. The PC can be connected either to the port at the front or at the rear of the IED.

These events are logged as internal events.

Table 20: Events available for the internal event list in the IED

<table>
<thead>
<tr>
<th>Event message:</th>
<th>Description</th>
<th>Generating signal:</th>
</tr>
</thead>
<tbody>
<tr>
<td>INT--FAIL</td>
<td>Off</td>
<td>INT--FAIL (reset event)</td>
</tr>
<tr>
<td>INT--FAIL</td>
<td></td>
<td>INT--FAIL (set event)</td>
</tr>
<tr>
<td>INT--WARNING</td>
<td>Off</td>
<td>INT--WARNING (reset event)</td>
</tr>
<tr>
<td>INT--WARNING</td>
<td></td>
<td>INT--WARNING (set event)</td>
</tr>
<tr>
<td>IOn--Error</td>
<td>Off</td>
<td>IOn--Error (reset event)</td>
</tr>
<tr>
<td>IOn--Error</td>
<td></td>
<td>IOn--Error (set event)</td>
</tr>
<tr>
<td>ADMn-Error</td>
<td>Off</td>
<td>ADMn-Error (reset event)</td>
</tr>
<tr>
<td>ADMn-Error</td>
<td></td>
<td>ADMn-Error (set event)</td>
</tr>
<tr>
<td>MIMI-Error</td>
<td>Off</td>
<td>MIMI-Error (reset event)</td>
</tr>
<tr>
<td>MIMI-Error</td>
<td></td>
<td>MIMI-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--SETCHGD</td>
<td></td>
<td>INT--TSYNC (set event)</td>
</tr>
<tr>
<td>DRPC-CLEARED</td>
<td></td>
<td></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.

12.2.3 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>
<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 <em>Block</em>, 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 <em>BlockOnLostUTC</em>, 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; 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; 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; 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>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>
<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>
</tbody>
</table>

12.2.4 **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 PCM600.

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.

12.3 Repair instruction

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

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

An alternative is to open the IED and send only the faulty circuit board to ABB for repair. When a printed circuit board is sent to ABB, it must always be placed in a metallic, ESD-proof, protection bag. The user can also purchase separate replacement modules.
Strictly follow the company and country safety regulations.

Most electronic components are sensitive to electrostatic discharge and latent damage may occur. Please observe usual procedures for handling electronics and also use an ESD wrist strap. A semi-conducting layer must be placed on the workbench and connected to 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.

12.4 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

12.5 Maintenance

The IED is self-supervised. No special maintenance is required.

Instructions from the power network company and other maintenance directives valid for maintenance of the power system must be followed.
## Section 13  Glossary

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Alternating current</td>
</tr>
<tr>
<td>ACC</td>
<td>Actual channel</td>
</tr>
<tr>
<td>ACT</td>
<td>Application configuration tool within PCM600</td>
</tr>
<tr>
<td>A/D converter</td>
<td>Analog-to-digital converter</td>
</tr>
<tr>
<td>ADBS</td>
<td>Amplitude deadband supervision</td>
</tr>
<tr>
<td>ADM</td>
<td>Analog digital conversion module, with time synchronization</td>
</tr>
<tr>
<td>AI</td>
<td>Analog input</td>
</tr>
<tr>
<td>ANSI</td>
<td>American National Standards Institute</td>
</tr>
<tr>
<td>AR</td>
<td>Autoreclosing</td>
</tr>
<tr>
<td>ASCT</td>
<td>Auxiliary summation current transformer</td>
</tr>
<tr>
<td>ASD</td>
<td>Adaptive signal detection</td>
</tr>
<tr>
<td>ASDU</td>
<td>Application service data unit</td>
</tr>
<tr>
<td>AWG</td>
<td>American Wire Gauge standard</td>
</tr>
<tr>
<td>BBP</td>
<td>Busbar protection</td>
</tr>
<tr>
<td>BFOC/2,5</td>
<td>Bayonet 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>EHV network</td>
<td>Extra high voltage network</td>
</tr>
<tr>
<td>EIA</td>
<td>Electronic Industries Association</td>
</tr>
<tr>
<td>EMC</td>
<td>Electromagnetic compatibility</td>
</tr>
<tr>
<td>EMF</td>
<td>Electromotive force</td>
</tr>
<tr>
<td>EMI</td>
<td>Electromagnetic interference</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</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>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>HMI</td>
<td>Human-machine interface</td>
</tr>
<tr>
<td>HSAR</td>
<td>High speed autoreclosing</td>
</tr>
<tr>
<td>HV</td>
<td>High-voltage</td>
</tr>
<tr>
<td>HVDC</td>
<td>High-voltage direct current</td>
</tr>
<tr>
<td>IDBS</td>
<td>Integrating deadband supervision</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electrical Committee</td>
</tr>
<tr>
<td>IEC 60044-6</td>
<td>IEC Standard, Instrument transformers – Part 6: Requirements for protective current transformers for transient performance</td>
</tr>
<tr>
<td>IEC 60870-5-103</td>
<td>Communication standard for protection equipment. A serial master/slave protocol for point-to-point communication</td>
</tr>
<tr>
<td>IEC 61850</td>
<td>Substation automation communication standard</td>
</tr>
<tr>
<td>IEC 61850–8–1</td>
<td>Communication protocol standard</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>IEEE 802.12</td>
<td>A network technology standard that provides 100 Mbits/s on twisted-pair or optical fiber cable</td>
</tr>
<tr>
<td>IEEE P1386.1</td>
<td>PCI Mezzanine Card (PMC) standard for local bus modules. References the CMC (IEEE P1386, also known as Common Mezzanine Card)</td>
</tr>
</tbody>
</table>
IEEE 1686
Standard for Substation Intelligent Electronic Devices (IEDs) Cyber Security Capabilities

IED
Intelligent electronic device

I-GIS
Intelligent gas-insulated switchgear

IOM
Binary input/output module

Instance
When several occurrences of the same function are available in the IED, they are referred to as instances of that function. One instance of a function is identical to another of the same kind but has a different number in the IED user interfaces. The word “instance” is sometimes defined as an item of information that is representative of a type. In the same way an instance of a function in the IED is representative of a type of function.

IP
1. Internet protocol. The network layer for the TCP/IP protocol suite widely used on Ethernet networks. IP is a connectionless, best-effort packet-switching protocol. It provides packet routing, fragmentation and reassembly through the data link layer.
2. Ingression protection, according to IEC 60529

IP 20
Ingression protection, according to IEC 60529, level 20

IP 40
Ingression protection, according to IEC 60529, level 40

IP 54
Ingression protection, according to IEC 60529, level 54

IRF
Internal failure signal

IRIG-B:
InterRange Instrumentation Group Time code format B, standard 200

ITU
International Telecommunications Union

LAN
Local area network

LIB 520
High-voltage software module

LCD
Liquid crystal display

LDCM
Line differential communication module

LDD
Local detection device

LED
Light-emitting diode

LNT
LON network tool

LON
Local operating network

MCB
Miniature circuit breaker

MCM
Mezzanine carrier module

MPM
Main processing module

MVAL
Value of measurement

MVB
Multifunction vehicle bus. Standardized serial bus originally developed for use in trains.

NCC
National Control Centre

NOF
Number of grid faults

NUM
Numerical module

OCO cycle
Open-close-open cycle

OCP
Overcurrent protection

OEM
Optical Ethernet module
OLTC  On-load tap changer
OTEV  Disturbance data recording initiated by other event than start/pick-up
OV    Overvoltage
Overreach  A term used to describe how the relay behaves during a fault condition. For example, a distance relay is overreaching when the impedance presented to it is smaller than the apparent impedance to the fault applied to the balance point, that is, the set reach. The relay “sees” the fault but perhaps it should not have seen it.
PCI   Peripheral component interconnect, a local data bus
PCM   Pulse code modulation
PCM600 Protection and control IED manager
PC-MIP Mezzanine card standard
PMC   PCI Mezzanine card
POR   Permissive overreach
POTT  Permissive overreach transfer trip
Process bus  Bus or LAN used at the process level, that is, in near proximity to the measured and/or controlled components
PSM   Power supply module
PST   Parameter setting tool within PCM600
PT ratio  Potential transformer or voltage transformer ratio
PUTT  Permissive underreach transfer trip
RASC  Synchrocheck relay, COMBIFLEX
RCA   Relay characteristic angle
RISC  Reduced instruction set computer
RMS value  Root mean square value
RS422 A balanced serial interface for the transmission of digital data in point-to-point connections
RS485 Serial link according to EIA standard RS485
RTC   Real-time clock
RTU   Remote terminal unit
SA    Substation Automation
SBO   Select-before-operate
SC    Switch or push button to close
SCL   Short circuit location
SCS   Station control system
SCADA Supervision, control and data acquisition
SCT   System configuration tool according to standard IEC 61850
SDU   Service data unit
SLM   Serial communication module.
SMA connector  Subminiature version A, A threaded connector with constant impedance.
SMT   Signal matrix tool within PCM600
SMS   Station monitoring system
SNTP  Simple network time protocol – is used to synchronize computer clocks on local area networks. This reduces the requirement to have accurate hardware clocks in every embedded system in a network. Each embedded node can instead synchronize with a remote clock, providing the required accuracy.

SOF  Status of fault

SPA  Strömberg Protection Acquisition (SPA), a serial master/slave protocol for point-to-point and ring communication.

SRY  Switch for CB ready condition

ST  Switch or push button to trip

Starpoint  Neutral point of transformer or generator

SVC  Static VAr compensation

TC  Trip coil

TCS  Trip circuit supervision

TCP  Transmission control protocol. The most common transport layer protocol used on Ethernet and the Internet.

TCP/IP  Transmission control protocol over Internet Protocol. The de facto standard Ethernet protocols incorporated into 4.2BSD Unix. TCP/IP was developed by DARPA for Internet working and encompasses both network layer and transport layer protocols. While TCP and IP specify two protocols at specific protocol layers, TCP/IP is often used to refer to the entire US Department of Defense protocol suite based upon these, including Telnet, FTP, UDP and RDP.

TEF  Time delayed earth-fault protection function

TLS  Transport Layer Security

TM  Transmit (disturbance data)

TNC connector  Threaded Neill-Concelman, a threaded constant impedance version of a BNC connector

TP  Trip (recorded fault)

TPZ, TPY, TPX, TPS  Current transformer class according to IEC

TRM  Transformer Module. This module transforms currents and voltages taken from the process into levels suitable for further signal processing.

TYP  Type identification

UMT  User management tool

Underreach  A term used to describe how the relay behaves during a fault condition. For example, a distance relay is underreaching when the impedance presented to it is greater than the apparent impedance to the fault applied to the balance point, that is, the set reach. The relay does not “see” the fault but perhaps it should have seen it. See also Overreach.

UTC  Coordinated Universal Time. A coordinated time scale, maintained by the Bureau International des Poids et Mesures (BIPM), which forms the basis of a coordinated dissemination of standard frequencies and time signals. UTC is derived from International Atomic Time (TAI) by the addition of a whole number of “leap seconds” to synchronize it with Universal Time 1 (UT1), thus allowing for the eccentricity of the Earth’s orbit, the rotational axis tilt (23.5 degrees), but still showing the Earth’s irregular rotation, on which UT1 is based. The Coordinated Universal Time is expressed using a 24-hour clock, and uses the Gregorian calendar. It is used for aeroplane and ship navigation, where it is also
sometimes known by the military name, “Zulu time.” "Zulu" in the phonetic alphabet stands for "Z", which stands for longitude zero.

**UV**  
Undervoltage

**WEI**  
Weak end infeed logic

**VT**  
Voltage transformer

**3I_o**  
Three times zero-sequence current. Often referred to as the residual or the earth-fault current

**3U_o**  
Three times the zero sequence voltage. Often referred to as the residual voltage or the neutral point voltage