The SEL-787 Transformer Protection Relay provides unsurpassed protection, integration, and control features in a flexible, compact, and cost-effective package.

➤ **Standard Protection Features.** Two-winding dual-slope differential protection with harmonic blocking and restraint, and phase, negative-sequence, residual-ground, and neutral-ground overcurrent elements provide backup protection. Breaker failure protection is included for two three-pole breakers.

➤ **Optional Protection Features.** Use the SEL-787 with optional voltage inputs to provide volts/hertz protection with frequency tracking from 20 to 70 Hz for generator step-up and other variable frequency applications. Implement load shedding and other control schemes with over- and underfrequency and over- and undervoltage elements. In addition, use Sensitive Restricted Earth Fault (REF) protection for grounded-wye transformers.

➤ **Transformer Monitoring.** Use transformer through-fault monitoring to measure accumulated through-fault levels of the transformer. Monitor ambient, load tap-changer (LTC), tank, and transformer oil temperature through the use of optional 4–20 mA or RTD thermal inputs.

➤ **Operator Controls.** Four programmable front-panel pushbuttons each with two programmable LEDs allow for a wide variety of uses including easy trip and close control and status indications for a breaker. Implement local and remote operator control schemes through use of 32 local and 32 remote control bits.

➤ **Relay and Logic Settings Software.** ACSELERATOR QuickSet® SEL-5030 Software reduces engineering costs for relay settings and logic programming. Tools in QuickSet make it easy to develop SELOGIC® control equations. Use the built-in phasor display to verify proper CT polarity and phasing.

➤ **Metering and Reporting.** Built-in metering functions eliminate separately mounted metering devices. Analyze Sequential Events Recorder (SER) reports and oscillographic event reports for rapid commissioning, testing, and post-fault diagnostics. Unsolicited SER protocol allows station-wide collection of binary SER messages.

➤ **Additional Standard Features.** Includes Modbus RTU, Event Messenger support, MIRRORED BITS® communications, load profile, support for 12 external RTDs (SEL-2600 series module), IRIG-B input, advanced SELOGIC, configurable labels, IEEE C37.118-compliant synchrophasor protocol, and SEL-2812 compatible ST connectors fiber-optic serial port.

➤ **Optional Features.** Select from a wide offering of optional features, including IEC 61850, Modbus TCP/IP, Simple Network Time Protocol (SNTP), DNP3 LAN/WAN, DNP3 Serial, 10 internal RTDs, expanded digital/analog I/O, voltage inputs, additional EIA-232 or EIA-485 communications ports, and single or dual copper wire or fiber-optic Ethernet ports.
Functional Overview

Protection Features

The SEL-787 provides the same dual-slope differential characteristic used in the popular SEL-387 and SEL-587 series of transformer differential relays. The SEL-787 includes a complete set of phase, negative-sequence, and residual overcurrent elements for each winding, as well as REF and neutral-overcurrent elements for grounded wye transformers.

Use as many as 12 independent RTD driven thermal elements with trip and alarm levels to monitor ambient and equipment temperatures throughout the substation.

For the optional volts/hertz element, you can add three-phase voltage inputs that give the SEL-787 volts/hertz protection with definite and time-delay characteristics, along with directional power, over- and underfrequency and voltage elements with two independent pickup levels.

Transformer Differential

The SEL-787 has three restrained differential elements (87R). These elements use operate and restraint quantities calculated from the winding input currents. Set the differential elements with either single- or dual-slope percentage differential characteristics. Figure 2 illustrates a dual-slope setting. The percent-slope characteristic helps prevent unwanted relay operation because of possible unbalance between CTs during external faults. CT unbalance can result from tap changing in the power transformer and error difference between the CTs on either side of a power transformer.
The relay allows you to choose harmonic blocking, harmonic restraint, or both, providing a reliable differential protection during transformer inrush conditions. Even-numbered harmonics (second and fourth) provide security during energization, while fifth-harmonic blocking provides security for overexcitation conditions. Set second-, fourth-, and fifth-harmonic thresholds independently.

An additional alarm function for the fifth-harmonic current employs a separate threshold and an adjustable timer to warn of overexcitation. This may be useful for transformer applications in or near generating stations. A set of unrestrained differential current elements simply compares the differential operating current quantity to a setting value, typically about 10 times the TAP setting. This pickup setting is only exceeded for internal faults.

The three independent unrestrained differential elements (87U) provide rapid assertion without delay when differential operate current levels exceed the 87U pickup threshold that is set depending on the application. Typical 87U pickup level settings are between 8 and 10 per unit of operate current.

**Restricted Earth Fault (REF) Protection**

Apply the REF protection feature to provide sensitive detection of internal ground faults on grounded wye-connected transformer windings and autotransformers. Order the SEL-787 with the Slot E card containing the 1 A or 5 A current input for REF protection. The single-phase 1 A or 5 A CT provided as a Slot E ordering option is used for introduction of neutral CT operating current. Polarizing current is derived from the residual current calculated for the protected winding (Winding 1, Winding 2, or both windings). A sensitive directional element determines whether the fault is internal or external. Zero-sequence current thresholds and selectable CT saturation logic supervise tripping.

**Overcurrent Protection**

The SEL-787 provides complete overcurrent protection for a two-winding transformer. Phase overcurrent protection is provided for both three-phase winding inputs. The following overcurrent elements are provided.

**Instantaneous Overcurrent Elements**

The following instantaneous overcurrent elements are provided in the SEL-787 base configuration. All instantaneous overcurrent elements provide torque control.

- Four instantaneous phase overcurrent (50P) elements for Windings 1 and 2 (eight total). These phase elements operate on the maximum of the phase currents. Level 1 phase overcurrent elements also include per-phase elements. Peak detection algorithms are used to enhance element sensitivity during high fault current conditions, where severe CT saturation may occur.

- Two instantaneous negative-sequence overcurrent (50Q) elements for Windings 1 and 2 (four total). These elements operate on negative-sequence content for each three-phase winding.

- Two residual overcurrent (50G) elements for windings 1 and 2 (four total). These elements use calculated residual (3I0) current levels from each winding for ground fault detection.

When ordered with the optional current channel in Slot E, the SEL-787 also provides two instantaneous neutral-overcurrent elements (50N) with two levels of neutral-overcurrent detection.

**Time-Overcurrent Elements**

The SEL-787 base configuration provides the following time-overcurrent elements. The time-overcurrent elements support the IEC and US (IEEE) time-overcurrent characteristics shown in Table 1. Electromechanical disc reset capabilities are provided for all time-overcurrent elements.

- Eight phase time-overcurrent (51P) elements are provided. These phase elements operate on the individual phases as well as the maximum of the phase currents for each winding.

- Two negative-sequence time-overcurrent (51Q) elements are provided. These elements operate on the calculated negative-sequence current for each set of three-phase winding inputs of the transformer.

- Two residual overcurrent (51G) elements are provided. These elements use calculated residual (3I0) current levels from each winding for ground fault detection.

When ordered with the optional current channel in Slot E, the SEL-787 also provides one neutral time-overcurrent element (51N).
Breaker Failure Protection

The SEL-787 offers breaker failure protection for two three-pole breakers. Use the breaker failure detection to issue re-trip commands to the failed breaker, or to trip adjacent breakers using the relay’s contact output logic or communications-based tripping schemes.

Breaker failure is initiated by the breaker failure initiate (BFI) SELogic input (see Figure 3). The BFI input is typically driven by local and remote open/trip commands to the breaker. Once the BFI input is received, the breaker failure element monitors positive- and negative-sequence current magnitudes and the breaker auxiliary contacts to determine when to initiate the breaker failure delay timer. If current or breaker auxiliary contact status does not indicate an open breaker condition within the time set by the breaker failure delay timer, the element issues a breaker failure trip output.

Volts/Hertz Protection

Overexcitation occurs when the magnetic core of a power apparatus becomes saturated. When saturation occurs stray flux is induced in nonlaminated components, which can result in overheating. By ordering the voltage option to the SEL-787, you can add a volts/hertz element to detect overexcitation. An SEL-787 with optional voltage inputs provides a sensitive definite-time delayed element, plus a tripping element with a composite operating time.

For example, the relay calculates the present transformer volts/hertz as a percentage of nominal, based on present measured values and the nominal voltage and frequency settings. The relay starts a timer when the system voltage causes an excursion that exceeds the volts/hertz overexcitation setting. If the condition remains for the set time delay, the relay asserts and typically provides an alarm function. The element is supervised by a SELogic torque control equation, which enables or disables the element as required by the application.

Use the SEL-5806 Volts/Hertz User Curve Design Software to set the user-defined curve (see Figure 4). For tripping, the relay provides a time integrating element with a settable operating characteristic. You can set the relay element to operate as an inverse-time element, a user-defined curve element, a composite element with an inverse-time characteristic and a definite-time characteristic, or a dual-level, definite-time element.

For any of these operating characteristics, the element provides a linear reset characteristic with a settable reset time. The torque-control setting also supervises this element. The tripping element has a percent-travel operating characteristic similar to that used by an induction-disc, time-overcurrent element. This characteristic emulates the heating effect of overexcitation on transformer components.

Table 1  Time-Overcurrent Curves

<table>
<thead>
<tr>
<th>US (IEEE)</th>
<th>IEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderately Inverse</td>
<td>Standard Inverse</td>
</tr>
<tr>
<td>Inverse</td>
<td>Very Inverse</td>
</tr>
<tr>
<td>Very Inverse</td>
<td>Extremely Inverse</td>
</tr>
<tr>
<td>Extremely Inverse</td>
<td>Long-Time Inverse</td>
</tr>
<tr>
<td>Short-Time Inverse</td>
<td>Short-Time Inverse</td>
</tr>
</tbody>
</table>

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<td>Inverse</td>
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<tr>
<td>Very Inverse</td>
<td>Extremely Inverse</td>
</tr>
<tr>
<td>Extremely Inverse</td>
<td>Long-Time Inverse</td>
</tr>
<tr>
<td>Short-Time Inverse</td>
<td>Short-Time Inverse</td>
</tr>
</tbody>
</table>

Over- and Undervoltage Protection

Phase undervoltage, overvoltage, and sequence overvoltage elements help you create protection and control schemes, such as undervoltage load shedding, or standby generation start/stop commands.

➤ Phase undervoltage elements operate with the minimum of the measured phase voltage magnitudes; these elements operate when any single-phase measurement falls below the set threshold.

➤ Phase overvoltage elements operate with the maximum of the measured phase voltage magnitudes.

➤ The negative-sequence overvoltage elements operate when respective measurements exceed set thresholds.

All voltage elements provide two pickup levels with definite-time delay settings.
Loss-of-Potential Detection
The SEL-787 with optional voltage inputs contains loss-of-potential (LOP) detection logic on the three-phase voltage input to the relay. The LOP logic detects open voltage transformer fuses or other conditions that cause a loss of relay secondary voltage input. The SEL-787 with optional voltage inputs includes LOP logic that detects one, two, or three open potential fuses. This patented LOP logic is unique, as it does not require settings and is universally applicable. The LOP feature allows for the blocking of protection elements to add security during fuse failure.

Over- and Underfrequency Protection
The SEL-787 with optional voltage inputs provides four over- and underfrequency elements. Each element operates as either an over- or underfrequency element with or without time delay, depending on the element pickup setting.

If the element pickup setting is less than the nominal system frequency setting, the element operates as an underfrequency element, picking up if the measured frequency is less than the set point. If the pickup setting exceeds the nominal system frequency, the element operates as an overfrequency element, picking up if the measured frequency exceeds the set point.

The SEL-787 with optional voltage inputs uses the positive sequence voltage to determine system frequency. All frequency elements are disabled if the positive sequence voltage is less than the minimum voltage threshold.

Directional Power Element Protection
The SEL-787 with optional voltage inputs provides two directional power elements for detecting real (watts) or reactive (VARs) directional power flow levels for the transformer winding associated with the three-phase voltage input. Each directional power element has a definite-time delay setting.

RTD Thermal Protection
When the SEL-787 is equipped with either the optional 10 RTD input expansion card or an external SEL-2600 RTD module with as many as 12 RTD inputs, as many as 12 thermal elements in the relay can be programmed for two levels of thermal protection per element. Each RTD input provides an alarm and trip thermal pickup setting in degrees C or F, provides open and shorted RTD detection, and is compatible with the following three-wire RTD types:
- PT100 (100 Ω platinum)
- NI100 (100 Ω nickel)
- NI120 (120 Ω nickel)
- CU10 (10 Ω copper)

Operator Controls
Operator Controls Eliminate Traditional Panel Control Switches
Four conveniently sized operator controls are located on the relay front panel (see Figure 5). The SER can be set to track operator controls. Change operator control functions by using SELOGIC control equations.

The following operator control descriptions are for factory-set logic.

Lock: The LOCK operator control blocks selected functions. Press it for at least three seconds to engage or disengage the lock function. While locked in position, the following operator controls cannot change state if pressed: TRIP and CLOSE.

Select: The SELECT operator control selects the control of Breaker 1 or Breaker 2. The indicating LED for the pushbutton indicates the selected breaker. The selected breaker can then be controlled using the CLOSE and TRIP pushbuttons.

Close and Trip: Use the CLOSE and TRIP operator controls to close and open the connected circuit breaker. They can be programmed with intentional time delays to support operational requirements for breaker-mounted relays. This allows the operator to press the CLOSE or TRIP pushbutton, then move to an alternate location before the breaker command is executed.

Figure 5 Operator Controls (Standard Model)
All text can be changed with the configurable labels.
## Relay and Logic Settings Software

QuickSet software simplifies settings and provides analysis support for the SEL-787. With QuickSet you have several ways to create and manage relay settings:

➤ Develop settings offline with an intelligent settings editor that only allows valid settings
➤ Create SELogic control equations with a drag-and-drop text editor
➤ Configure proper settings by using online help
➤ Organize settings with the relay database manager
➤ Load and retrieve settings through use of a simple PC communications link

With QuickSet, you can verify settings and analyze events and analyze power system events with the integrated waveform and harmonic analysis tools.

## Metering and Monitoring

The SEL-787 provides extensive metering capabilities. See Specifications for metering and power measurement accuracies. As shown in Table 2, metered quantities include phase voltages and currents, neutral currents; sequence voltages and currents; harmonics, power, frequency, and energy; and maximum/minimum logging of selected quantities.

### Table 2  SEL-787 Metered Values

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{xWn}$ ($x = A, B, C \ n = 1, 2$)</td>
<td>Winding phase current magnitude and angle, primary A</td>
</tr>
<tr>
<td>IN1</td>
<td>Neutral current magnitude and angle, primary A</td>
</tr>
<tr>
<td>IG$Wn$ ($n = 1, 2$)</td>
<td>Residual-ground fault current and angle per winding, primary A</td>
</tr>
<tr>
<td>$3I_{2Wn}$ ($n = 1, 2$)</td>
<td>Negative-sequence current and angle per winding, primary A</td>
</tr>
<tr>
<td>IOP$z$ ($z = 1, 2, 3$)</td>
<td>Differential operate current, scaled to TAP</td>
</tr>
<tr>
<td>IRT$z$ ($z = 1, 2, 3$)</td>
<td>Differential restraint current, scaled to TAP</td>
</tr>
<tr>
<td>InF2, InF4, InF5 ($n = 1, 2$)</td>
<td>Current harmonics, InF2/IOPn (%) for second-, fourth-, fifth-harmonics</td>
</tr>
<tr>
<td>VA, VB, VC</td>
<td>Phase voltages and angles, primary volts, for wye-connected potential transformers</td>
</tr>
<tr>
<td>VAB, VBC, VCA</td>
<td>Phase-to-phase voltages and angles, primary volts, for delta-connected potential transformers</td>
</tr>
<tr>
<td>VG</td>
<td>Residual-ground voltage and phase angle, primary volts, for wye-connected potential transformers</td>
</tr>
<tr>
<td>$3V2$</td>
<td>Negative-sequence voltage and phase angle, primary volts</td>
</tr>
<tr>
<td>kVA, kW, kVAR</td>
<td>Calculated apparent, real, and reactive power scaled to primary values</td>
</tr>
<tr>
<td>MWh, MVARh</td>
<td>Three-phase positive and negative megawatt-hours, megavolt-ampere reactive hour</td>
</tr>
<tr>
<td>PF</td>
<td>Power factor (leading or lagging)</td>
</tr>
<tr>
<td>V/Hz</td>
<td>Calculated volts/hertz in percent, using highest measured voltage and measured frequency</td>
</tr>
<tr>
<td>FREQ</td>
<td>Measured system frequency (Hz)</td>
</tr>
<tr>
<td>RTD$n$ ($n = 1$ to $12$)</td>
<td>RTD temperature measurement (degrees C)</td>
</tr>
</tbody>
</table>
Synchronized Phasor Measurement

Combine the SEL-787 with an SEL IRIG-B time source to measure the system angle in real time with a timing accuracy of ±10 µs. Measure instantaneous voltage and current phase angles in real time to improve system operation with synchrophasor information. Replace state measurement, study validation, or track system stability. Use SEL-5077 SYNCHROWAVE® Server Software or SEL-5078-2 SYNCHROWAVE® Central Visualization and Analysis Software to view system angle at multiple locations for precise system analysis and system-state measurement (see Figure 6).

![Figure 6 View of System Angle at Multiple Locations](image)

Through-Fault Monitoring

A through fault is an overcurrent event external to the differential protection zone. While a through fault is not an in-zone event, the currents required to feed this external fault can cause great stress on the apparatus inside the differential protection zone. Through-fault currents can cause transformer winding displacement leading to mechanical damage and increased transformer thermal wear. An SEL-787 through-fault event monitor gathers current level, duration, and date/time for each through fault. The monitor also calculates a simple $I^2t$ and cumulatively stores these data per phase. Use through-fault event data to schedule proactive transformer bank maintenance and help justify through-fault mitigation efforts. Apply the accumulated alarm capability of the relay to indicate excess through-fault current ($I^2t$) over time.

Event Reporting and Sequential Events Recorder (SER)

Event reports and the SER simplify post-fault analysis and improve understanding of simple and complex protective scheme operations. In response to a user-selected trigger, the voltage, current, frequency, and element status information contained in each event report confirms the relay scheme and system performance for every fault. Decide how much detail is necessary when you request an event report (e.g., 1/4-cycle or 1/16-cycle resolution, filtered or raw analog data).

The relay stores as many as 25 of the most recent 64-cycle event reports or as many as 100 15-cycle event reports in nonvolatile memory. The relay always appends relay settings to the bottom of each event report.

The following analog data formats are available:

- 1/4-cycle or 1/16-cycle resolution
- Unfiltered or filtered analog
- ASCII or Compressed ASCII

The relay SER feature stores the latest 1024 entries. Use this feature to gain a broad perspective at a glance. An SER entry helps to monitor input/output change-of-state occurrences, element pickup/dropout.

The IRIG-B time-code input synchronizes the SEL-787 time to within ±5 ms of the time-source input. A convenient source for this time code is an SEL-2401 Satellite-Synchronized Clock or the SEL-2032, SEL-2030, or SEL-2020 Communications Processor (via serial Port 3 on the SEL-787).

Available reports, which also show the status of digital inputs and outputs, include:

- **Analog event reports** that use filtered data and show all analog channels at 4 samples per cycle
- **Digital event reports** that show pickup of protection elements including overcurrent, demand, voltage overexcitation, frequency, and over- and undervoltage elements at 4 samples per cycle
- **Differential event reports** that show differential quantities, element pickup, SEL LOGIC control equation set variables, and inputs and outputs at 4 samples per cycle
- **Raw analog event reports** that use unfiltered data at 16 samples per cycle
Automation

Flexible Control Logic and Integration Features

The SEL-787 is equipped with as many as four independently operated serial ports: one EIA-232 port on the front, one EIA-232 or EIA-485 port on the rear, one fiber-optic port, and one EIA-232 or EIA-485 port option card. The relay does not require special communications software. Use any system that emulates a standard terminal system for engineering access to the relay.

Establish communication by connecting computers, modems, protocol converters, printers, an SEL-2032, SEL-2030 or SEL-2020 Communications Processor, SCADA serial port, or an RTU for local or remote communication. Refer to Table 3 for a list of communications protocols available in the SEL-787. Apply an SEL communications processor as the hub of a star network, with point-to-point fiber or copper connection between the hub and the SEL-787.

Table 3 Communications Protocols

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple ASCII</td>
<td>Plain language commands for human and simple machine communications. Use for metering, setting, self-test status, event reporting, and other functions.</td>
</tr>
</tbody>
</table>
| Compressed ASCII          | Comma-delimited ASCII data reports.
Allow external devices to obtain relay data in an appropriate format for direct import into spreadsheets and database programs.
Data are checksum protected. |
| Extended Fast Meter and Fast Operate | Binary protocol for machine-to-machine communications.
Quickly updates SEL-2032, SEL-2030, and SEL-2020 communications processors, RTUs, and other substation devices with metering information, relay element, I/O status, time-tags, open and close commands, and summary event reports.
Data are checksum protected.
Binary and ASCII protocols operate simultaneously over the same communications lines so control operator metering information is not lost while a technician is transferring an event report.
Direct communications with the SEL-2600 RTD Module are possible using the unsolicited Fast Meter protocol to read incoming temperature data from the SEL-2600. |
| Fast SER Protocol         | Provides SER events to an automated data collection system. |
| DNP3                      | Serial or Ethernet-based DNP3 protocols.
Provide default and mappable DNP3 objects that include access to metering data, protection elements, Relay Word bits, contact I/O, targets, SER, relay summary event reports, and setting group selection. |
| Modbus                    | Serial- or Ethernet-based Modbus protocol with point remapping.
Includes access to metering data, protection elements, contact I/O, targets, SER, relay summary event reports, and setting groups. |
| IEC 61850                 | Ethernet-based international standard for interoperability between intelligent devices in a substation.
Operates remote bits and I/O. Monitors Relay Word bits and analog quantities. |
| Synchrophasors            | IEEE C37.118-compliant synchrophasors for system state, response, and control capabilities. |
| Event Messenger           | With the use of the SEL-3010 allows user to receive alerts sent directly to your cell phone. Alerts can be triggered through relay events and can include measured quantities by the relay. |
| DeviceNet                 | Allows for connection to a DeviceNet network for access to metering data, protection elements, contact I/O, targets, and setting groups. |
| SNTP                      | Ethernet-based protocol that provides time synchronization of the relay. |

SEL-787 control logic improves integration in the following ways:

➤ **Replaces traditional panel control switches.** Eliminate traditional panel control switches with 32 local bits. Set, clear, or pulse local bits with the front-panel pushbuttons and display. Program the local bits into your control scheme with SELOGIC control equations. Use the local bits to perform functions such as a trip test or a breaker trip/close.

➤ **Eliminates RTU-to-relay wiring.** Eliminate RTU-to-relay wiring with 32 remote bits. Set, clear, or pulse remote bits through use of serial port commands. Program the remote bits into your control scheme with SELOGIC control equations. Use remote bits for SCADA-type control operations such as trip, close, and settings group selection.
Replaces traditional latching relays. Replace as many as 32 traditional latching relays for such functions as “remote control enable” with latch bits. Program latch set and latch reset conditions with SELOGIC control equations. Set or reset the nonvolatile latch bits by using optoisolated inputs, remote bits, local bits, or any programmable logic condition. The latch bits retain their state when the relay loses power.

Replaces traditional indicating panel lights. Replace traditional indicating panel lights with 32 programmable displays. Define custom messages (e.g., Breaker Open, Breaker Closed) to report power system or relay conditions on the front-panel display. Use advanced SELOGIC control equations to control what messages the relay displays.

Eliminates external timers. Eliminate external timers for custom protection or control schemes with 32 general purpose SELOGIC control equation timers. Each timer has independent time-delay pickup and dropout settings. Program each timer input with the element you want (e.g., time qualify a current element). Assign the timer output to trip logic, transfer trip communications, or other control scheme logic.

Eliminates settings changes. Selectable setting groups make the SEL-787 ideal for applications requiring frequent setting changes and for adapting the protection to changing system conditions. The relay stores four setting groups. Select the active setting group by optoisolated input, command, or other programmable conditions. Use these setting groups to cover a wide range of protection and control contingencies. Switching setting groups switches logic and relay element settings. Program groups for different operating conditions, such as rental/spare transformer applications, station maintenance, seasonal operations, emergency contingencies, loading, source changes, and downstream relay setting changes.

Fast SER Protocol
SEL Fast Sequential Events Recorder (SER) protocol provides SER events to an automated data collection system. SEL Fast SER protocol is available on any rear serial port. Devices with embedded processing capability can use these messages to enable and accept unsolicited binary SER messages from SEL-787 relays. SEL relays and communications processors have two separate data streams that share the same serial port. The normal serial interface consists of ASCII character commands and reports that are intelligible to people using a terminal or terminal emulation package. The binary data streams can interrupt the ASCII data stream to obtain information, and then allow the ASCII data stream to continue. This mechanism allows a single communications channel to be used for ASCII communications (e.g., transmission of a long event report) interleaved with short bursts of binary data to support fast acquisition of metering or SER data.

Ethernet Network Architectures

Set Port 1 (Ethernet) settings in each relay.

Figure 7 Simple Ethernet Network Configuration
Additional Features

**MIRRORED BITS Relay-to-Relay Communications**

The SEL-patented MIRRORED BITS communications technology provides bidirectional relay-to-relay digital communication. The MIRRORED BITS technology can operate independently on as many as two EIA-232 rear serial ports and one fiber-optic rear serial port on a single SEL-787.

This bidirectional digital communication creates eight additional virtual outputs (transmitted MIRRORED BITS) and eight additional virtual inputs (received MIRRORED BITS) for each serial port operating in the MIRRORED BITS mode (see Figure 10). Use these MIRRORED BITS to transmit/receive information between upstream relays and a downstream relay to enhance coordination and achieve faster tripping for downstream faults. MIRRORED BITS technology also helps reduce total scheme operating time by eliminating the need to assert output contacts to transmit information.

**Figure 10 MIRRORED BITS Transmit and Receive Bits**
Status and Trip Target LEDs

The SEL-787 includes 16 status and trip target LEDs on the front panel. When shipped from the factory, all LEDs are predefined and fixed in settings. You can reprogram these LEDs for specific applications. This combination of targets is explained and shown in Figure 13. Some front-panel relabeling of LEDs may be needed if you reprogram them for unique or specific applications—see Configurable Labels.

Event Messenger Points

The SEL-787, when used with the SEL-3010 Event Messenger, can allow for ASCII-to-voice translation of as many as 32 user-defined messages, along with analog data that have been measured or calculated by the relay. This combination can allow the user to receive voice messages on any phone for alerts to transition of any Relay Word bits in the relay. Verbal notification of breaker openings, fuse failures, RTD alarms, etc. can now be sent directly to your cell phone through the use of your SEL-787 and SEL-3010 (must be connected to an analog telephone line). In addition, messages can include an analog value such as current, voltage, or power measurements made by the SEL-787.

Configurable Labels

Use the configurable labels to relabel the operator controls and LEDs (shown in Figure 13) to suit the installation requirements. This feature includes preprinted labels (with factory-default text), blank label media, and a Microsoft Word template on CD-ROM. This allows for quick, professional-looking labels for the SEL-787. Labels may also be customized without the use of a PC by writing the new label on the blank stock provided. The ability to customize the control and indication features allows specific utility or industry procedures to be implemented without the need for adhesive labels. All of the figures in this data sheet show the factory-default labels of the SEL-787, including the standard model shown in Figure 13.

Relay Dimensions

![CHASSIS Diagram](image)

**Figure 11** SEL-787 Dimensions for Rack- and Panel-Mount Models
Figure 12  Wiring Diagram for SEL-787 Transformer Protection Relay

** SEL Fiber-Optic Cables
240-1506 – 1 m (3.3 ft) ST/ST
240-1507 – 5 m (16.4 ft) ST/ST
240-1508 – 15 m (49.2 ft) ST/ST
Other lengths available by request

A diagram for a four-wire wye connection is also available in the instruction manual.
Relay Panel Diagrams

Figure 13  Front Panel With Default Configurable Labels

Figure 14  Dual-Fiber Ethernet, EIA-232 Communication, 3 DI/4 DO/1 AO, and Current/Voltage Option
Figure 15  Single Copper Ethernet, 8 DI, RTD, and 4 AI/4 AO Option

Figure 16  DeviceNet, Fast Hybrid 4 DI/4 DO, and Current/Voltage Option
Application

The SEL-787 is designed to provide differential and overcurrent protection for two-winding power transformers, generator step-up transformers and autotransformers. In addition, the SEL-787 contains advanced integration and control features that will allow its application in a wide variety of automation and control schemes.

Use the optional Slot E single-phase CT channel along with the RTD thermal elements to provide fan bank control and protection as shown in Figure 17. Use additional RTD thermal elements to monitor load tap-changer (LTC) tank temperatures and SELOGIC programming to indicate temperature differential alarms between transformer and LTC tank temperatures.

Apply the transformer through-fault monitoring of the SEL-787 to keep track of accumulated through-fault $I^2t$ values. Monitor the number of through-faults, accumulated $I^2t$, and fault duration times to determine the frequency (through-fault events per day, week, month, or year) and impact of external faults on the transformer.

![Figure 17  Transformer Fan Bank Control With LTC Monitoring](image-url)
Specifications

Compliance

Designed and manufactured under an ISO 9001 certified quality management system

49 CFR 15B, Class A

This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

UL Listed to U.S. and Canadian safety standards (File E212775, NRGU, NRGU7)
CE Mark
RCM Mark

Hazardous Locations

UL Certified Hazardous Locations to U.S. and Canadian standards (File E470448)
EU


Note: Where so marked, ATEX and UL Hazardous Locations Certification tests are applicable to rated supply specifications only and do not apply to the absolute operating ranges, continuous thermal, or short circuit duration specifications.

General

AC Current Input

Phase and Neutral Currents

\( I_{\text{NOM}} = 1 \text{ A or 5 A secondary depending on model} \)

<table>
<thead>
<tr>
<th>( I_{\text{NOM}} = 5 \text{ A} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Rating:</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>A/D Measurement Limit:</td>
</tr>
<tr>
<td>1-Second Thermal:</td>
</tr>
<tr>
<td>Burden (Per Phase):</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( I_{\text{NOM}} = 1 \text{ A} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Rating:</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>A/D Measurement Limit:</td>
</tr>
<tr>
<td>1-Second Thermal:</td>
</tr>
<tr>
<td>Burden (Per Phase):</td>
</tr>
<tr>
<td>Measurement Category:</td>
</tr>
</tbody>
</table>

AC Voltage Inputs

\( V_{\text{NOM}} \) (L-L secondary)

Range:

- 100–250 V (if \( \text{DELTA}_Y := \text{DELTA} \))
- 100–440 V (if \( \text{DELTA}_Y := \text{WYE} \))

Rated Continuous Voltage: 300 Vac

10-Second Thermal: 600 Vac

<table>
<thead>
<tr>
<th>Vphase</th>
<th>Burden Input Impedance (Per Phase)</th>
<th>Input Impedance (Phase-to-Phase)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.008 VA @ 120 Vac</td>
<td>2 MΩ</td>
<td>4 MΩ</td>
</tr>
</tbody>
</table>

Power Supply

- Relay Start-Up Time: Approximately 5–10 seconds (after power is applied until the ENABLED LED turns on)

High-Voltage Supply

- Rated Supply Voltage: 110–240 Vac, 50/60 Hz
- Input Voltage Range (Design Range): 85–264 Vac
- Power Supply: 85–300 Vdc
- Power Consumption: <50 VA (ac) <25 W (dc)
- Interruptions: 50 ms @ 125 Vac/Vdc
- 100 ms @ 250 Vac/Vdc

Low-Voltage Supply

- Rated Supply Voltage: 24–48 Vdc
- Input Voltage Range (Design Range): 19.2–60.0 Vdc
- Power Consumption: <25 W (dc)
- Interruptions: 10 ms @ 24 Vdc
- 50 ms @ 48 Vdc

Fuse Ratings

LV Power Supply Fuse

- Rating: 3.15 A
- Maximum Rated Voltage: 300 Vdc, 250 Vac
- Breaking Capacity: 1500 A at 250 Vac
- Type: Time-lag T

HV Power Supply Fuse

- Rating: 3.15 A
- Maximum Rated Voltage: 300 Vdc, 250 Vac
- Breaking Capacity: 1500 A at 250 Vac
- Type: Time-lag T
- Heater Fuses F2, F3: 5 A, 125 V slow blow
- 125 Vdc/50 A break rating

Output Contacts

General

The relay supports Form A, B, and C outputs.

Dielectric Test Voltage: 2500 Vac

Impulse Withstand Voltage (\( U_{\text{IMP}} \)): 5000 V

Mechanical Durability: 100,000 no-load operations

Standard Contacts

- Pickup/Dropout Time: \( \leq 8 \text{ ms (coil energization to contact closure)} \)

DC Output Ratings

- Rated Operational Voltage: 250 Vdc
- Rated Voltage Range: 19.2–275 Vdc
- Rated Insulation Voltage: 300 Vdc
- Make: 30 A @ 250 Vdc per IEEE C37.90
- Continuous Carry: 6 A @ 70°C
- 4 A @ 85°C
- 1-Second Thermal: 50 A
- Contact Protection: 360 Vdc, 115 J MOV protection across open contacts
**Breaking Capacity (10,000 Operations) per IEC 60255-0-20:1974:**

- **24 Vdc**
  - 0.75 A L/R = 40 ms
- **48 Vdc**
  - 0.50 A L/R = 40 ms
- **125 Vdc**
  - 0.30 A L/R = 40 ms
- **250 Vdc**
  - 0.20 A L/R = 40 ms

**Cyclic (2.5 Cycles/Second) per IEC 60255-0-20:1974:**

- **24 Vdc**
  - 0.75 A L/R = 40 ms
- **48 Vdc**
  - 0.50 A L/R = 40 ms
- **125 Vdc**
  - 0.30 A L/R = 40 ms
- **250 Vdc**
  - 0.20 A L/R = 40 ms

**AC Output Ratings**

- **Maximum Operational Voltage (Ue)** Rating: 240 Vac
- **Insulation Voltage (Ui)** Rating (excluding EN 61010-1): 300 Vac
- **1-Second Thermal:** 50 A
- **Contact Rating Designation:** B300

**Utilization Category:** AC-15

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Maximum Current</th>
<th>Max VA</th>
</tr>
</thead>
<tbody>
<tr>
<td>120 Vac</td>
<td>240 Vac</td>
<td></td>
</tr>
<tr>
<td>30 A</td>
<td>15 A</td>
<td>3600</td>
</tr>
<tr>
<td>3 A</td>
<td>1.5 A</td>
<td>360</td>
</tr>
</tbody>
</table>

**Voltage Protection Across Open Contacts:** 270 Vac, 115 J

**Fast Hybrid (High-Speed, High-Current Interrupting)**

**DC Output Ratings**

- **Rated Operational Voltage:** 250 Vdc
- **Rated Voltage Range:** 19.2–275 Vdc
- **Rated Insulation Voltage:** 300 Vdc
- **Make:** 30 A @ 250 Vdc per IEEE C37.90
- **Carry:** 6 A @ 70°C
- **4 A @ 85°C**

**1-Second Thermal:** 50 A

**Open State Leakage Current:** <500 µA

**MOV Protection (maximum voltage):** 250 Vac/330 Vdc

**Pickup Time:** <50 µs, resistive load

**Dropout Time:** <8 ms, resistive load

**Breaking Capacity (10,000 Operations) per IEC 60255-0-20:1974:**

- **48 Vdc**
  - 10.0 A L/R = 40 ms
- **125 Vdc**
  - 10.0 A L/R = 40 ms
- **250 Vdc**
  - 10.0 A L/R = 20 ms

**Cyclic Capacity (4 Cycles in 1 Second, Followed by 2 Minutes Idle for Thermal Dissipation) per IEC 60255-0-20:1974:**

- **48 Vdc**
  - 10.0 A L/R = 40 ms
- **125 Vdc**
  - 10.0 A L/R = 40 ms
- **250 Vdc**
  - 10.0 A L/R = 20 ms

**AC Output Ratings**

See **AC Output Ratings for Standard Contacts.**

---

**Optoisolated Control Inputs**

When Used With DC Control Signals

- **250 V:** ON for 200–312.5 Vdc
  - OFF below 150 Vdc
- **220 V:** ON for 176–275 Vdc
  - OFF below 132 Vdc
- **125 V:** ON for 100–156.2 Vdc
  - OFF below 75 Vdc
- **110 V:** ON for 88–137.5 Vdc
  - OFF below 66 Vdc
- **48 V:**
  - ON for 38.4–60 Vdc
  - OFF below 28.8 Vdc
- **24 V:**
  - ON for 15–30 Vdc
  - OFF for <5 Vdc

When Used With AC Control Signals

- **250 V:**
  - ON for 170.6–312.5 Vac
  - OFF below 106 Vac
- **220 V:**
  - ON for 150.2–275 Vac
  - OFF below 93.3 Vac
- **125 V:**
  - ON for 85–156.2 Vac
  - OFF below 53 Vac
- **110 V:**
  - ON for 75.1–137.5 Vac
  - OFF below 46.6 Vac
- **48 V:**
  - ON for 32.8–60 Vac
  - OFF below 20.3 Vac
- **24 V:**
  - ON for 14–30 Vac
  - OFF below 5 Vac

Current draw at nominal dc voltage:

- 2 mA (at 220–250 V)
- 4 mA (at 48–125 V)
- 10 mA (at 24 V)

**Rated Impulse Withstand Voltage (U_imp):** 4000 V

**Analog Output (Optional)**

<table>
<thead>
<tr>
<th>1A0</th>
<th>4A0</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current:</strong></td>
<td>4–20 mA</td>
</tr>
<tr>
<td><strong>Voltage:</strong></td>
<td>—</td>
</tr>
<tr>
<td><strong>Load at 1 mA:</strong></td>
<td>—</td>
</tr>
<tr>
<td><strong>Load at 20 mA:</strong></td>
<td>0–300 Ω</td>
</tr>
<tr>
<td><strong>Load at 10 V:</strong></td>
<td>—</td>
</tr>
<tr>
<td><strong>Refresh Rate:</strong></td>
<td>100 ms</td>
</tr>
<tr>
<td><strong>% Error, Full Scale, at 25°C:</strong></td>
<td>±1%</td>
</tr>
</tbody>
</table>

**Select From:** Analog quantities available in the relay

**Analog Inputs (Optional)**

- **Maximum Input Range:** ±20 mA
- **±10 V**
  - Operational range set by user
- **Input Impedance:**
  - 200 Ω (current mode)
  - >10 kΩ (voltage mode)
- **Accuracy at 25°C:**
  - With user calibration: 0.05% of full scale (current mode)
  - 0.025% of full scale (voltage mode)
  - Without user calibration: Better than 0.5% of full scale at 25°C
- **Accuracy Variation With Temperature:** ±0.015% per °C of full-scale
  - (±20 mA or ±10 V)

**Frequency and Phase Rotation**

- **System Frequency:** 50, 60 Hz
- **Phase Rotation:** ABC, ACB
- **Frequency Tracking:** 20–70 Hz (requires ac voltage inputs option)
**Time-Code Input**
Format: Demodulated IRIG-B
On (1) State: \( V_{ih} \geq 2.2 \, \text{V} \)
Off (0) State: \( V_{il} \leq 0.8 \, \text{V} \)
Input Impedance: \( 2 \, \text{k}\Omega \)
Synchronization Accuracy:
- Internal Clock: \( \pm 1 \, \mu\text{s} \)
- Synchrophasor Reports (e.g., MET PM): \( \pm 10 \, \mu\text{s} \)
- All Other Reports: \( \pm 5 \, \text{ms} \)
**Communications Ports**
Standard EIA-232 (2 ports)
- Location: Front Panel
- Rear Panel
- Data Speed: 300–38400 bps
EIA-485 Port (optional)
- Location: Rear Panel
- Data Speed: 300–19200 bps
Ethernet Port (optional)
- Single/Dual 10/100BASE-T copper (RJ45 connector)
- Single/Dual 100BASE-FX (LC connector)
- Location: Front Panel
- Rear Panel
- Data Speed: 300–38400 bps
**Fiber-Optic Ports Characteristics**
Port 1 (or 1A, 1B) Ethernet
- Wavelength: 1300 nm
- Optical Connector Type: LC
- Fiber Type: Multimode
- Link Budget: 16.1 dB
- Typical TX Power: –15.7 dBm
- RX Min. Sensitivity: –31.8 dBm
- Fiber Size: 62.5/125 \( \mu \text{m} \)
- Approximate Range: –6.4 km
- Data Rate: 100 Mbps
- Typical Fiber Attenuation: –2 dB/km
Port 2 Serial (SEL-2812 compatible)
- Wavelength: 820 nm
- Optical Connector Type: ST
- Fiber Type: Multimode
- Link Budget: 8 dB
- Typical TX Power: –16 dBm
- RX Min. Sensitivity: –24 dBm
- Fiber Size: 62.5/125 \( \mu \text{m} \)
- Approximate Range: –1 km
- Data Rate: 5 Mbps
- Typical Fiber Attenuation: –4 dB/km
**Optional Communications Cards**
- Option 1: EIA-232 or EIA-485 communications card
- Option 2: DeviceNet communications card
**Communications Protocols**
- SEL, Modbus, DNP, FTP, TCP/IP, Telnet, SNTP, IEC 61850, MIRRORED
- BTS Communications, EVMSG, C37.118 (synchrophasors), and DeviceNet. See Table 7.3 for details.

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**Operating Temperature**
IEC Performance Rating: –40° to +85°C (–40° to +185°F)
(per IEC/EN 60068-2-1 & 60068-2-2)

**NOTE:** Not applicable to UL applications.

**NOTE:** LCD contrast is impaired for temperatures below –20°C and above +70°C

**DeviceNet Communications**
- Card Rating: +60°C (140°F) maximum

**Operating Environment**
- Pollution Degree: 2
- Overvoltage Category: II
- Atmospheric Pressure: 80–110 kPa
- Relative Humidity: 5%–95%, noncondensing
- Maximum Altitude: 2000 m

**Dimensions**
- 144.0 mm (5.67 in) x 192.0 mm (7.56 in) x 147.4 mm (5.80 in)

**Weight**
- 2.7 kg (6.0 lb)

**Relay Mounting Screws (#8-32) Tightening Torque**
- Minimum: 1.4 Nm (12 in-lb)
- Maximum: 1.7 Nm (15 in-lb)

**Terminal Connections**
- Terminal Block
- Screw Size: #6
- Ring Terminal Width: 0.310 in maximum
- Terminal Block Tightening Torque
- Minimum: 0.9 Nm (8 in-lb)
- Maximum: 1.4 Nm (12 in-lb)
- Compression Plug Tightening Torque
- Minimum: 0.5 Nm (4.4 in-lb)
- Maximum: 1.0 Nm (8.8 in-lb)
- Compression Plug Mounting Ear Screw Tightening Torque
- Minimum: 0.18 Nm (1.6 in-lb)
- Maximum: 0.25 Nm (2.2 in-lb)

**Product Standards**
- Electromagnetic: IEC 60255-26:2013
- UL 508
- CSA C22.2 No. 14-05

**Type Tests**

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**Environmental Tests**
- IP65 enclosed in panel
- IP50-rated terminal dust protection assembly (SEL Part #915900170).
- The 10°C temperature derating applies to the temperature specifications of the relay.
- IEC 60255-27:2013, Section 10.6.2.1
- Endurance: Class 2
- Response: Class 2
- IEC 60255-27:2013, Section 10.6.2.2
- IEC 60255-27:2013, Section 10.6.2.3
- Withstand: Class 1
- Response: Class 2
- Bump: Class 1
- Seismic (Quake Response): IEC 60255-21-3:1993
- IEC 60255-27:2013, Section 10.6.2.4
- Response: Class 2
Cold:  
IEC 60068-2-1:2007
IEC 60255-27:2013, Section 10.6.1.2
–40°C, 16 hours

Dry Heat:  
IEC 60068-2-2:2007
IEC 60255-27:2013, Section 10.6.1.1
85°C, 16 hours

Damp Heat, Steady State:  
IEC 60068-2-7:2001
IEC 60255-27:2013, Section 10.6.1.5
Severity Level: 93% relative humidity minimum
40°C, 10 days

Damp Heat, Cyclic:  
IEC 60068-2-30:2001
IEC 60255-27:2013, Section 10.6.1.6
Test Db; Variant 2; 25°–55°C, 6 cycles, 95% relative humidity minimum

Dielectric Strength and Impulse Tests
Dielectric (HiPot):  
IEC 60255-27:2013, Section 10.6.4.3
IEEE C37.90-2005
1.0 kVac on analog outputs, Ethernet ports
2.0 kVac on analog inputs, IRIG
2.5 kVac on contact I/O
3.6 kVdc on power supply, IN and VN terminals

Impulse:  
IEC 60255-27:2013, Section 10.6.4.2
Severity Level: 0.5 J, 5 kV on power supply, contact I/O, ac current, and voltage inputs
0.5 J, 530 V on analog outputs
IEEE C37.90:2005
Severity Level: 0.5 J, 5 kV
0.5 J, 530 V on analog outputs

RFI and Interference Tests
EMC Immunity
Electrostatic Discharge Immunity:  
IEC 61000-4-2:2008
IEC 60255-26:2013, Section 7.2.3
IEEE C37.90.3:2001
Severity Level 4
8 kV contact discharge
15 kV air discharge

Radiated RF Immunity:  
IEC 61000-4-3:2010
IEC 60255-26:2013, Section 7.2.4
10 V/m
IEEE C37.90-2004
20 V/m

Fast Transient, Burst Immunity:  
IEC 61000-4-4:2012
IEC 60255-26:2013, Section 7.2.5
4 kV @ 5.0 kH
2 kV @ 5.0 kHz for comm. ports

Surge Immunity:  
IEC 61000-4-5:2005
IEC 60255-26:2013, Section 7.2.7
2 kV line-to-line
4 kV line-to-earth

Surge Withstand Capability Immunity:  
IEC 61000-4-8:2010
IEC 60255-26:2013, Section 7.2.6
2.5 kV common mode
1 kV differential mode
1 kV common mode on comm. ports
IEEE C37.90.1-2002
2.5 kV oscillatory
4 kV fast transient

Conducted RF Immunity:  
IEC 61000-4-6:2008
IEC 60255-26:2013, Section 7.2.8
10 Vrms

Magnetic Field Immunity:  
IEC 61000-4-8:2009
IEC 60255-26:2013, Section 7.2.10
Severity Level: 1000 A/m for 3 seconds
100 A/m for 1 minute; 50/60 Hz
IEC 61000-4-9:2001
Severity Level: 1000 A/m
IEC 61000-4-10:2001
Severity Level: 100 A/m (100 kHz and 1 MHz)

Power Supply Immunity:  
IEC 61000-4-11:2004
IEC 61000-4-17:1999
IEC 61000-4-29:2000
IEC 60255-26:2013, Section 7.2.11
IEC 60255-26:2013, Section 7.2.12
IEC 60255-26:2013, Section 7.2.13

EMC Emissions
Conducted Emissions:  
IEC 60255-26:2013 Class A
FCC 47 CFR Part 15.107 Class A
ICES-003 Issue 6
EN 55011:2009 + A1:2010 Class A
EN 55022:2010 + AC:2011 Class A
EN 55032:2012 + AC:2013 Class A
CISPR 11:2009 + A1:2010 Class A
CISPR 22:2008 Class A
CISPR 32:2015 Class A

Radiated Emissions:  
IEC 60255-26:2013 Class A
FCC 47 CFR Part 15.109 Class A
ICES-003 Issue 6
EN 55011:2009 + A1:2010 Class A
EN 55022:2010 + AC:2011 Class A
EN 55032:2012 + AC:2013 Class A
CISPR 11:2009 + A1:2010 Class A
CISPR 22:2008 Class A
CISPR 32:2015 Class A

Processing Specifications and Oscillography
AC Voltage and Current Inputs:  
16 samples per power system cycle

Frequency Tracking Range:  
20–70 Hz (requires ac voltage inputs option)

Digital Filtering:  
One-cycle cosine after low-pass analog filtering. Net filtering (analog plus digital) rejects dc and all harmonics greater than the fundamental.

Protection and Control Processing:  
Processing interval is 4 times per power system cycle (except for math variables and analog quantities, which are processed every 100 ms). The 51 elements are processed 2 times per power system cycle.

Oscillography
Length:  
15 or 64 cycles

Sampling Rate:  
16 samples per cycle unfiltered
4 samples per cycle filtered

Trigger:  
Programmable with Boolean expression

Format:  
ASCII and Compressed ASCII

Time-Stamp Resolution:  
1 ms

Time-Stamp Accuracy:  
±5 ms

Sequential Events Recorder
Time-Stamp Resolution:  
1 ms

Time-Stamp Accuracy (with respect to time source):  
±5 ms
## Relay Elements

### Instantaneous/Definite-Time Overcurrent (50P, 50G, 50N, 500)

**Pickup Setting Range, A secondary:**
- **5 A models:** 0.50–96.00 A, 0.01 A steps
- **1 A models:** 0.10–19.20 A, 0.01 A steps

**Accuracy:** ±5% of setting plus ±0.02 • $I_{\text{NOM}}$ A (Secondary Steady State pickup)

**Time Delay:** 0.00–5.00 seconds, 0.01-second steps, ±0.5% plus ±0.25 cycle

**Pickup/Dropout Time:** <1.5 cycles

### Inverse Time Overcurrent (51P, 51G, 51N, 51Q)

**Pickup Setting Range, A secondary:**
- **5 A models:** 0.50–16.00 A, 0.01 A steps
- **1 A models:** 0.10–3.20 A, 0.01 A steps

**Accuracy:** ±5% of setting plus ±0.02 • $I_{\text{NOM}}$ A (Steady State pickup)

**Time Delay:**
- **US:** 0.50–15.00, 0.01 steps
- **IEC:** 0.05–1.00, 0.01 steps

**Accuracy:** ±1.5 cycles plus ±4% between 2 and 30 multiples of pickup (within rated range of current)

### Differential (87)

**Unrestrained Pickup Range:** 1.0–20.0 in per unit of TAP
**Restricted Pickup Range:** 0.10–1.00 in per unit of TAP

**Pickup Accuracy (A secondary):**
- **5 A Model:** ±5% plus ±0.10 A
- **1 A Model:** ±5% plus ±0.02 A

**Unrestrained Element**

**Pickup Time:** 0.8/1.0/1.9 cycles (Min/Typ/Max)

**Restricted Element (with harmonic blocking)**

**Pickup Time:** 1.2/1.67/2.2 cycles (Min/Typ/Max)

**Restricted Element (with harmonic restraint)**

**Pickup Time:** 2.62/2.72/2.86 cycles (Min/Typ/Max)

### Harmonics

**Pickup Range (% of fundamental):** 5%–100%

**Pickup Accuracy (A secondary):**
- **5 A Model:** ±5% plus ±0.10 A
- **1 A Model:** ±5% plus ±0.02 A

**Time Delay Accuracy:** ±0.5% of setting or ±0.25 cycle

### Restricted Earth Fault (REF)

**Pickup Range (per unit of INOM of neutral current input, IN):** 0.05–3.00 per unit, 0.01 per-unit steps

**Pickup Accuracy (A secondary):**
- **5 A Model:** ±5% plus ±0.10 A
- **1 A Model:** ±5% plus ±0.02 A

**Timing Accuracy:**

#### Directional Output

- ANSI Extremely Inverse TOC Curve (U4 With 0.5 Time Dial): 1.5 ±0.25 cycle

- ±5 cycles plus ±5% between 2 and 30 multiples of pickup (within rated range of current)

**Undervoltage (27)**

**Setting Range:** Off, 12.5–300.0 V

**Accuracy:** ±1% of setting plus ±0.5 V

**Pickup/Dropout Time:** <1.5 cycle

**Time Delay:** 0.0–120.0 seconds, 0.1-second steps

**Accuracy:** ±0.5% of setting or ±0.25 cycle

### Overvoltage (59)

**Setting Range:** Off, 12.5–300.0 V

**Accuracy:** ±1% of setting plus ±0.5 V

**Pickup/Dropout Time:** <1.5 cycle

**Time Delay:** 0.0–120.0 seconds, 0.1-second steps

**Accuracy:** ±0.5% of setting or ±0.25 cycle

### Negative-Sequence Overvoltage (59Q)

**Setting Range:** 12.5–200.0 V

**Accuracy:** ±5% of setting plus ±2 V

**Pickup/Dropout Time:** <1.5 cycle

**Time Delay:** 0.0–120.0 seconds, 0.1-second steps

**Accuracy:** ±0.5% of setting or ±0.25 cycle

### Volts/Hertz (24)

**Definite-Time Element**

**Pickup Range:** 100%–200%

**Steady-State Pickup Accuracy:** ±1% of set point

**Pickup Time:** 25 ms @ 60 Hz (Max)

**Time-Delay Range:** 0.00–400.00 s

**Time-Delay Accuracy:** ±0.1% of setting or ±4.2 ms @ 60 Hz

**Reset Time Range:** 0.00–400.00 s

**Inverse-Time Element**

**Pickup Range:** 100%–200%

**Steady-State Pickup Accuracy:** ±1% of set point

**Pickup Time:** 25 ms @ 60 Hz (Max)

**Curve:** 0.5, 1.0, or 2.0

**Factor:** 0.1–10.0 s

**Timing Accuracy:** ±4% plus ±25 ms @ 60 Hz, for V/Hz above 1.05 multiples (Curve 0.5 and 1.0) or 1.10 multiples (Curve 2.0) of pickup setting, and for operating times >4 s

**Reset Time Range:** 0.00–400.00 s

**Composite-Time Element**

Combination of definite-time and inverse-time specifications

**User-Definable Curve Element**

**Pickup Range:** 100%–200%

**Steady-State Pickup Accuracy:** ±1% of set point

**Pickup Time:** 25 ms @ 60 Hz (Max)

**Reset Time Range:** 0.00–400.00 s

**Directional Power (32)**

**Instantaneous/Definite Time, 3 Phase Elements**

**Type:** +W, −W, +VAR, −VAR

**Pickup Settings Range, VA secondary:**
- **5 A Model:** 1.0–6500.0 VA, 0.1 VA steps
- **1 A Model:** 0.2–1300.0 VA, 0.1 VA steps

**Accuracy:** ±10 A • (L-L voltage secondary) and ±5% of setting at unity power factor for power elements and zero power factor for reactive power element (5 A nominal)

**Negative-Sequence Overvoltage (59Q)**

**Setting Range:** 12.5–200.0 V

**Accuracy:** ±5% of setting plus ±2 V

**Pickup/Dropout Time:** <1.5 cycle

**Time Delay:** 0.0–120.0 seconds, 0.1-second steps

**Accuracy:** ±0.5% of setting or ±0.25 cycle
### Frequency (81) (requires ac voltage option)

<table>
<thead>
<tr>
<th>Setting Range</th>
<th>Off, 20.0–70.0 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>±0.01 Hz (V1 &gt; 60 V) with voltage tracking</td>
</tr>
<tr>
<td>Pickup/Dropout Time</td>
<td>&lt;4 cycles</td>
</tr>
<tr>
<td>Time Delay</td>
<td>0.0–240.0 seconds, 0.1-second steps</td>
</tr>
<tr>
<td>Accuracy</td>
<td>±0.5% of setting or ±0.25 cycle</td>
</tr>
</tbody>
</table>

### RTD Protection

<table>
<thead>
<tr>
<th>Setting Range</th>
<th>Off, 1°–250°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>±2°C</td>
</tr>
<tr>
<td>RTD Open-Circuit Detection</td>
<td>&gt;250°C</td>
</tr>
<tr>
<td>RTD Short-Circuit Detection</td>
<td>&lt;−50°C</td>
</tr>
<tr>
<td>RTD Types</td>
<td>PT100, NI100, NI120, CU10</td>
</tr>
<tr>
<td>RTD Lead Resistance</td>
<td>25 ohm max. per lead</td>
</tr>
<tr>
<td>Update Rate</td>
<td>&lt;3 s</td>
</tr>
<tr>
<td>Noise Immunity on RTD Inputs</td>
<td>To 1.4 Vac (peak) at 50 Hz or greater</td>
</tr>
</tbody>
</table>

### Metering Accuracy

Accuracies are specified at 20°C, nominal frequency, ac currents within (0.2–20.0) • I_{NOM} A secondary, and ac voltages within 50–250 V secondary unless otherwise noted.

<table>
<thead>
<tr>
<th>Phase Currents</th>
<th>±1% of reading, ±1° at 0.2–0.5 A for relays with I_{NOM} = 1 A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three-Phase Average Current</td>
<td>±2% of reading</td>
</tr>
<tr>
<td>Differential Quantities</td>
<td>±5% of reading plus ±0.1 A (5 A nominal), ±0.02 A (1 A nominal)</td>
</tr>
<tr>
<td>Current Harmonics</td>
<td>±5% of reading plus ±0.1 A (5 A nominal), ±0.02 A (1 A nominal)</td>
</tr>
<tr>
<td>IG (Residual Current)</td>
<td>±3% of reading, ±2° (±5.0° at 0.2–0.5 A for relays with I_{NOM} = 1 A)</td>
</tr>
<tr>
<td>IN (Neutral Current)</td>
<td>±1% of reading, ±1° at 0.2–0.5 A for relays with I_{NOM} = 1 A</td>
</tr>
<tr>
<td>3I2 Negative-Sequence Current</td>
<td>±3% of reading</td>
</tr>
<tr>
<td>System Frequency</td>
<td>±0.01 Hz of reading for frequencies within 20.00–70.00 Hz (V1 &gt; 60 V) with voltage tracking</td>
</tr>
<tr>
<td>Line-to-Line Voltages</td>
<td>±1% of reading, ±1° for voltages within 24–264 V</td>
</tr>
<tr>
<td>Three-Phase Average Line-to-Line Voltage</td>
<td>±1% of reading for voltages within 24–264 V</td>
</tr>
<tr>
<td>Line-to-Ground Voltages</td>
<td>±1% of reading, ±1° for voltages within 24–264 V</td>
</tr>
<tr>
<td>Three-Phase Average Line-to-Ground Voltages</td>
<td>±1% of reading for voltages within 24–264 V</td>
</tr>
<tr>
<td>Voltage Harmonics</td>
<td>±5% of reading plus ±0.5 V</td>
</tr>
<tr>
<td>3V2 Negative-Sequence Voltage</td>
<td>±3% of reading for voltages within 24–264 V</td>
</tr>
<tr>
<td>Real Three-Phase Power (kW)</td>
<td>±3% of reading for 0.10 &lt; pf &lt; 1.00</td>
</tr>
<tr>
<td>Reactive Three-Phase Power (kVAR)</td>
<td>±3% of reading for 0.00 &lt; pf &lt; 0.90</td>
</tr>
<tr>
<td>Apparent Three-Phase Power (kVA)</td>
<td>±3% of reading</td>
</tr>
<tr>
<td>Power Factor</td>
<td>±2% of reading for 0.86 ≤ pf ≤ 1</td>
</tr>
<tr>
<td>RTD Temperatures</td>
<td>±2°C</td>
</tr>
</tbody>
</table>

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