SEL-787-2, -3, -4 Transformer Protection Relays

As Many as Four-Terminal Differential and REF Protection

New Features

- ➤ IEC 61850 simulation mode, local/remote control authority, and functional naming support for easy commissioning and control.
- ➤ Rapid Spanning Tree Protocol (RSTP) provides faster recovery in response to network changes and failures in switched mode applications.
- ➤ Disconnect control from the Bay Screens application.
- ➤ Three-position disconnects for increased safety.
- ➤ A built-in web server that simplifies access to relay data and supports firmware upgrade.
- ➤ Faster firmware downloads via the Ethernet port.
- ➤ IEEE 1588-2008 firmware-based Precision Time Protocol (PTP) provides ease of integration.
- ➤ EtherNet/IP provides ease of integration for industrial automation applications.

Major Features and Benefits

The SEL-787 Transformer Protection Relay provides unsurpassed protection, integration, and control features in a flexible, compact, and cost-effective package. The SEL-787 offers an extensive variety of protection features, depending on the model and options selected. In this document, SEL-787 refers to all the models in *Table 1*. For protection functions specific to a given MOT, the relay is referred to as SEL-787-4X, SEL-787-3E, SEL-787-3S, SEL-787-2X, SEL-787-21, or SEL-787-2E explicitly, where needed. *Table 2* shows the protection features available across models.

Table 1 Current (ACI) and Voltage (AVI) Card Selection for SEL-787 Models

Model	Description/Application	Slot Z Card (MOT Digits)	Slot Z Inputs	Slot E Card (MOT Digits)	Slot E Inputs
787-2X	2 Winding/Terminal Current Differential	6ACI (81, 82, 85)	IAW1, IBW1, ICW1, IAW2, IBW2, ICW2		
787-21	2 Winding/Terminal Current Differential 1 Neutral Current Input	6ACI (81, 82, 85)	IAW1, IBW1, ICW1, IAW2, IBW2, ICW2	1ACI (A6, A7)	IN
787-2E	2 Winding/Terminal Current Differential 1 Neutral Current Input 3 Voltage Inputs (Phase)	6ACI (81, 82, 85)	IAW1, IBW1, ICW1, IAW2, IBW2, ICW2	1ACI/3AVI (78, 79)	IN, VA, VB, VC
787-3E	3 Winding/Terminal Current Differential 1 Neutral Current Input 3 Voltage Inputs (Phase)	6 ACI (81, 82, 85)	IAW1, IBW1, ICW1, IAW2, IBW2, ICW2	4 ACI/3 AVI (72, 73, 76, 77)	IAW3, IBW3, ICW3, IN, VA, VB, VC
787-3S	3 Winding/Terminal Current Differential 3 Voltage Inputs (Phase) 1 Voltage Input (Vsync or Vbat)	6 ACI (81, 82, 85)	IAW1, IBW1, ICW1, IAW2, IBW2, ICW2	3 ACI/4 AVI (71, 75)	IAW3, IBW3, ICW3, VS/VBAT, VA, VB, VC
787-4X	4 Winding/Terminal Current Differential	6 ACI (81, 82, 85)	IAW1, IBW1, ICW1, IAW2, IBW2, ICW2	6 ACI (A1, A2, A5)	IAW3, IBW3, ICW3, IAW4, IBW4, ICW4

Table 2 SEL-787 Protection Elements (Sheet 1 of 2)

Protection Elements		2 Windings	2 Windings With IN Channel	2 Windings With IN Channel and 3-Phase Voltages	3 Windings With IN Channel and 3-Phase Voltages	3 Windings With VS/VBAT Channel and 3-Phase Voltages	4 Windings
		SEL-787-2X	SEL-787-21	SEL-787-2E	SEL-787-3E	SEL-787-3S	SEL-787-4X
87	Phase Differential	X	X	X	X	X	X
REF	Restricted Earth Fault (REF)		X[a]	X[a]	X[a]	X[a]	X[a]
50P	Phase Overcurrent	X	X	X	X	X	X
50Q	Neg.-Seq. Overcurrent	X	X	X	X	X	X
50G	Ground Overcurrent	X	X	X	X	X	X
50N	Neutral Overcurrent		X	X	X		
51P	Phase Time-Overcurrent	X	X	X	X	X	X
51Q	Neg.-Seq. Time-Overcurrent	X	X	X	X	X	X
51G	Ground Time-Overcurrent	X	X	X	X	X	X
51PC	Combined Winding Phase Time-Overcurrent				X	X	X
51GC	Combined Winding Ground Time-Overcurrent				X	X	X

Table 2 SEL-787 Protection Elements (Sheet 2 of 2)

Protection Elements		2 Windings SEL-787-2X	2 Windings With IN Channel SEL-787-21	2 Windings With IN Channel and 3-Phase Voltages SEL-787-2E	3 Windings With IN Channel and 3-Phase Voltages SEL-787-3E	3 Windings With VS/VBAT Channel and 3-Phase Voltages SEL-787-3S	4 Windings SEL-787-4X
51N	Neutral Time-Overcurrent		X	X	X		
27P	Phase Undervoltage			X	X	X	
27PP	Phase-to-Phase Undervoltage			X	X	X	
27S	VS Channel Undervoltage					X	
27I	Inverse-Time Undervoltage			X	X	X	
59P	Phase Overvoltage			X	X	X	
59PP	Phase-to-Phase Overvoltage			X	X	X	
59Q	Neg.-Seq. Overvoltage			X	X	X	
59G	Ground Overvoltage			X	X	X	
59S	VS Channel Overvoltage					X	
59I	Inverse-Time Overvoltage			X	X	X	
24	Volts/Hz			X	X	X	
25	Synchronism Check					X	
32	Directional Power			X	X	X	
49RTD	Resistance Temperature Detector (RTDs)	X	X	X	X	X	X
60LOP	Loss of Potential (LOP)			X	X	X	
81	Over- and Underfrequency			X	X	X	
BF	Breaker Failure	X	X	X	X	X	X

[a] Refer to Table 3 for the available REF elements.

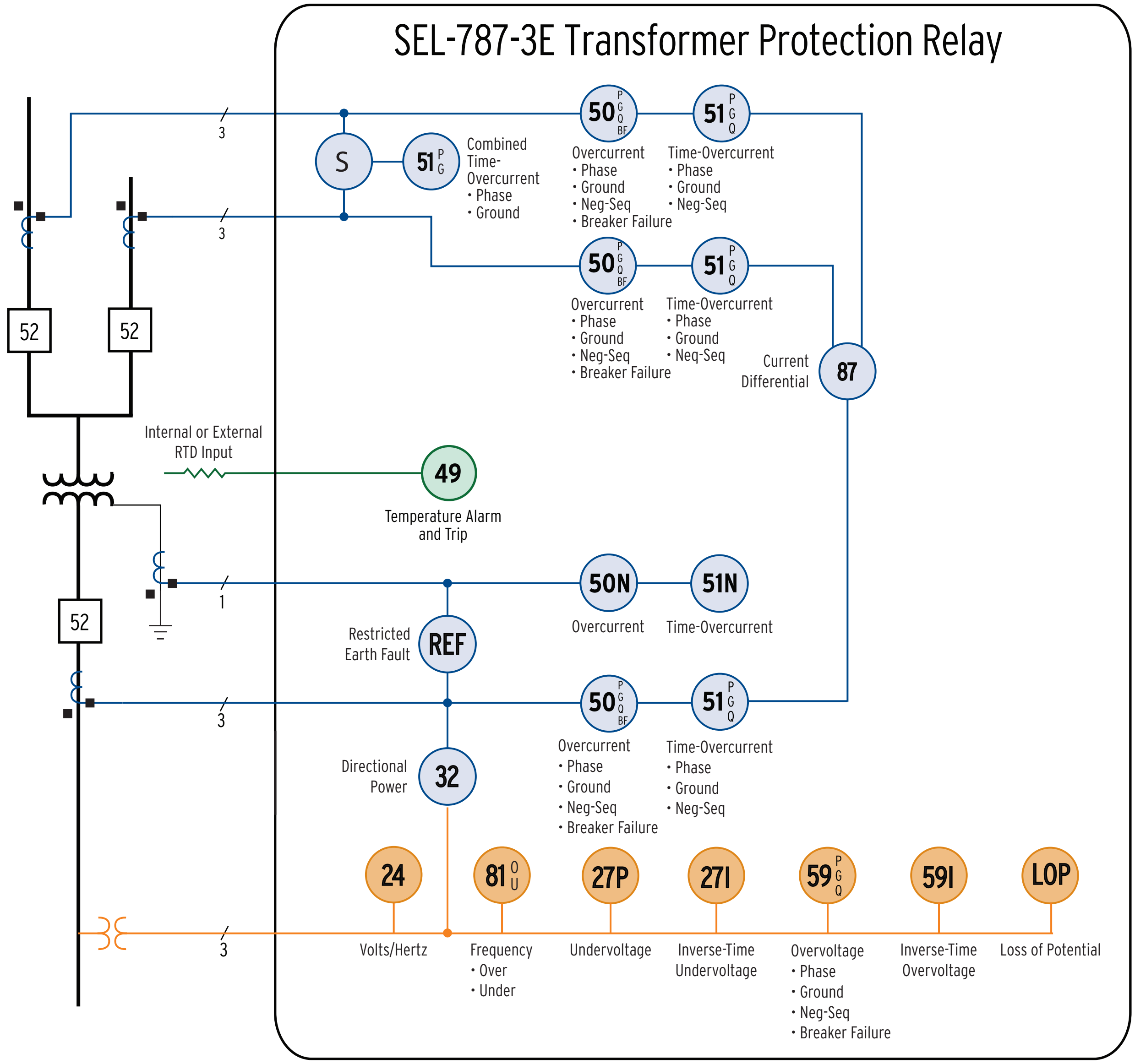
Table 3 Available Differential and REF Elements

Elements	SEL-787-2X	SEL-787-21	SEL-787-2E	SEL-787-3E	SEL-787-3S	SEL-787-4X
Differential Protection Windings (Standard)	2	2	2	3	3	4
REF Elements (Standard)	0	1	1	1	0	0
Differential Protection Windings (Winding 3 Configured for REF)				2	2	3
REF Elements (Winding 3 Configured for REF)				2	2	2

- **Standard Protection Features**. Use standard dual-slope differential protection with harmonic blocking and restraint for as many as four windings and as many as three independent REF elements for sensitive ground-fault detection in grounded wye-transformers. Refer to *Table 3* for the available REF elements. The relay also includes phase, negative-sequence, residual ground, and neutral-ground overcurrent elements for backup protection. Breaker failure protection for as many as four three-pole breakers is standard.
- **Additional Protection Features.** Take advantage of the SEL-787-3E/3S/2E models volts/hertz protection with frequency tracking from 15 to 70 Hz for generator step-up and variable frequency applications. Use over- and underfrequency and over- and undervoltage elements to implement load shedding and other control schemes on the relay.

- **Synchronism Check/Station DC Battery Monitor.** Program the VS/VBAT voltage channel in the SEL-787-3S model to perform a synchronism check across a circuit breaker or to monitor dc voltage levels of the substation battery.
- **Transformer Monitoring.** Measure accumulated through-fault levels with the transformer through-fault monitor. Additionally, use the optional 4–20 mA or RTD thermal inputs to monitor ambient, load tap changer (LTC) tank, and transformer oil temperatures.
- **Operator Controls.** Take advantage of eight programmable front-panel pushbuttons, each with two programmable tricolor LEDs, for various uses, such as easy trip and close control and status indication for all the breakers. Use the operator control interface pushbuttons to easily implement local and remote operator control schemes using 32 local and 32 remote control bits. Use SELOGIC® control equations and slide-in, configurable front-panel labels to change the function and identification of target LEDs and operator control pushbuttons and LEDs.
- **Integrated Web Server.** Log in to the built-in web server to view metering and monitoring data and to download events. Use the web server to view relay settings and to perform relay firmware upgrades.
- **Relay and Logic Settings Software.** Reduce engineering costs by using ACSELERATOR QuickSet® SEL-5030 Software for relay settings and logic programming and to simplify development of SELOGIC control equations. Verify proper CT polarity and phasing through use of the built-in phasor display.
- **Metering and Reporting.** Use built-in metering functions to 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.
- **Front-Panel HMI.** Navigate the relay HMI using a 2 x 16-character LCD or optional 5-inch, color, 800 x 480-pixel touchscreen display.
- **Additional Standard Features.** Further enhance your power system protection by taking advantage of several other SEL-787 standard features in communication, monitoring, and support. Modbus RTU, Event Messenger support, MIRRORED BITS® communications, as well as load profile and breaker wear monitoring all come standard with the SEL-787. The relay also supports 12 additional external RTDs (SEL-2600 RTD Module), IRIG-B input, advanced SELOGIC control equations, 128 remote analogs, IEEE C.37.118-2005-compliant synchrophasor protocol, configurable labels, and an SEL-2812 compatible ST fiber-optic serial port.
- **Optional Features.** Communicate with a number of additional optional communications protocols and ports, digital/analog I/O, and RTDs. Optional communications protocols include IEC 61850 Edition 2, EtherNet/IP, Modbus TCP/IP, Simple Network Time Protocol (SNTP), IEEE 1588-2008 firmware-based PTP, RSTP, PRP, DNP3 LAN/WAN, DNP3 serial, and IEC 60870-5-103. Elective communications ports include EIA-232 or EIA-485 and single or dual, copper or fiber-optic Ethernet ports. Several digital/analog I/O options are available. These include 4 AI/4 AO, 4 DI/4 DO, 8 DI, 8 DO, 3 DI/4 DO/1 AO, 4 DI/3 DO, and 14 DI. An optional 10 internal RTD card is also available for the SEL-787 relay. Conformal coating for chemically harsh and/or high moisture environments is also available as an option.
- **Language Support.** Choose English or Spanish for your serial ports, including the front-panel serial port. The standard relay front-panel overlay is in English; a Spanish overlay is available as an ordering option.

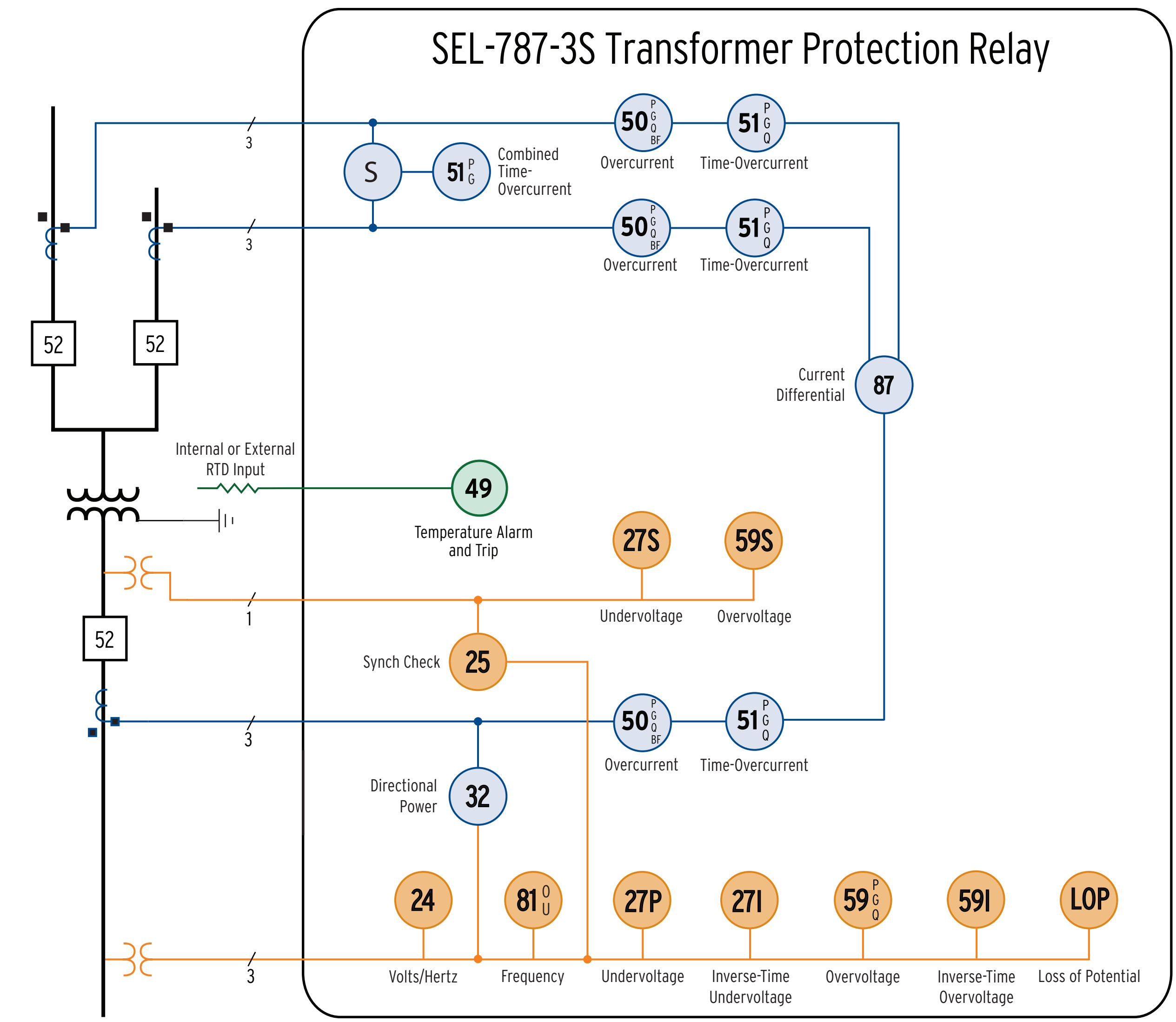
Functional Overview



- Sequential Events Recorder
- Event Reports
- Web Server
- SEL, Ethernet*, Modbus RTU, Modbus TCP/IP*, DNP3 serial*, DNP3 LAN/WAN*, FTP*, Telnet*, SNTP*, IEEE 1588-2008 firmware-based PTP*, IEC 61850 Edition 2*, IEC 60870-5-103*, EtherNet/IP*, RSTP*, PRP*, Event Messenger, DeviceNet* Communications
- Synchrophasor Data and IEEE C37.118-2005 Compliant Protocol
- Two Inputs and Three Outputs Standard
- I/O Expansion*--Additional Contact Inputs/Outputs, Analog Inputs/Outputs, and RTD Inputs
- Single or Dual Ethernet Copper or Fiber-Optic Communications Port*
- Battery-Backed Clock, IRIG-B Time Synchronization
- Instantaneous, Differential, Harmonic, and RMS Metering
- Programmable Pushbuttons and LED Indicators
- Through-Fault Monitoring
- Transformer Thermal Monitoring
- Circuit Breaker Contact Wear Monitor
- Advanced SELogic Control Equations
- 32 Programmable Display Messages
- Mirrored Bits Communications
- Front-Panel Programmable Tricolor LED Targets
- Front-Panel HMI With 2 x 16-Character LCD
- 5-Inch, Color, 800 x 480-Pixel Touchscreen Display*

*Optional Functions

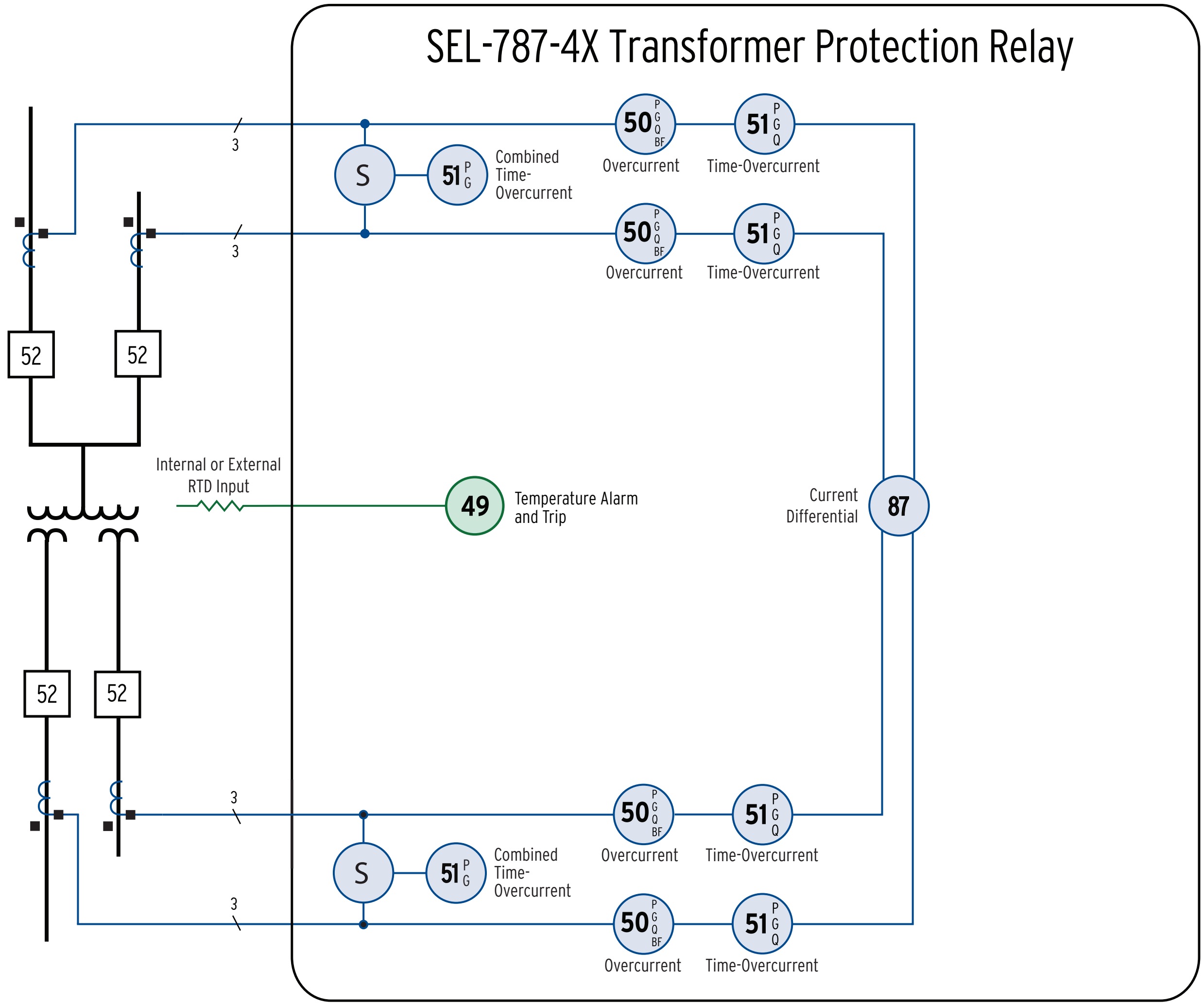
Figure 1 SEL-787-3E Functional Diagram



- Sequential Events Recorder
- Event Reports
- Web Server
- SEL, Ethernet*, Modbus RTU, Modbus TCP/IP*, DNP3 serial*, DNP3 LAN/WAN*, FTP*, Telnet*, SNTP*, IEEE 1588-2008 firmware-based PTP*, IEC 61850 Edition 2*, IEC 60870-5-103*, EtherNet/IP*, RSTP*, PRP*, Event Messenger, DeviceNet* Communications
- Synchrophasor Data and IEEE C37.118-2005 Compliant Protocol
- Two Inputs and Three Outputs Standard
- I/O Expansion*--Additional Contact Inputs/Outputs, Analog Inputs/Outputs, and RTD Inputs
- Single or Dual Ethernet Copper or Fiber-Optic Communications Port*
- Battery-Backed Clock, IRIG-B Time Synchronization
- Instantaneous, Differential, Harmonic, and RMS Metering
- Programmable Pushbuttons and LED Indicators
- Through-Fault Monitoring
- Transformer Thermal Monitoring
- Circuit Breaker Contact Wear Monitor
- Advanced SELogic Control Equations
- 32 Programmable Display Messages
- Mirrored Bits Communications
- Front-Panel Programmable Tricolor LED Targets
- Front-Panel HMI With 2 x 16-Character LCD
- 5-Inch, Color, 800 x 480-Pixel Touchscreen Display*

*Optional Functions

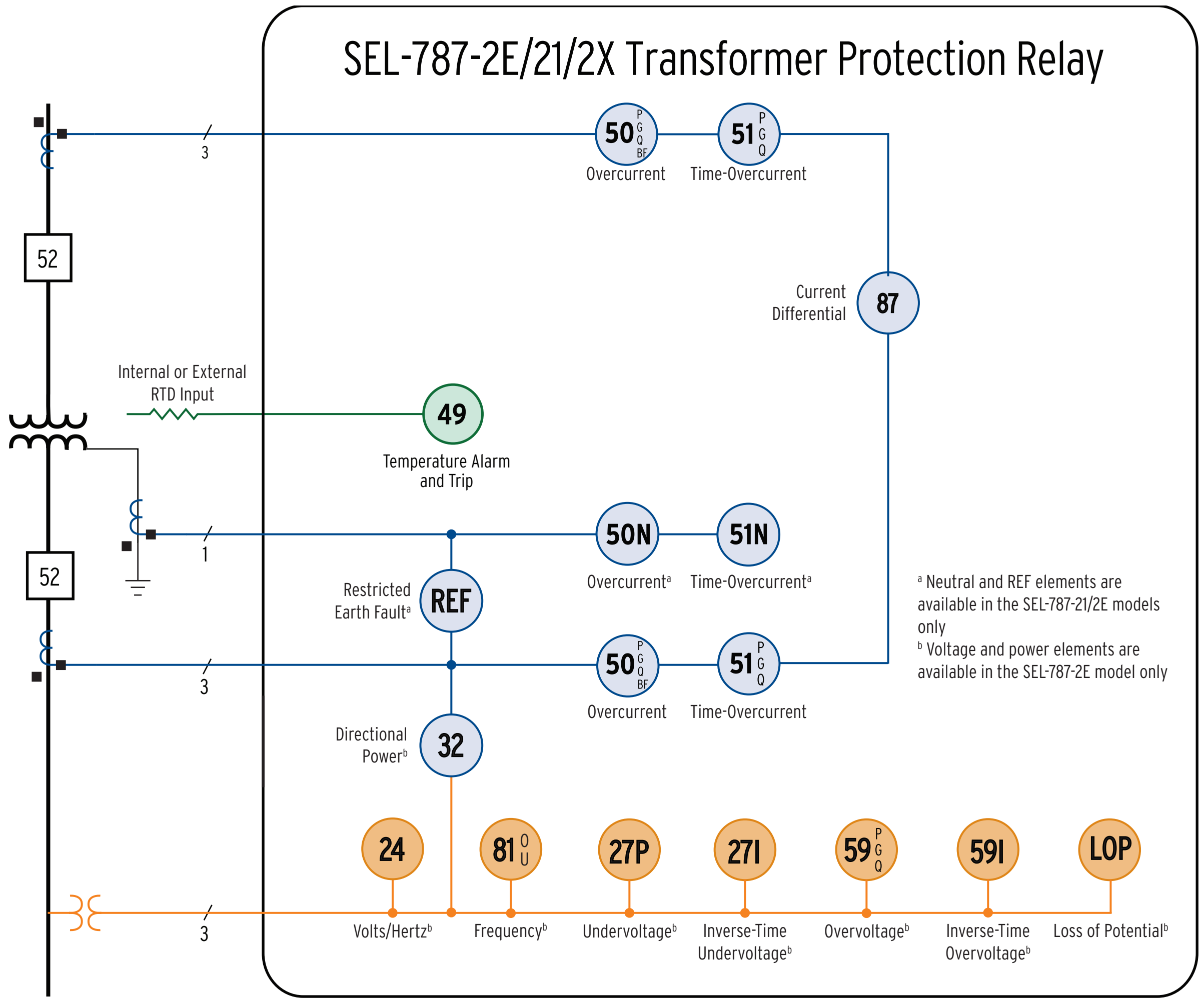
Figure 2 SEL-787-3S Functional Diagram



- Sequential Events Recorder
- Event Reports
- Web Server
- SEL, Ethernet*, Modbus RTU, Modbus TCP/IP*, DNP3 serial*, DNP3 LAN/WAN*, FTP*, Telnet*, SNTP*, IEEE 1588-2008 firmware-based PTP*, IEC 61850 Edition 2*, IEC 60870-5-103*, EtherNet/IP*, RSTP*, PRP*, Event Messenger, DeviceNet* Communications
- Synchrophasor Data and IEEE C37.118-2005 Compliant Protocol
- Two Inputs and Three Outputs Standard
- I/O Expansion*--Additional Contact Inputs/Outputs, Analog Inputs/Outputs, and RTD Inputs
- Single or Dual Ethernet Copper or Fiber-Optic Communications Port*
- Battery-Backed Clock, IRIG-B Time Synchronization
- Instantaneous, Differential, Harmonic, and RMS Metering
- Programmable Pushbuttons and LED Indicators
- Through-Fault Monitoring
- Transformer Thermal Monitoring
- Circuit Breaker Contact Wear Monitor
- Advanced SELogic Control Equations
- 32 Programmable Display Messages
- Mirrored Bits Communications
- Front-Panel Programmable Tricolor LED Targets
- Front-Panel HMI With 2 x 16-Character LCD
- 5-Inch, Color, 800 x 480-Pixel Touchscreen Display*

*Optional Functions

Figure 3 SEL-787-4X Functional Diagram



- Sequential Events Recorder
- Event Reports
- Web Server
- SEL, Ethernet*, Modbus RTU, Modbus TCP/IP*, DNP3 serial*, DNP3 LAN/WAN*, FTP*, Telnet*, SNTP*, IEEE 1588-2008 firmware-based PTP*, IEC 61850 Edition 2*, IEC 60870-5-103*, EtherNet/IP*, RSTP*, PRP*, Event Messenger, DeviceNet* Communications
- Synchrophasor Data and IEEE C37.118-2005 Compliant Protocol
- Two Inputs and Three Outputs Standard
- I/O Expansion*--Additional Contact Inputs/Outputs, Analog Inputs/Outputs, and RTD Inputs
- Single or Dual Ethernet Copper or Fiber-Optic Communications Port*
- Battery-Backed Clock, IRIG-B Time Synchronization
- Instantaneous, Differential, Harmonic, and RMS Metering
- Programmable Pushbuttons and LED Indicators
- Through-Fault Monitoring
- Transformer Thermal Monitoring
- Circuit Breaker Contact Wear Monitor
- Advanced SELogic Control Equations
- 32 Programmable Display Messages
- Mirrored Bits Communications
- Front-Panel Programmable Tricolor LED Targets
- Front-Panel HMI With 2 x 16-Character LCD
- 5-Inch, Color, 800 x 480-Pixel Touchscreen Display*

*Optional Functions

Figure 4 SEL-787-2E/21/2X Functional Diagram

Protection Features

The SEL-787 relay offers a dual-slope differential characteristic for transformer differential protection. The SEL-787 includes a complete set of phase, negative-sequence, and residual overcurrent elements for each terminal (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-time and time-delay characteristics, along with directional power, over- and underfrequency, and over- and undervoltage elements with two independent pickup levels and time delays.

Transformer Differential

The SEL-787 has three restrained differential elements (87R). These elements use operate and restraint quantities calculated from as many as four winding input currents. Set the differential elements with either single- or dual-slope percentage differential characteristics. *Figure 5* illustrates a dual-slope setting. The percent-slope characteristic helps prevent undesired relay operation because of a 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.

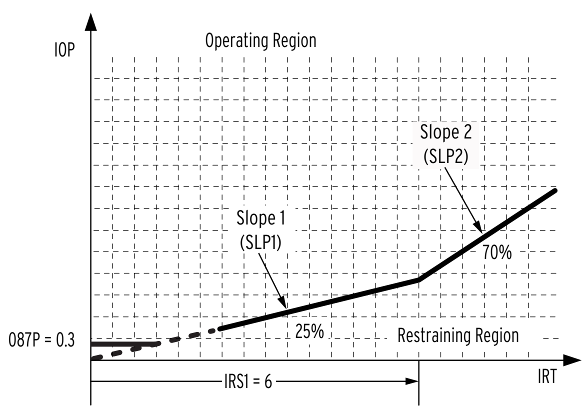


Figure 5 Dual-Slope Restrained Differential Characteristic

With the SEL-787, you can choose harmonic blocking, harmonic restraint, or both, to provide 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. Typical 87U pickup level settings are between 8 and 10 per unit of the operate current.

Restricted Earth Fault Protection

Apply the REF protection feature to provide sensitive detection of internal ground faults on grounded wye-connected transformer windings and auto-transformers. Refer to *Table 3* for the available REF elements across the models. Polarizing current is derived from the residual current calculated for the protected winding(s). A sensitive directional element determines whether the fault is internal or external. Zero-sequence current thresholds supervise tripping.

Overcurrent Protection

The SEL-787 offers instantaneous overcurrent and time-overcurrent elements. All the elements can be controlled individually by using the SELOGIC torque control equations associated with the element.

Instantaneous Overcurrent Elements

The following instantaneous overcurrent elements are available in the SEL-787.

- Four instantaneous phase overcurrent (50P) elements per winding that operate on the maximum of the phase currents. A peak detection algorithm is used to enhance element sensitivity during high-fault current conditions where severe CT saturation may occur.
- Per-phase instantaneous overcurrent (50P) elements, one element per phase, that operate on the corresponding phase current of Winding 3 (only available on models with Winding 3). A peak detection algorithm is used to enhance element sensitivity during high-fault current conditions where severe CT saturation may occur.
- Two instantaneous negative-sequence overcurrent (50Q) elements per winding that operate on the calculated negative-sequence current.

- ➤ Two residual instantaneous overcurrent (50G) elements per winding that operate on the calculated residual (3I0) current.
- ➤ Two neutral instantaneous overcurrent (50N) elements that operate on the neutral current associated with the neutral channel (MOT dependent).

Time-Overcurrent Elements

The time-overcurrent elements support the IEC and U.S. (IEEE) time-overcurrent characteristics shown in *Table 4*.

Table 4 Inverse-Time Overcurrent Curves

U.S. (IEEE)	IEC
Moderately Inverse	Standard Inverse
Inverse	Very Inverse
Very Inverse	Extremely Inverse
Extremely Inverse	Long-Time Inverse
Short-Time Inverse	Short-Time Inverse

Electromechanical disk reset capabilities are provided for all time-overcurrent elements. The following time-overcurrent elements are available in the SEL-787.

- ➤ One maximum phase time-overcurrent (51P) element per winding that operates on the maximum of the corresponding winding phase currents.
- ➤ Three per-phase (A-, B-, and C-phase) time-overcurrent (51P) elements, one element per phase, that operate on the corresponding phase current of Winding 3 (only available on models with Winding 3).
- ➤ One negative-sequence time-overcurrent (51Q) element per winding that operates on the calculated negative-sequence current.
- ➤ One residual time-overcurrent (51G) element per winding that operates on the calculated residual (3I0) current.
- ➤ One neutral time-overcurrent (51N) element that operates on the neutral current associated with the neutral channel (MOT dependent).

Combined Time-Overcurrent Elements

The combined time-overcurrent elements can be used for transformers connected to a ring-bus or breaker and one-half systems. The SEL-787-4X/2E/3S models allow you to combine Winding 1 and Winding 2 and/or Winding 3 and Winding 4 currents. The following combined time-overcurrent elements are available:

- ➤ Two phase time-overcurrent (51P) elements, one each for combined Windings 1 and 2 and Windings 3 and 4, that operate on the maximum of the corresponding combined phase currents.
- ➤ Two zero-sequence time-overcurrent (51G) elements, one each for combined Windings 1 and 2 and Windings 3 and 4, that operate on the calculated zero-sequence current of the corresponding combined currents.

Breaker Failure Protection

The SEL-787 offers breaker failure protection for as many as four three-pole breakers. Use breaker failure detection to issue retrip commands to the failed breaker or to trip adjacent breakers using the relays contact output logic or communications-based tripping schemes.

Breaker failure is initiated by the breaker failure initiate (BFI) SELOGIC input. 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.

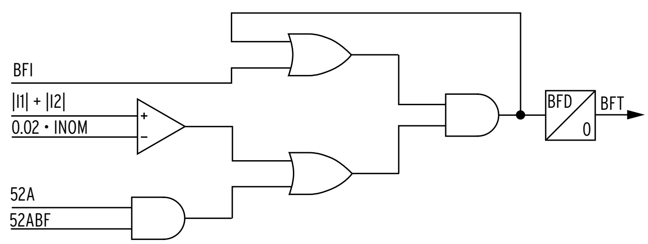


Figure 6 Breaker Failure Protection

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 for 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 transformer volts/hertz as a percentage of nominal, based on 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 the SELOGIC torque control equation, which enables or disables the element as required by the application.

Use the SEL-5806 Curve Designer Software to set the user-defined curve (see *Figure 7*). 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 one used by an induction-disk, time-overcurrent element. This characteristic emulates the heating effect of overexcitation on transformer components.

Figure 7 SEL-5806 Volts/Hertz User Curve Design Example

Over- and Undervoltage Protection

The SEL-787 with optional voltage inputs contains phase over- and undervoltage and sequence overvoltage elements that help create protection and control schemes, such as undervoltage load shedding or standby generation start/stop commands. All voltage elements provide two pickup levels with definite-time delay settings. The following over- and undervoltage elements are available:

- Phase undervoltage (27P) and overvoltage (59P) elements that operate on the measured phase-to-neutral voltages.
- Phase-to-phase undervoltage (27PP) and overvoltage (59PP) elements that operate on the measured phase-to-phase voltages.
- Negative-sequence overvoltage (59Q) and residual-ground overvoltage (59G) elements that operate on the calculated negative-sequence and residual-ground voltage, respectively.
- Phase undervoltage (27S) and phase overvoltage (59S) elements that operate on VS channel voltage.
- Inverse-time overvoltage (59I) and inverse-time undervoltage (27I) elements that operate on the measured phase-to-neutral voltages, phase-to-phase voltages, positive-sequence voltage, or VS channel voltage.

Loss-of-Potential Detection

The SEL-787 with optional voltage inputs contains 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 potentially open fuses. This patented LOP logic is unique, because it does not require settings and is universally applicable. The LOP feature allows for the blocking of protection elements to add security during voltage transformer fuse failure.

Synchronism Check/Station DC Battery Monitor

The SEL-787-3S allows you to program the VS/Vbat voltage channel for use as either a synchronism check or station dc battery monitor. When programmed as a synchronism-check channel, single-phase voltage (phase-to-neutral or phase-to-phase) can be connected to the voltage input for a synchronism check or hot/dead line check across the circuit breaker to which the three-phase voltages are assigned. When the channel is programmed for the battery monitor, the station dc battery voltage can be monitored. The relay also allows you to program over- and undervoltage elements on the voltage channel.

Over- and Underfrequency Protection

The SEL-787 with optional voltage inputs contains four frequency 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(s) 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 an optional 10 RTD input expansion card or an external SEL-2600 RTD Module with as many as 12 RTD inputs, you can program as many as 12 thermal elements in the relay for two levels of thermal protection per element. Each RTD input provides an alarm and trip thermal pickup setting in degrees Celsius, 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. Eight conveniently sized operator controls, each with two programmable tricolor LEDs, are located on the relay front panel (see *Figure 8*, *Figure 9*, and *Figure 10*). You can set the SER to track operator controls. Use SELOGIC control equations to change operator control functions. Use configurable labels to change all of the text shown in *Figure 8*, *Figure 9*, and *Figure 10*.

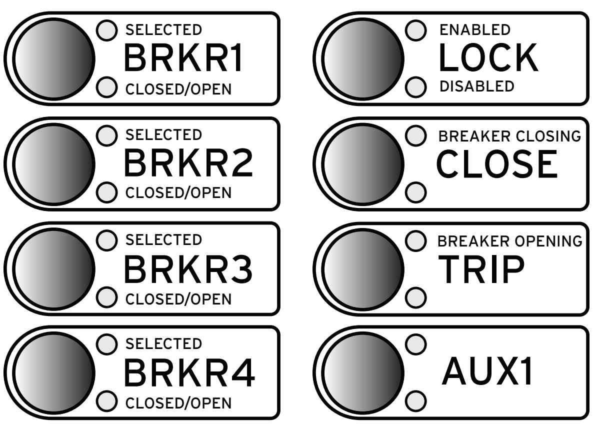


Figure 8 Operator Controls (787-4X Model)

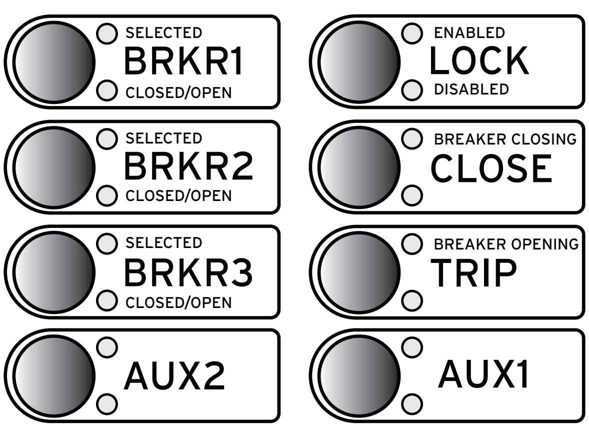


Figure 9 Operator Controls (787-3E/3S Models)

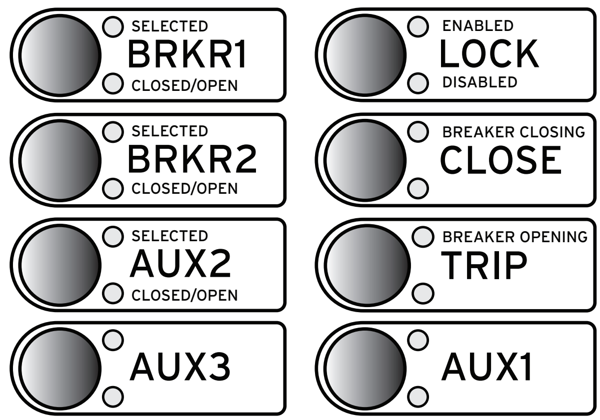


Figure 10 Operator Controls (787-2E/21/2X Models)

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. When the **LOCK** pushbutton is engaged, the **CLOSE** operator control is blocked.

BRKRn: Each of the **BRKRn** (*n* = 1, 2, 3, or 4) pushbuttons allows you to select the breaker on which a close or trip control operation is to be performed. Only one breaker can be selected at any given time. Breaker select status for a given breaker is indicated by the upper pushbutton LED. The lower pushbutton LED indicates the CLOSED/OPEN (RED/GREEN, respectively) status of the corresponding breaker.

CLOSE and **TRIP:** Use the **CLOSE** and **TRIP** operator controls to close and open the circuit breaker. You can program these controls with intentional time delays to support operational requirements for breaker-mounted relays. This allows you to press the **CLOSE** or **TRIP** pushbutton, then move to an alternate location before the breaker command is executed.

AUXn: You can program the **AUXn** ($n = 1$, 2, or 3) pushbuttons for additional control of your specific application.

In the SEL-787 with the touchscreen display, you can use the front-panel operator control pushbuttons to jump to a specific screen while also using them for LOCK/TRIP/CLOSE operations, etc. You can program the selectable operator pushbutton screen settings under the Touchscreen settings category in QuickSet to map the button to a specific screen.

Built-In Web Server

Every Ethernet-equipped SEL-787 relay includes a built-in web server. Interface with the relay by using any standard web browser to perform the following actions:

- ➤ Log in with password protection.
- ➤ Safely read the relay settings.
- ➤ Verify the relay self-test status and view the relay configuration.
- ➤ Inspect meter reports.
- ➤ Download event reports.
- ➤ Upload new firmware (firmware upgrade).

Figure 11 shows the fundamental metering screen that can be accessed by clicking **Meter** > **Fundamental**. Use the Meter menu to view all the available relay metering statistics.

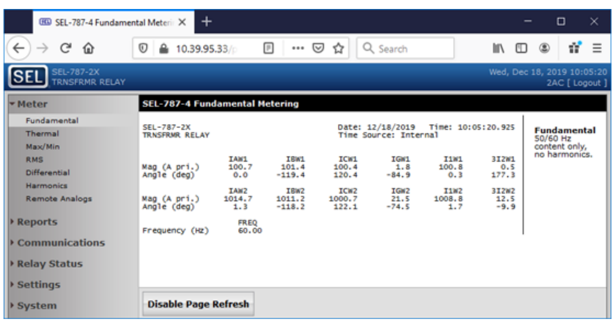


Figure 11 Fundamental Meter Report Webpage

Figure 12 shows the Group 1 settings webpage. You can view the settings of each relay settings class by selecting **Settings** and the respective relay settings class.

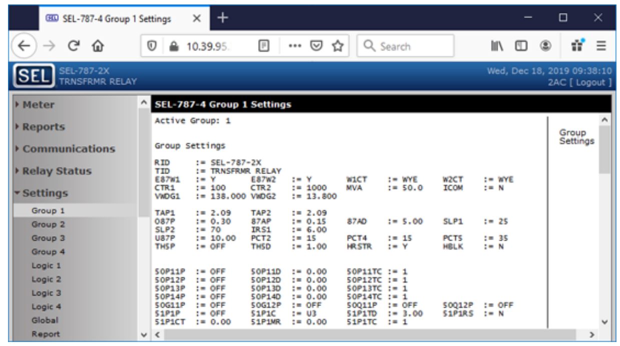


Figure 12 Group 1 Settings Webpage

You can upgrade the relay firmware through the relay web server by clicking **System** > **File Management** (available at Access Level 2) and selecting the firmware upgrade file. *Figure 13* shows the firmware upgrade webpage.

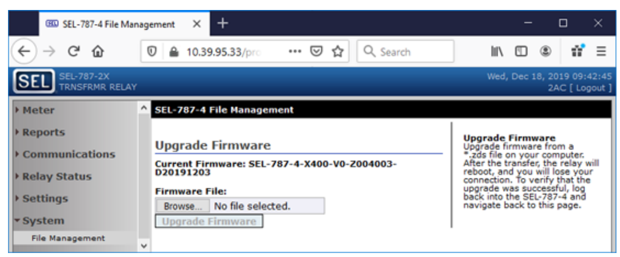


Figure 13 Upgrade the Relay Firmware From the File Management Webpage

Relay and Logic Settings Software

QuickSet simplifies settings and provides analytical support for the SEL-787. There are several ways to create and manage relay settings with QuickSet.

- ➤ 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 using online help.
- ➤ Organize settings with the relay database manager.
- ➤ Load and retrieve settings using a simple PC communications link.

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

Use the following features of QuickSet to monitor, commission, and test the SEL-787.

- ➤ Use the HMI to monitor meter data, Relay Word bits, and output contact statuses during testing.
- ➤ Use the PC interface to remotely retrieve power system data.

- ➤ Use the Event Report Analysis tool for easy retrieval and visualization of ac waveforms and digital inputs and outputs the relay processes.
- ➤ Use the graphical current phasor display in the HMI to visualize differential current relationships.
- ➤ Use bay control to design new bay screens and edit existing bay screens by launching ACSELERATOR Bay Screen Builder SEL-5036 Software for SEL-787 relays with the touchscreen display.

ACSELERATOR Bay Screen Builder SEL-5036 Software

The SEL-787 with the touchscreen display option provides you with the ability to design bay configuration screens to meet your system needs. You can display the bay configuration as a single-line diagram (SLD) on the touchscreen. You can use ANSI and IEC symbols, along with analog and digital labels, for the SLD to indicate the status of the breaker and disconnects, bus voltages, and power flow through the breaker. In addition to SLDs, you can design the screens to show the status of various relay elements via Relay Word bits or to show analog quantities for commissioning or day-to-day operations. You can design these screens with the help of Bay Screen Builder in conjunction with QuickSet. Bay Screen Builder provides an intuitive and powerful interface to design bay screens to meet your application needs.

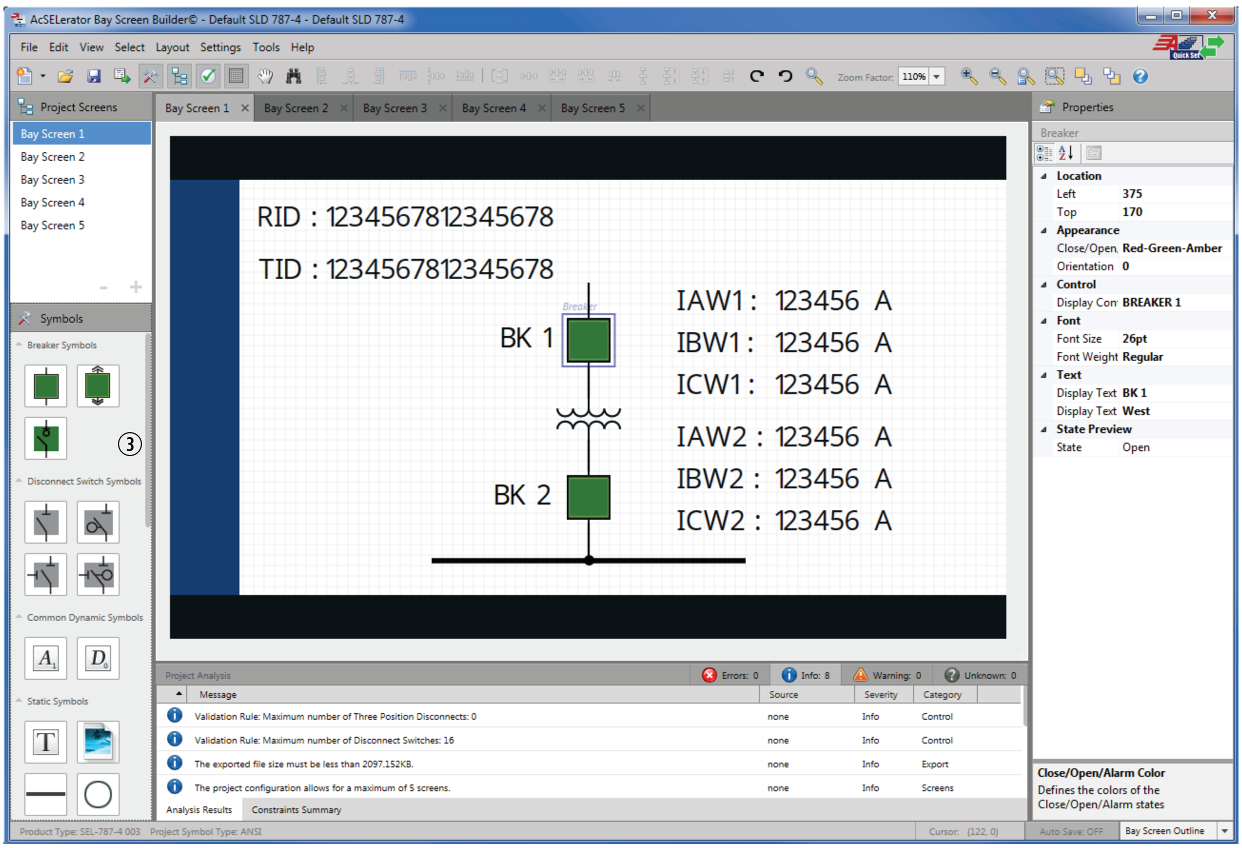


Figure 14 Bay Screen Builder

Metering and Monitoring

The SEL-787 provides extensive metering capabilities. See *Specifications on page 35* for metering and power measurement accuracies. As shown in *Table 5*, metered quantities include phase voltages and currents; neutral current; sequence voltages and currents; harmonics, power, frequency, and energy; and maximum/minimum logging of selected quantities. The relay reports all metered quantities in primary quantities (current in A primary and voltage in V primary).

Table 5 SEL-787 Metered Values (Model Dependent)

Types of Metering			
Instantaneous Math Variables Demand and Peak Demand	RMS Synchrophasors Analog Inputs	Remote Analogs Max/Min	Energy Thermal

Quantity	Description
Currents IxWn (x = A, B, C, n = 1, 2, 3, 4)	Winding phase current magnitude and angle, primary A
IN	Neutral current magnitude and angle, primary A
IGWn (n = 1, 2, 3, 4)	Residual-ground fault current and angle per winding, primary A
3I2Wn (n = 1, 2, 3, 4)	Negative-sequence current and angle per winding, primary A
IOPz (z = 1, 2, 3)	Differential operate current, scaled to TAP
IRTz (z = 1, 2, 3)	Differential restraint current, scaled to TAP
InF2, InF4, InF5 (n = 1, 2, 3, 4)	Current harmonics, InF2/IOPn (%) for 2nd, 4th, 5th harmonics
Voltages VA, VB, VC	Phase voltages and angles, primary volts, for wye-connected potential transformers
Voltages VAB, VBC, VCA	Phase-to-phase voltages and angles, primary volts, for delta-connected potential transformers
Voltage VG	Residual-ground voltage and phase angle, primary volts, for wye-connected potential transformers
Voltage 3V2	Negative-sequence voltage and phase angle, primary volts
Power kVA, kW, kVAR	Calculated apparent, real, and reactive power scaled to primary values (single and three-phase)[a]
Energy MWh, MVARh	Three-phase positive and negative megawatt-hours, megavar-hours
Power Factor PF	Single and three-phase power factor (leading or lagging)[a]
Voltage VS	Synchronism-check voltage channel, voltage magnitude and angle, primary volts
Voltage VDC	Station battery voltage
Frequency FREQ	Measured system frequency (Hz)
Frequency FREQS	Measured frequency (Hz) of synchronism-check channel
V/Hz	Calculated volts/hertz in percent, using highest measured voltage and frequency
AIx01–AIx04 (x = 3, 4, or 5)	Analog inputs
MV01–MV32	Math variables
RA001–RA128	Remote analogs
RTD1–RTD12	RTD temperature measurement (degrees C)

[a] Single-phase power and power factor quantities are not available when delta-connected PTs are used.

Load Profile

The SEL-787 features a programmable Load Data Profile (LDP) recorder that records as many as 17 metering quantities into nonvolatile memory at fixed time intervals. The LDP saves several days to several weeks of the most recent data depending on the LDP settings (9800 entries total).

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 angles at multiple locations for precise system analysis and system-state measurement (see *Figure 15*).

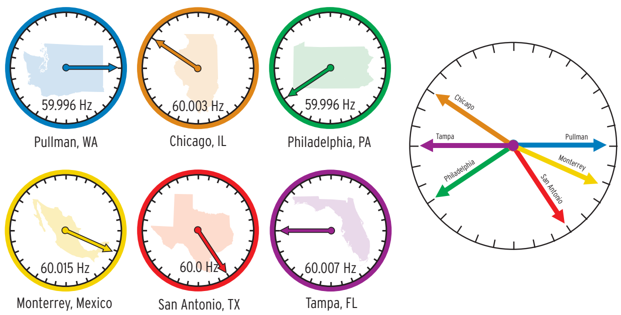


Figure 15 View of System Angle at Multiple Locations

Send synchrophasor data using IEEE C37.118-2005 protocol to SEL synchrophasor applications. These include the SEL-3378 Synchrophasor Vector Processor (SVP), SEL-3530 Real-Time Automation Controller (RTAC), and the SEL-5078-2 SYNCHROWAVE® Central Visualization and Analysis Software suite.

The SEL-3373 Station Phasor Data Concentrator (PDC) and the SEL-5073 SYNCHROWAVE PDC software correlate data from multiple SEL-787 relays and concentrate the result into a single output data stream. These products also provide synchrophasor data archiving capability. These SEL-3378 SVP enables control applications based on synchrophasors. Directly measure the oscillation modes of your power system and then act on the result. Use wide-area phase angle slip and acceleration measurements to properly control islanding of distributed generation. With the SVP, you can customize a synchrophasor control application according to the unique requirements of your power system.

The data rate of SEL-787 synchrophasors is selectable with a range of 1–60 messages per second. This flexibility is important for efficient use of communication capacity.

The SEL-787 phasor measurement accuracy meets the highest IEEE C37.118-2005 Level 1 requirement of 1 percent total vector error (TVE). This means you can use any SEL-787 model in an application that otherwise would require purchasing a separate dedicated phasor measurement unit (PMU).

Use the SEL-787 with SEL communications processors, or the SEL-3530 RTAC, to change nonlinear state estimation into linear state estimation. If all necessary lines include synchrophasor measurements then state estimation is no longer necessary. The system state is directly measured.

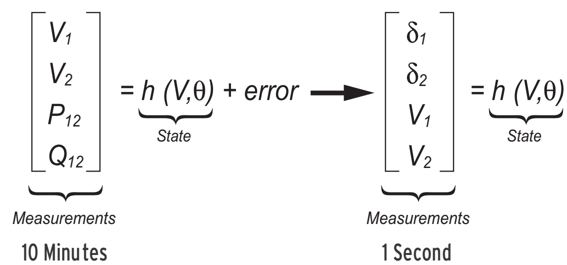


Figure 16 Synchrophasor Measurements Turn State Estimation Into State Measurement

Improve Situational Awareness

Provide improved information to system operators. Advanced synchrophasor-based tools produce a real-time view of system conditions. Use system trends, alarm points, and preprogrammed responses to help operators prevent a cascading system collapse and maximize system stability. Awareness of system trends provides operators with an understanding of future values based on measured data.

- ➤ Increase system loading while maintaining adequate stability margins.
- ➤ Improve operator response to system contingencies such as overload conditions, transmission outages, or generator shutdown.
- ➤ Advance system knowledge with correlated event reporting and real-time system visualization.
- ➤ Validate planning studies to improve system load balance and station optimization.

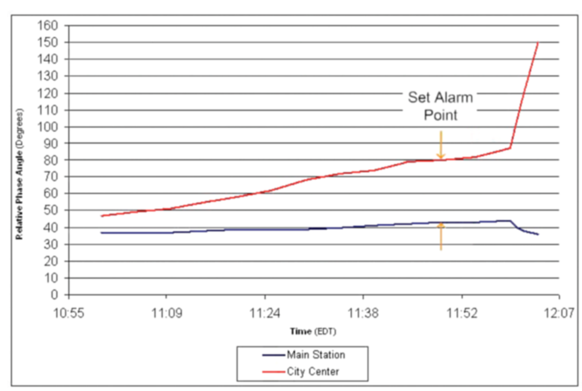


Figure 17 Visualization of Phase Angle Measurements Across a Power System

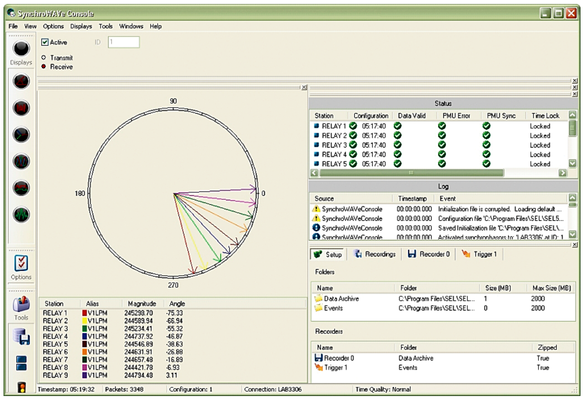


Figure 18 SEL-5078 SYNCHROWAVE Console Real-Time, Wide-Area Visualization Tool

Event Reporting and 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 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 1/32-cycle resolution, filtered or raw analog data, respectively).

The relay stores as many as 5 of the most recent 180-cycle event reports, 18 of the most recent 64-cycle event reports, or 50 of the most recent 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 1/32-cycle resolution, filtered or unfiltered analog, ASCII or Compressed ASCII reports
➤ 1/4-cycle filtered analog, ASCII differential reports
➤ 1/32-cycle resolution COMTRADE reports

The relay SER feature stores the latest 1,024 entries. Use this feature to gain a broad perspective at a glance. An SER entry helps to monitor input/output change-of-state occurrences and element pickup/dropout.

Synchronized Measurements

The IRIG-B time-code input synchronizes the SEL-787 internal clock time to within ±1 µs of the time-source input. Convenient sources for this time code are an SEL-2401 Satellite-Synchronized Clock, an SEL communications processor, or an SEL RTAC (via Serial Port 3 on the SEL-787). For time accuracy specifications for metering, synchrophasors, and events, see *Specifications*.

Substation Battery Monitor

The SEL-787 relays that include the enhanced voltage option with the monitoring package measure and report the substation battery voltage connected to the VBAT terminals. The relay includes two programmable threshold comparators and associated logic for alarm and control. For example, if the battery charger fails, the measured dc falls below a programmable threshold. The SEL-787 alarms to alert operations personnel before the substation battery voltage falls to unacceptable levels. Monitor these thresholds with an SEL communications processor and trigger messages, telephone calls, or other actions.

The measured dc voltage appears in the meter display and the Vdc column of the event report. Use the event report column data to see an oscillographic display of the battery voltage. This display shows how much the substation battery voltage drops during trip, close, and other control operations.

Circuit Breaker Contact Wear Monitor

Circuit breakers experience mechanical and electrical wear every time they operate. Intelligent scheduling of breaker maintenance takes into account the manufacturer's published data of contact wear versus interruption levels and operation count. With the breaker manufacturer's maintenance curve as input data, the SEL-787 breaker monitor feature compares these input data to the measured (unfiltered) ac current at the time of a trip and the number of close-to-open operations.

Every time the breaker trips, the relay integrates the measured current information. When the result of this integration exceeds the breaker wear curve threshold (see *Figure 19*), the relay alarms via output contact, communications port, or front-panel display. This kind of information allows timely and economical scheduling of breaker maintenance.

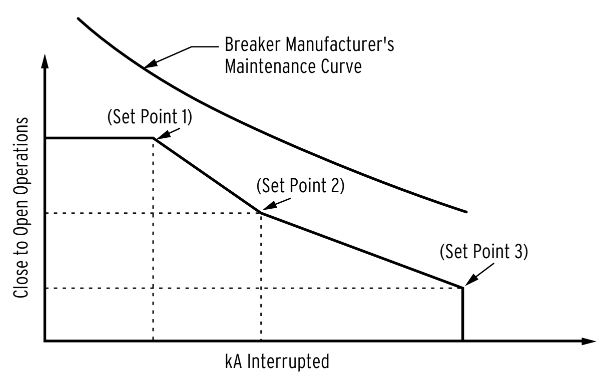


Figure 19 Breaker Contact Wear Curve and Settings

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 to help justify through-fault mitigation efforts. Apply the accumulated alarm capability of the relay to indicate excess through-fault current (I^2t) over time.

IEC 61850 Test Mode

Test mode allows you to test an in-service relay without operating control output contacts. Test mode includes five different modes.

On: In On mode, the relay operates as normal; it reports IEC 61850 Mode/Behavior status as On and processes all inputs and outputs as normal. If the quality of the subscribed GOOSE messages satisfies the GOOSE processing, the relay processes the received GOOSE messages as valid.

Blocked: This mode is similar to On mode, except that the device does not trip any physical contact output.

Test: In Test mode, the relay processes valid incoming test signals and normal messages and operates physical contact outputs, if the outputs are triggered.

Test/Blocked: This is similar to Test mode, except that the device does not trip any physical contact outputs.

Off: The device does not process any incoming data or control commands (except commands to change the mode). All protection logic is disabled and all data quality is marked as invalid.

Simulation: In this mode, the relay continues to process normal GOOSE messages until a simulated GOOSE message is received for a subscription. Once a simulated GOOSE message is received, only simulated GOOSE messages are processed for that subscription. The simulated mode only terminates when LPHDSIM is returned to FALSE. When the relay is not in simulation mode, only normal GOOSE messages are processed for all subscriptions.

Touchscreen Display

You can order the SEL-787 Transformer Protection Relay with an optional touchscreen display (5-inch, color, 800 x 480 pixels). The touchscreen display makes relay data metering, monitoring, and control quick and efficient. The touchscreen display option in the SEL-787 features a straightforward application-driven control structure and includes intuitive and graphical screen designs.

The touchscreen display allows you to:

- View and control bay screens
- Access metering and monitoring data
- Inspect targets
- View event history, summary data, and SER information
- View relay status and configuration
- Control relay operations
- View and edit settings
- Enable the rotating display
- Program control pushbuttons to jump to a specific screen

You can navigate the touchscreen by tapping the folders and applications. The folders and applications of the Home screen are shown in *Figure 20*. Folders and applications are labeled according to functionality. Additional folder and application screens for the SEL-787 touchscreen display option can be seen in *Figure 21* through *Figure 30*.

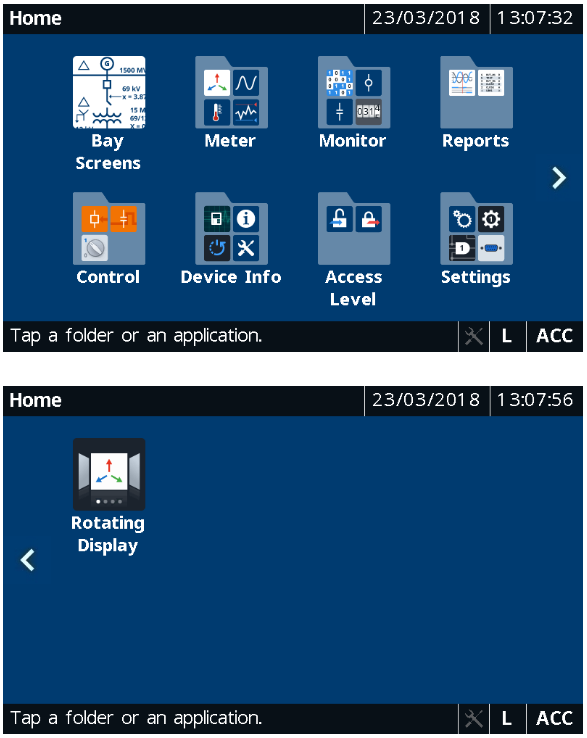


Figure 20 Home (Default FPHOME Screen)

Bay Screens Application

The SEL-787 with the touchscreen display option provides you with the ability to design bay configuration screens to meet your system needs. The bay configuration can be displayed as an SLD on the touchscreen. You can create as many as 5 bay screens with as many as 4 controllable breakers, 16 controllable 2-position disconnects, and 2 controllable 3-position disconnects. ANSI and IEC symbols, along with analog and digital labels, are available for you to create detailed SLDs of the bay to indicate the status of the breaker and disconnects, bus voltages, and power flow through the breaker. *Figure 21* shows the default SLD for the touchscreen display option.

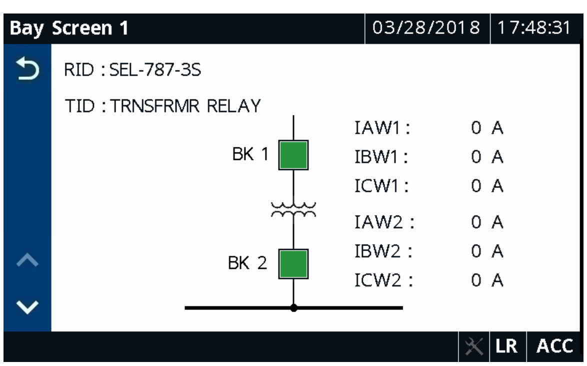


Figure 21 Default Bay Screen

Meter Folder Applications

The applications in the Meter folder are part-number dependent. Only those metering applications specific to your part number appear in the Meter folder. Tapping an application in the Meter folder shows you the report for that particular application. Tap the **Phasor** application to view the current and voltage phasors (see *Figure 22*).

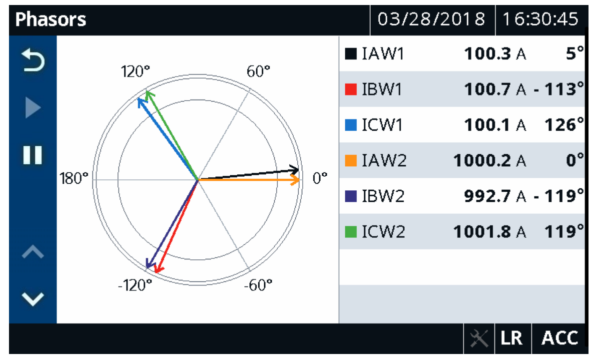


Figure 22 Meter Phasors

Tap the **Energy** application to view the energy metering quantities (see *Figure 23*). A reset feature is provided for the Energy, Max/Min, Demand, and Peak Demand applications. Tap the **Reset** button (see *Figure 23*) to navigate to the reset confirmation screen. Once you confirm the reset, the data are reset to zero.

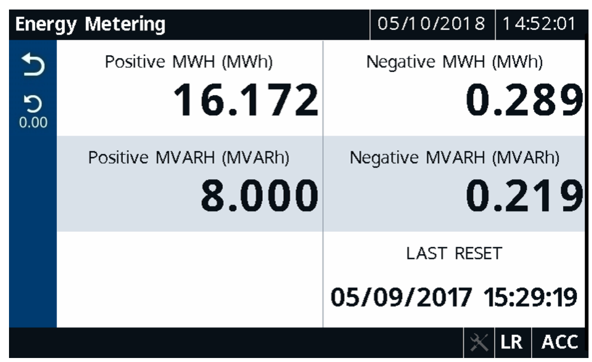
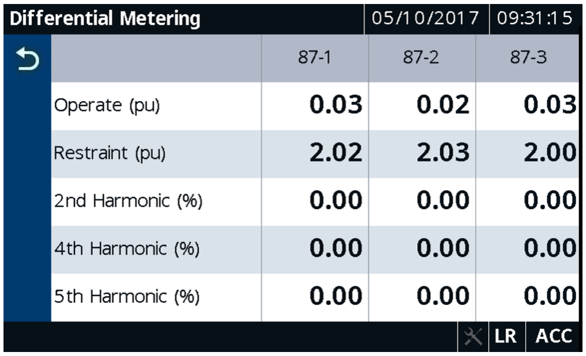


Figure 23 Meter Energy

Tap the **Differential** application to view the operate and restraint currents for each differential element (87) of your transformer in multiples of TAP. Use these quantities in conjunction with the phasors or fundamental metering screen to visualize the differential protection of your transformer and for commissioning exercises.

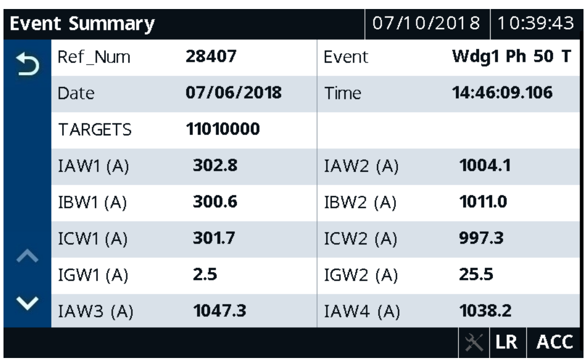


Differential Metering	05/10/2017	09:31:15	
	87-1	87-2	87-3
Operate (pu)	0.03	0.02	0.03
Restraint (pu)	2.02	2.03	2.00
2nd Harmonic (%)	0.00	0.00	0.00
4th Harmonic (%)	0.00	0.00	0.00
5th Harmonic (%)	0.00	0.00	0.00

Figure 24 Meter Differential

Reports Folder Applications

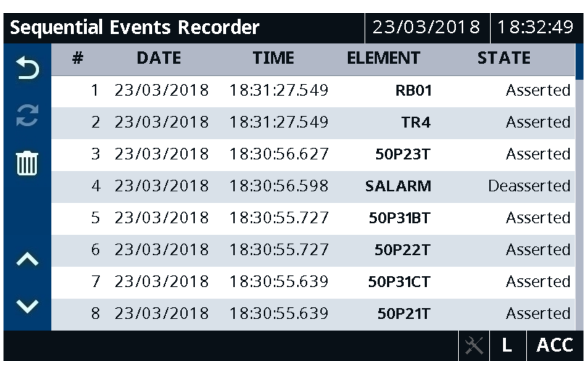
Tapping the **Reports** folder navigates you to the screen where you can access the Events and SER applications. Use these applications to view events and SERs. To view the event summary (see *Figure 25*) of a particular event record, tap the event record on the Event History screen. You can also trigger an event from the Event History screen.



Event Summary		07/10/2018	10:39:43
Ref_Num	28407	Event	Wdg1 Ph 50 T
Date	07/06/2018	Time	14:46:09.106
TARGETS	11010000		
IAW1 (A)	302.8	IAW2 (A)	1004.1
IBW1 (A)	300.6	IBW2 (A)	1011.0
ICW1 (A)	301.7	ICW2 (A)	997.3
IGW1 (A)	2.5	IGW2 (A)	25.5
IAW3 (A)	1047.3	IAW4 (A)	1038.2

Figure 25 Event Summary

Tap the **Sequential Events Recorder** application to view a history of the SER reports (see *Figure 26*).



Sequential Events Recorder 23/03/2018 18:32:49

#	DATE	TIME	ELEMENT	STATE
1	23/03/2018	18:31:27.549	RB01	Asserted
2	23/03/2018	18:31:27.549	TR4	Asserted
3	23/03/2018	18:30:56.627	50P23T	Asserted
4	23/03/2018	18:30:56.598	SALARM	Deasserted
5	23/03/2018	18:30:55.727	50P31BT	Asserted
6	23/03/2018	18:30:55.727	50P22T	Asserted
7	23/03/2018	18:30:55.639	50P31CT	Asserted
8	23/03/2018	18:30:55.639	50P21T	Asserted

Figure 26 Sequential Events Recorder

Tapping the **Trash** button, shown in *Figure 26*, on the Event History and Sequential Events Recorder screens and confirming the delete action removes the records from the relay.

Control Folder Applications

Tapping the **Control** folder navigates you to the screen where you can access the Breaker Control, Output Pulsing, and Local Bits applications. Use the applications to perform breaker control operations, pulse output contacts (*Figure 27*), and control the local bits (*Figure 28*).

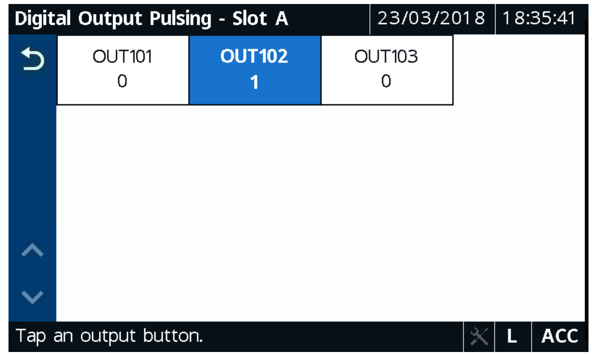
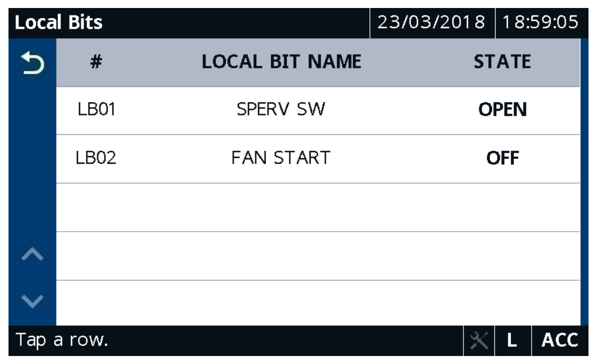


Figure 27 Digital Output Pulsing-Slot A



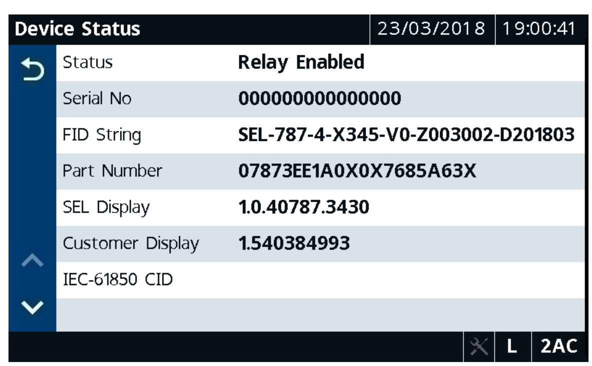
Local Bits 23/03/2018 18:59:05

#	LOCAL BIT NAME	STATE
LB01	SPERV SW	OPEN
LB02	FAN START	OFF

Figure 28 Local Bits

Device Info Folder Applications

Tapping the **Device Info** folder navigates you to the screen where you can access specific device information applications (Status, Configuration, and Trip & Diag. Messages) and the Reboot application. Tap the **Status** application to view the relay status, firmware version, part number, etc. (see *Figure 29*).



Device Status	23/03/2018 19:00:41
Status	Relay Enabled
Serial No	000000000000000
FID String	SEL-787-4-X345-V0-Z003002-D201803
Part Number	07873EE1A0X0X7685A63X
SEL Display	1.0.40787.3430
Customer Display	1.540384993
IEC-61850 CID	

Figure 29 Device Status

To view the trip and diagnostic messages, tap the **Trip & Diag. Messages** application (see *Figure 30*). When a diagnostic failure, trip, or warning occurs, the relay displays the diagnostic message on the screen until it is either overriden by the restart of the rotating display or the inactivity timer expires.

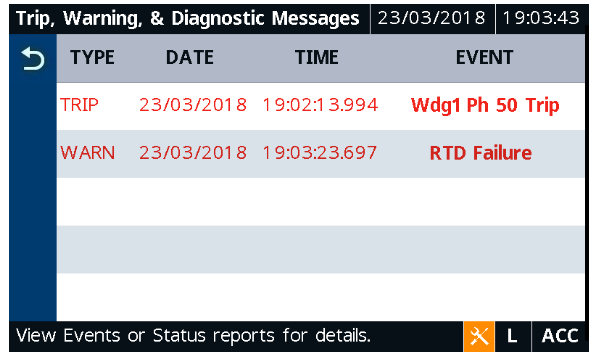


Figure 30 Trip and Diagnostics

Automation

Flexible Control Logic and Integration Features

The SEL-787 can be ordered with as many as four independently operated serial ports:

- EIA-232 port on the front panel
- EIA-232 or EIA-485 port on the Slot B card in the rear
- EIA-232 fiber-optic port on the Slot B card in the rear
- EIA-232 or EIA-485 port on the optional communications card in Slot C in the rear

Optionally, the relay supports single or dual, copper or fiber-optic Ethernet ports. The relay does not require special communications software. You can use any system that emulates a standard terminal system for engineering access to the relay. Establish local or remote communication by connecting computers, modems, protocol converters, printers, an SEL RTAC, SEL communications processor, SEL computing platform, SCADA serial port, or RTUs. Refer to *Table 6* for a list of communications protocols available in the SEL-787.

Table 6 Communications Protocols

Type	Description
Simple ASCII	Plain language commands for human and simple machine communications. Use for metering, setting, self-test status, event reporting, and other functions.
Compressed ASCII	Comma-delimited ASCII data reports. Allows 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 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.
Fast SER Protocol	Provides SER events to an automated data collection system.
Fast Message Protocol	Use this protocol to write remote analog data from other SEL relays or communications processors via unsolicited writes.
DNP3	Serial or Ethernet-based DNP3 protocols. Provides 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 Edition 2	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 C37.118-2005-compliant synchrophasors for system state, response, and control capabilities.
Event Messenger	The use of SEL-3010 Event Messenger allows you to receive alerts directly on your cell phone. Alerts can be triggered through relay events and can include quantities measured 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. (The DeviceNet option has been discontinued and is no longer available to order as of September 25, 2017.)
SNTP	Ethernet-based protocol that provides time synchronization of the relay.
IEEE 1588-2008 firmware-based PTP	Ethernet-based protocol that provides time synchronization of the relay.
PRP	Provides seamless recovery from any single Ethernet network failure in a dual redundant Ethernet network, in accordance with IEC 62439-3.
IEC 60870-5-103	Serial communications protocol–international standard for interoperability between intelligent devices in a substation.
EtherNet/IP	Ethernet-based protocol that provides access to metering data, protection elements, targets, and contact I/O.
RSTP	Provides faster recovery in response to changes and failures in switched mode dual redundant Ethernet networks in accordance with IEEE 802.1Q-2014.

Apply an SEL communications processor as the hub of a star network with a point-to-point fiber or copper connection between the hub and the SEL-787 (see *Figure 31*).

The communications processor supports external communications links, including the public switched telephone network, for engineering access to dial-out alerts and private line connections of the SCADA system.

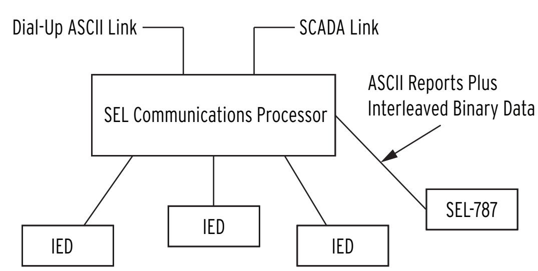


Figure 31 Example Communications System

SEL manufactures a variety of standard cables for connecting this and other relays to a variety of external devices. Consult your SEL representative for more information on cable availability.

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 with 32 remote bits.** Set, clear, or pulse remote bits using 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 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 which 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 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.

Fast Message Protocol

SEL Fast Message Protocol is a method to input or modify remote analogs in the SEL-787. These remote analogs can then be used in SEL Math or SELOGIC control equations. Remote analogs can also be modified via Modbus, DNP3, and IEC 61850.

Ethernet Network Architectures

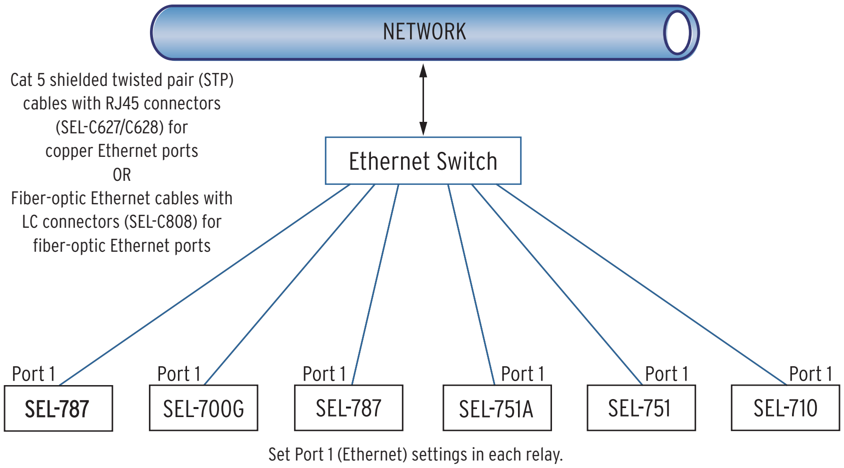


Figure 32 Simple Ethernet Network Configuration

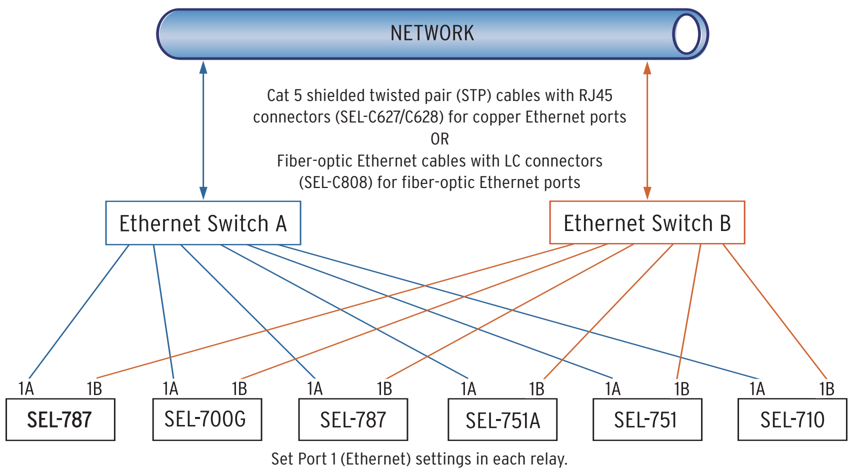


Figure 33 Ethernet Network Configuration With Dual Redundant Connections (Failover Mode)

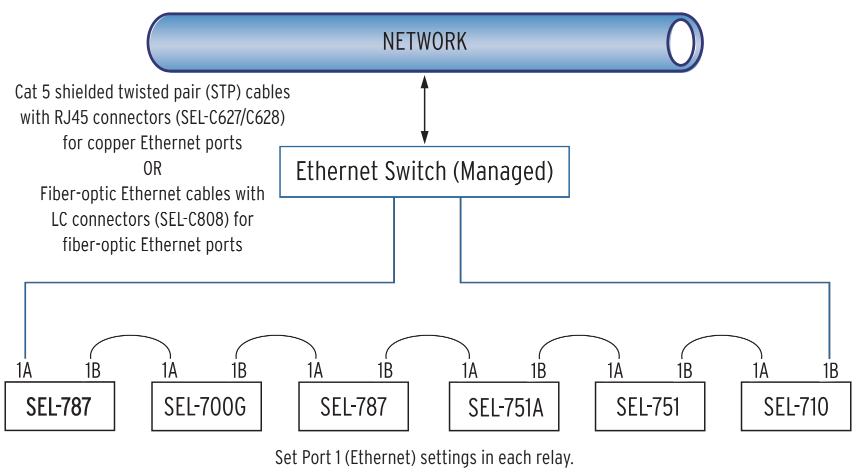


Figure 34 Ethernet Network Configuration With Ring Structure (Switched Mode)

Additional Features

MIRRORED BITS Relay-to-Relay Communications

The SEL-patented MIRRORED BITS communications technology provides bidirectional relay-to-relay digital communication. MIRRORED BITS communications 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 35*). 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.

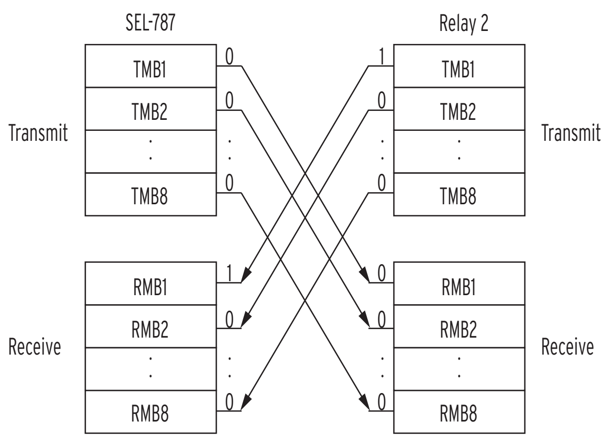


Figure 35 MIRRORED BITS Transmit and Receive Bits

Status and Trip Target LEDs

The SEL-787 includes 24 tricolor 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 38*. 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, allows for ASCII-to-voice translation of as many as 32 user-defined messages, along with analog data that has been measured or calculated by the relay. This combination allows you to receive voice message alerts (on any phone) regarding Relay Word bit transitions in the relay.

Verbal notification of breaker openings, fuse failures, RTD alarms, etc., can be sent directly to your cell phone through the use of your SEL-787 and an 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 38*) to suit your installation requirements. This feature includes preprinted labels (with factory-default text), blank label media, and a Microsoft Word template on CD-ROM. This allows 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.

Web Server

The web server allows you to communicate with the relay via the Ethernet port without the need for additional communication software (web browser required). The web server allows you to access metering and monitoring data and to perform firmware upgrades.

Firmware Download Via Ethernet Ports

Relay firmware can be securely downloaded to your relay via the Ethernet port. The firmware is digitally signed to prevent malicious modification. Additionally, the Ethernet firmware download allows you to access and update all your network relays simultaneously.

Relay Dimensions

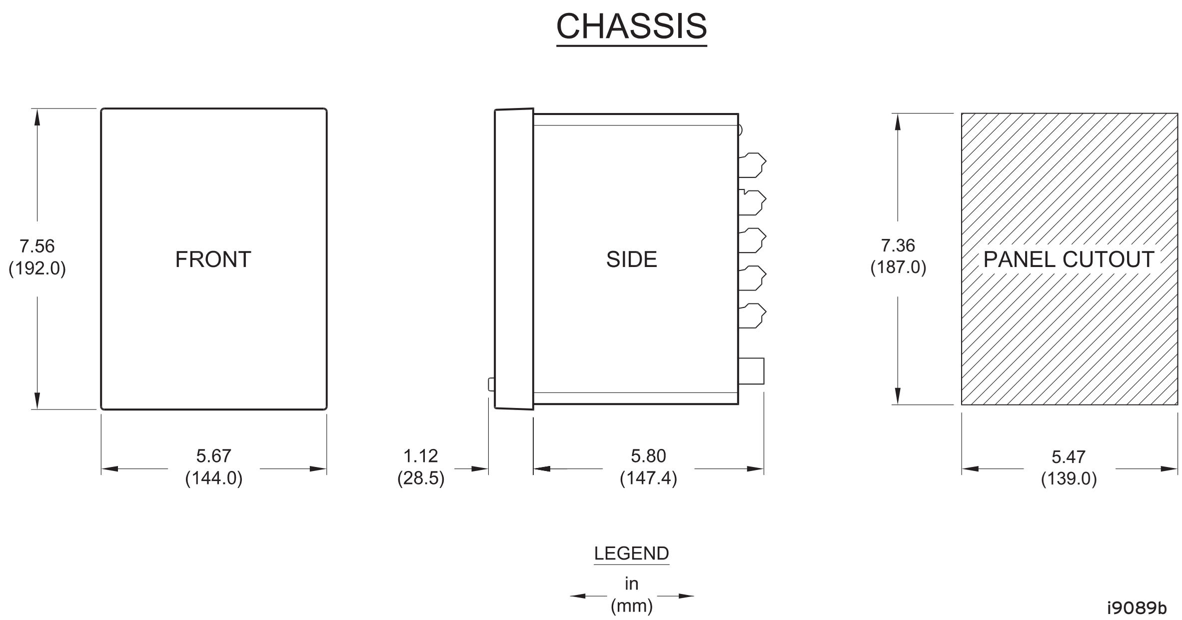


Figure 36 SEL-787 Dimensions for Rack- and Panel-Mount Models

Hardware Overview

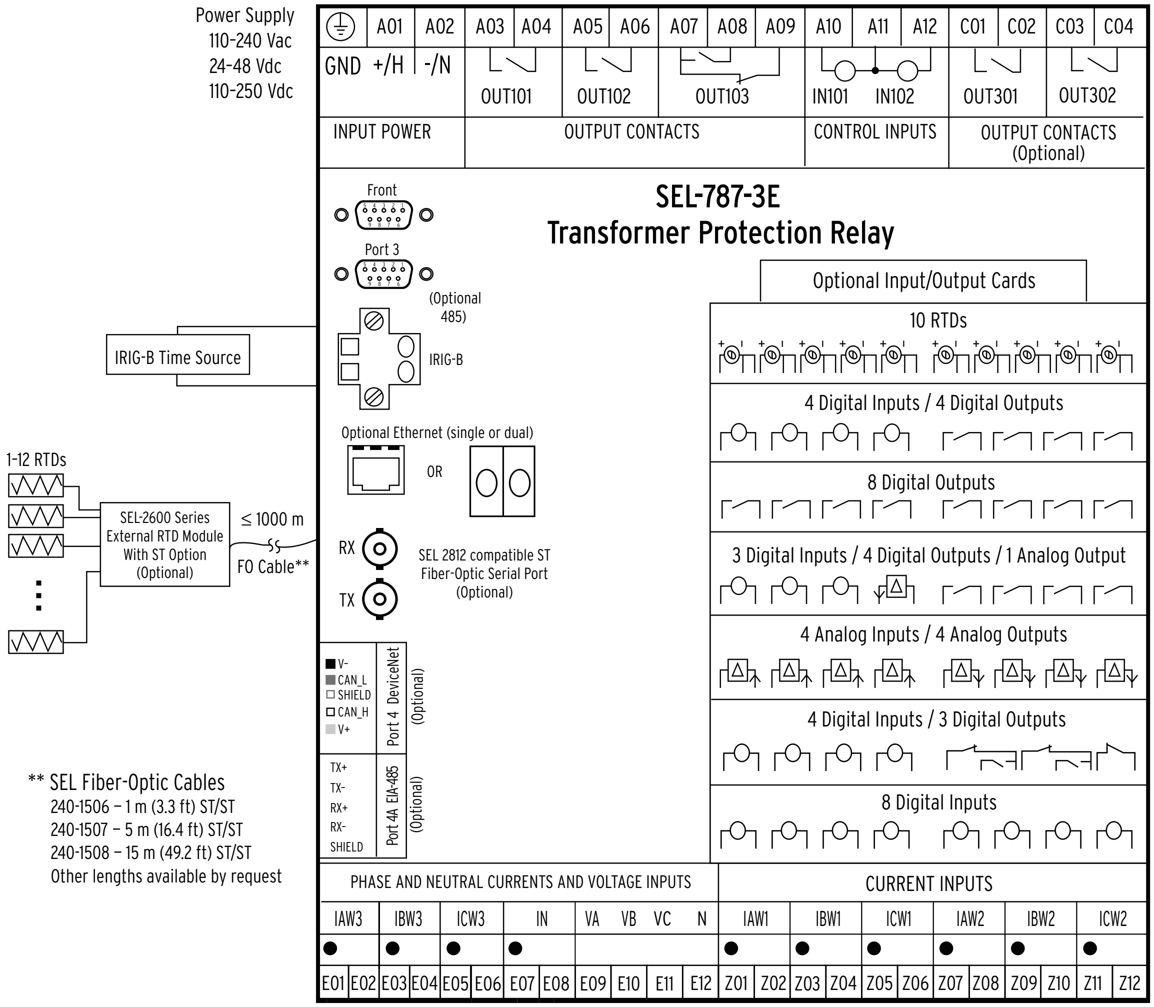


Figure 37 SEL-787-3E Wiring Diagram

Relay Panel Diagrams

SEL-787-4X Front Panel

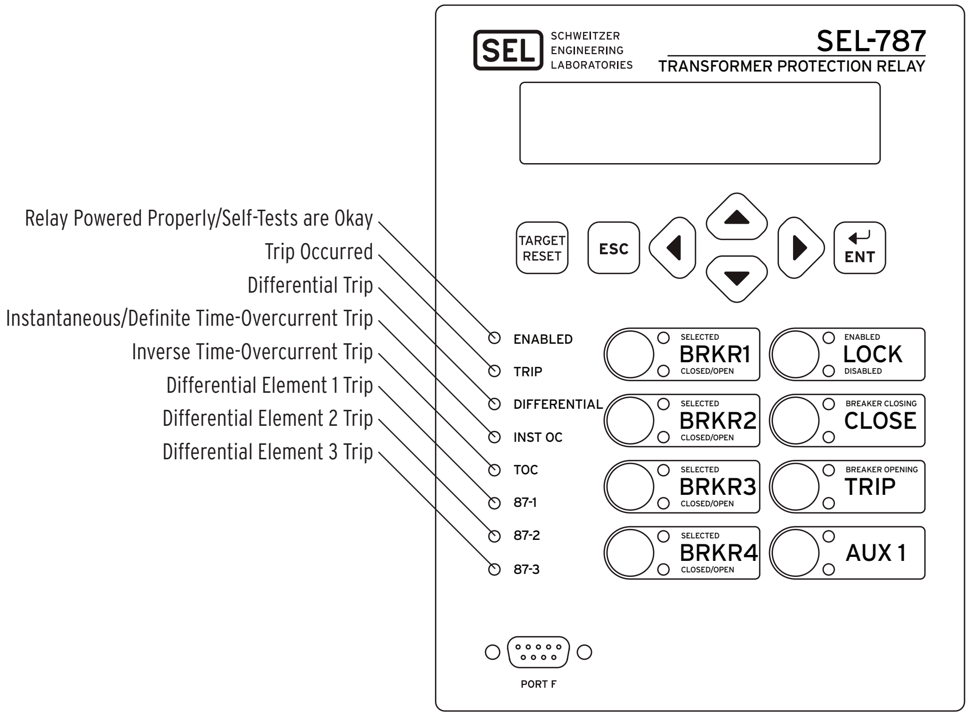
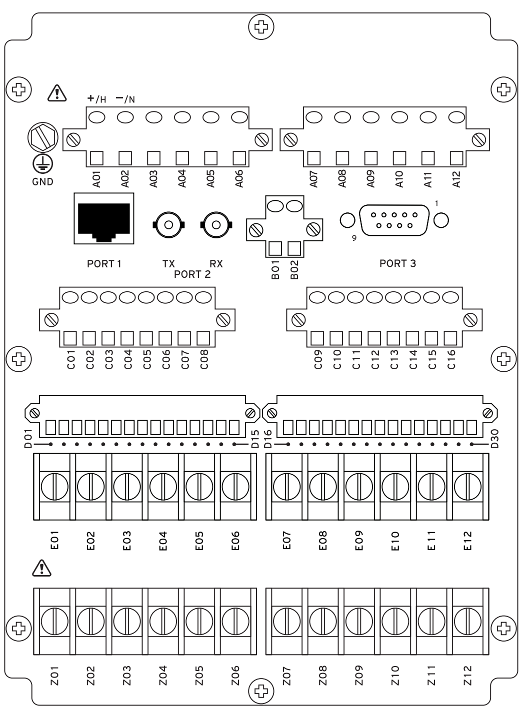
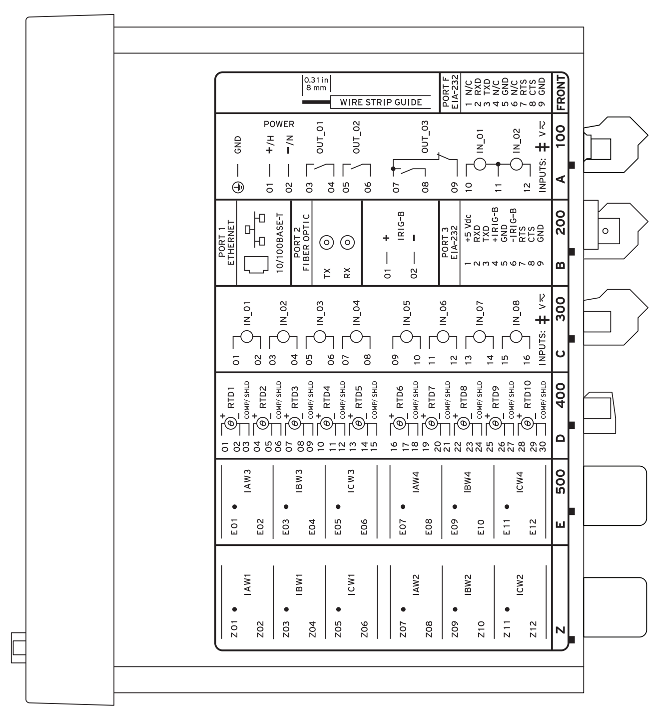


Figure 38 Front Panel With Default Configurable Labels

SEL-787-4X Rear and Side Panels



(A) Rear-Panel Layout



(B) Side-Panel Layout

Figure 39 SEL-787-4X With Single Copper Ethernet, 8 DI, and RTD Option

SEL-787-3E/S Front Panel

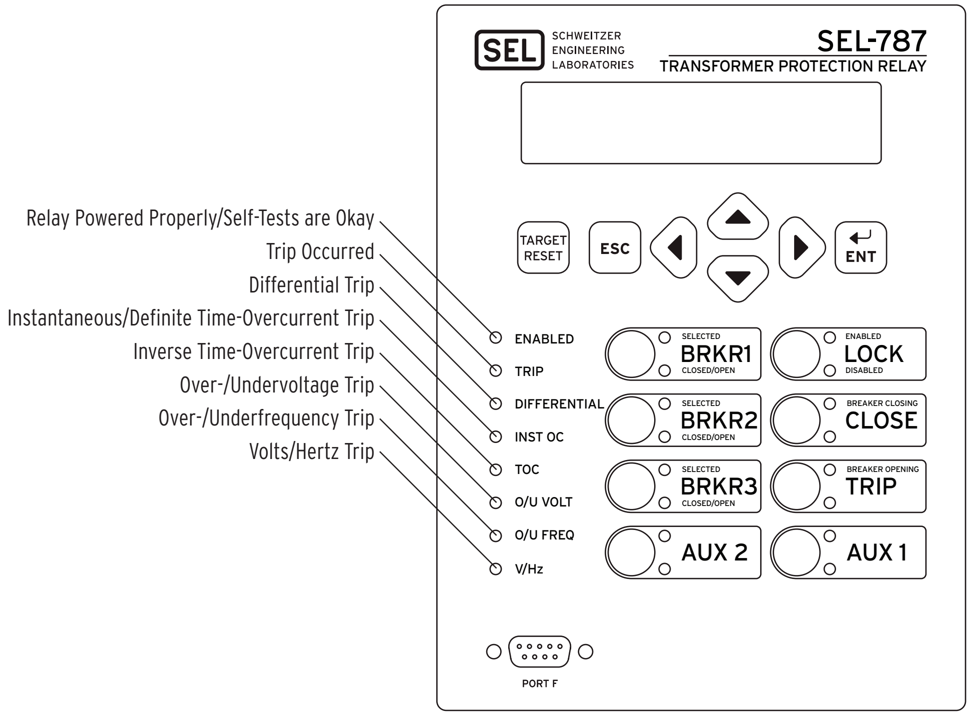
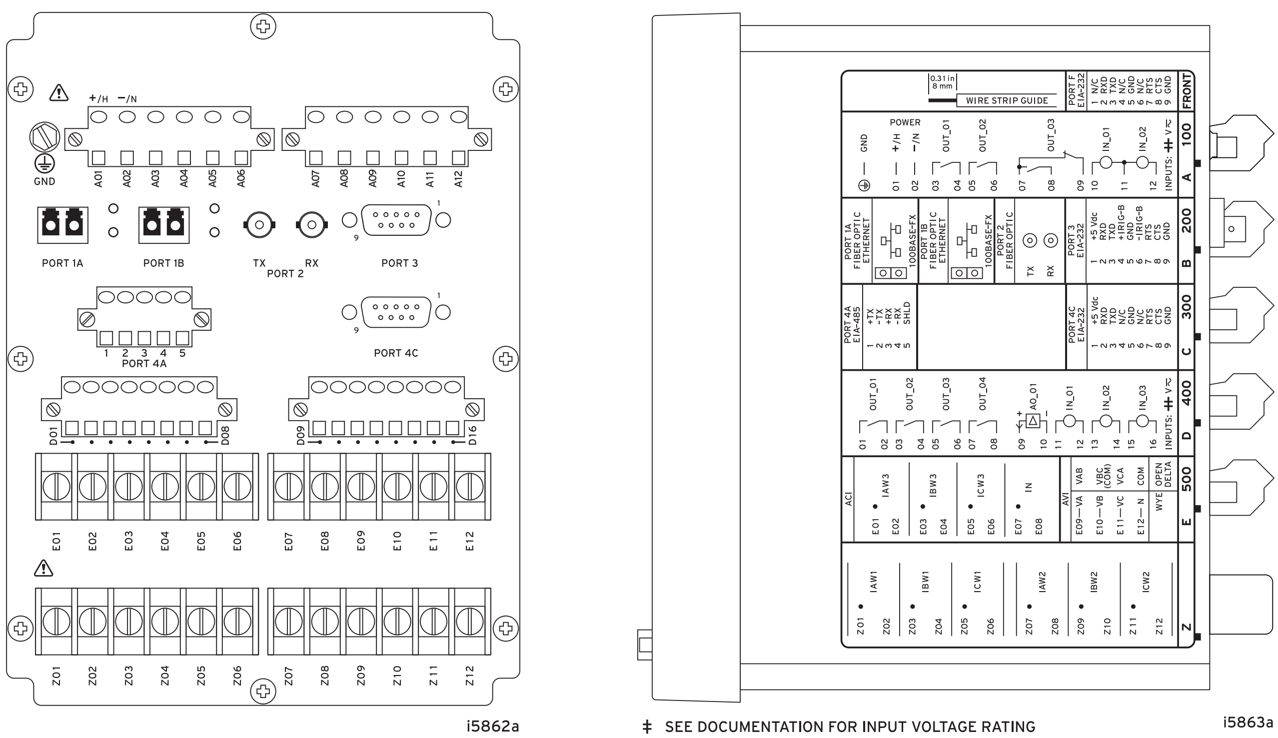


Figure 40 Front Panel With Default Configurable Labels

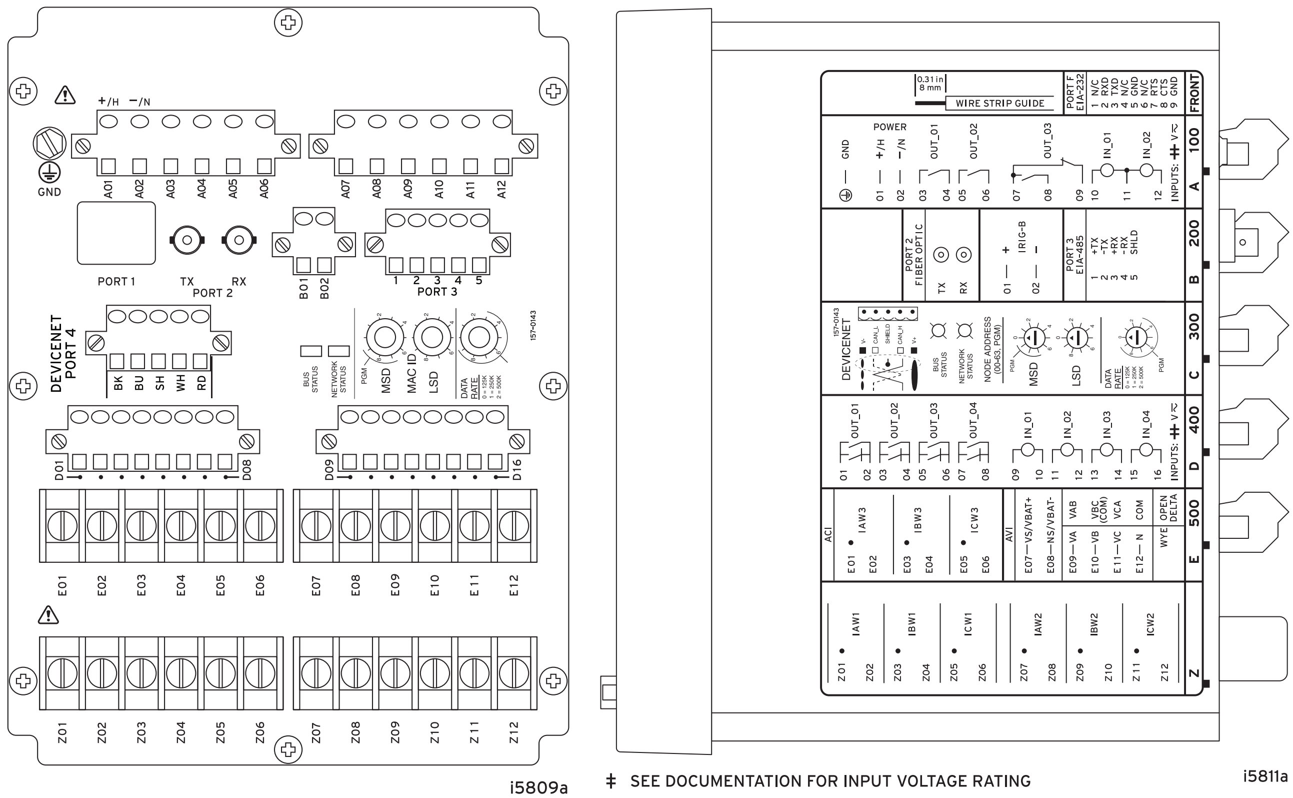
SEL-787-3E Rear and Side Panels



(A) Rear-Panel Layout (B) Side-Panel Layout

Figure 41 SEL-787-3E With Dual-Fiber Ethernet, EIA-232 Communication, 3 DI/4 DO/1 AO Option

SEL-787-3S Rear and Side Panels



(A) Rear-Panel Diagram (B) Side-Panel Diagram

Figure 42 SEL-787-3S With DeviceNet and Hybrid 4 DI/4 DO Option

SEL-787-2E Front Panel

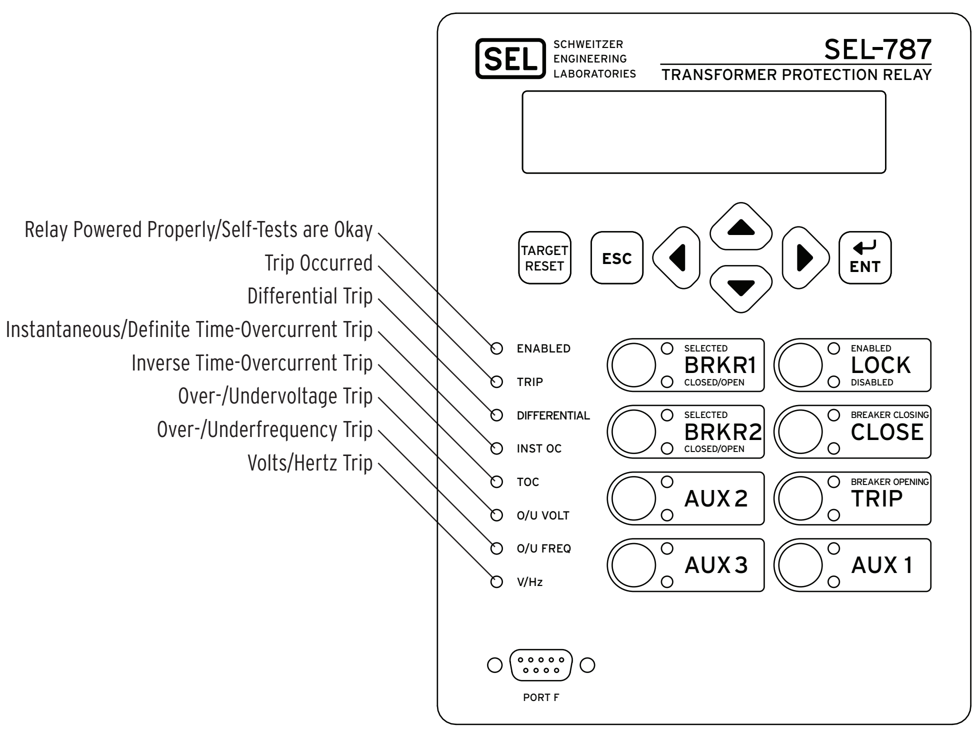
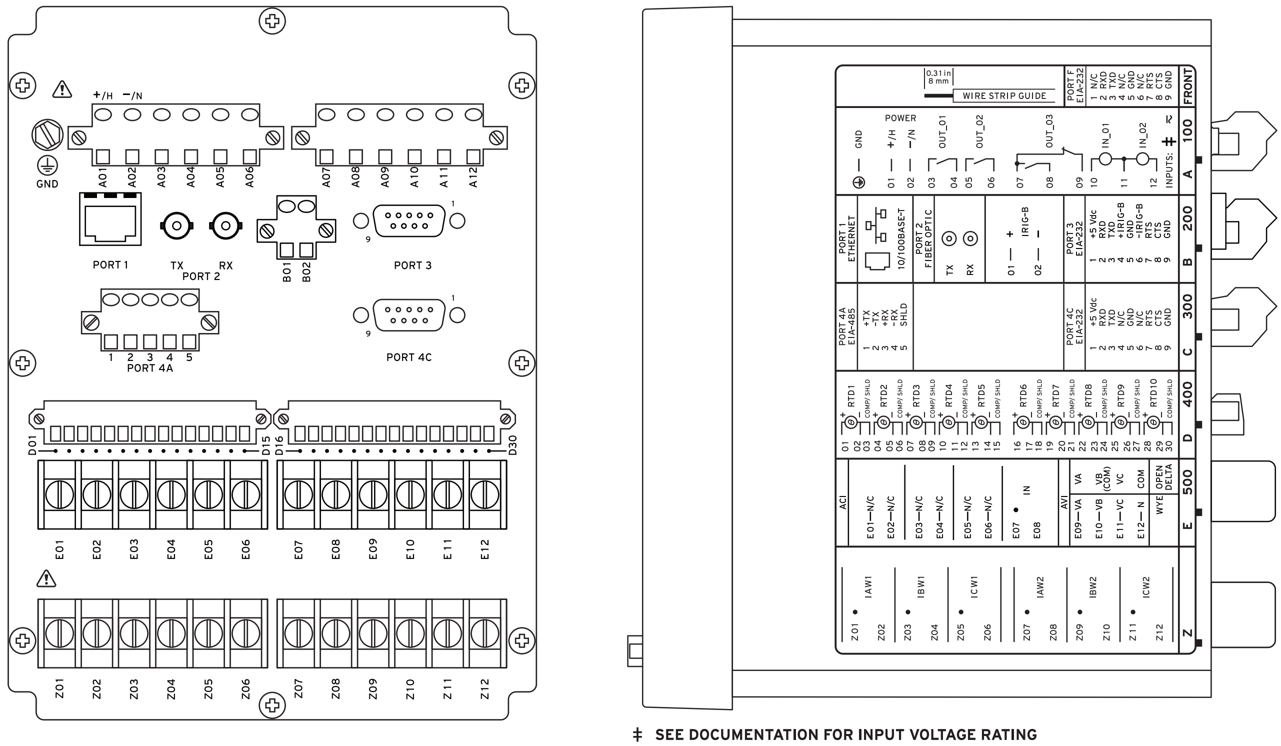


Figure 43 Front Panel With Default Configurable Labels

SEL-787-2E Rear and Side Panels



(A) Rear-Panel Layout (B) Side-Panel Layout

Figure 44 SEL-787-2E With Single Ethernet, EIA-232/EIA-485 Communications, and RTD Option

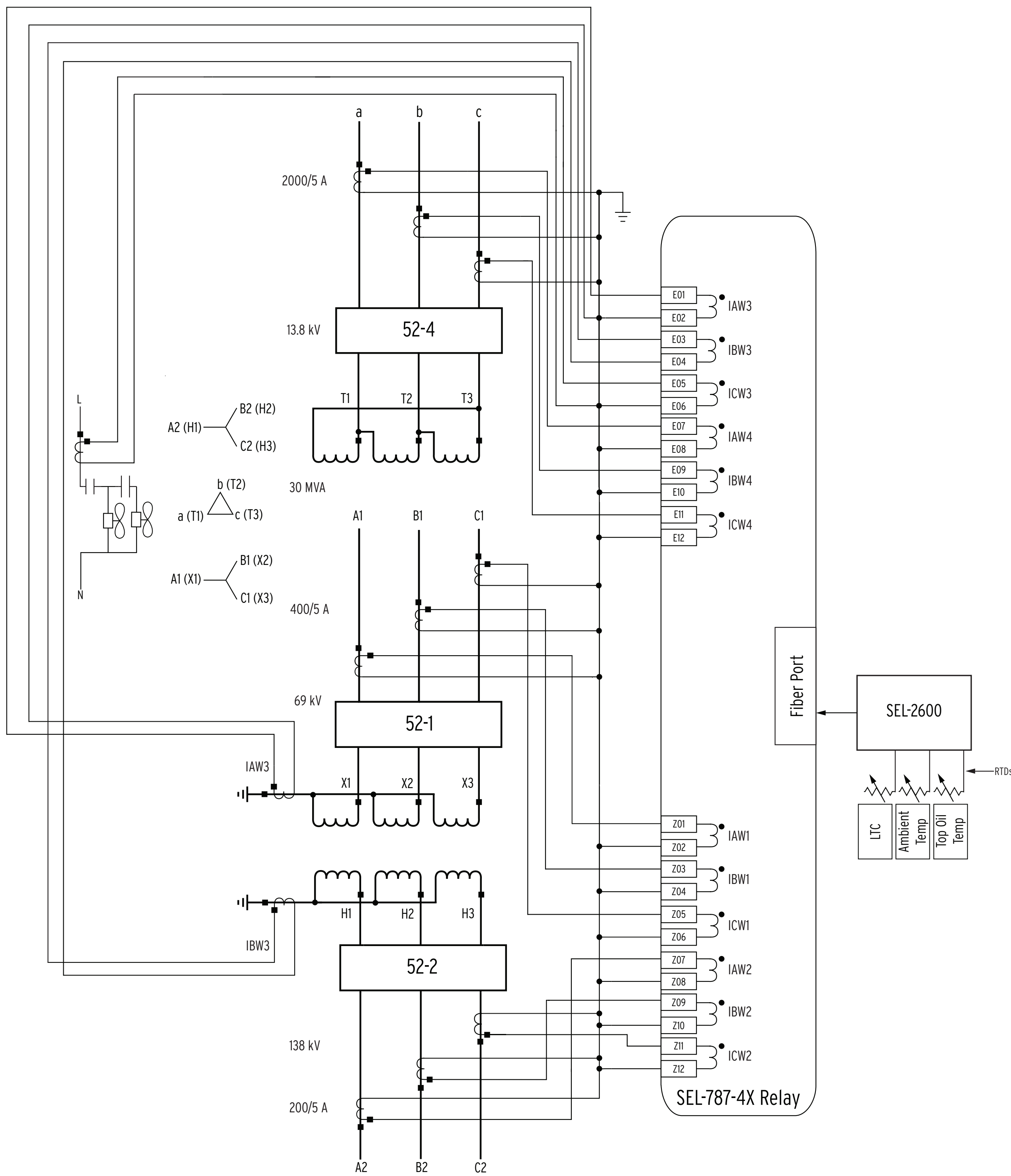
Applications

The SEL-787 is designed to provide differential and overcurrent protection for power transformers, generator step-up transformers, and autotransformers with as many as four windings/terminals. 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. Refer to *Section 2: Installation* and *Section 4: Protection and Logic Functions* of the instruction manual for more details.

Figure 45 shows the application of an SEL-787-4X Relay for protection of a three-winding transformer. You can configure Windings 1, 2, and 4 on the relay for differential protection, and you can apply the 50/51 elements associated with each winding towards overcurrent protection. You can configure A-phase and B-phase of Winding 3 on the relay for REF protection for Windings 1 and 2, respectively. You can configure C-phase of Winding 3, along with the RTD thermal elements, to provide fan bank control and protection. Use additional RTD thermal elements to monitor LTC tank temperatures and SELOGIC programming to indicate temperature differential alarms between transformer and LTC tank temperatures.

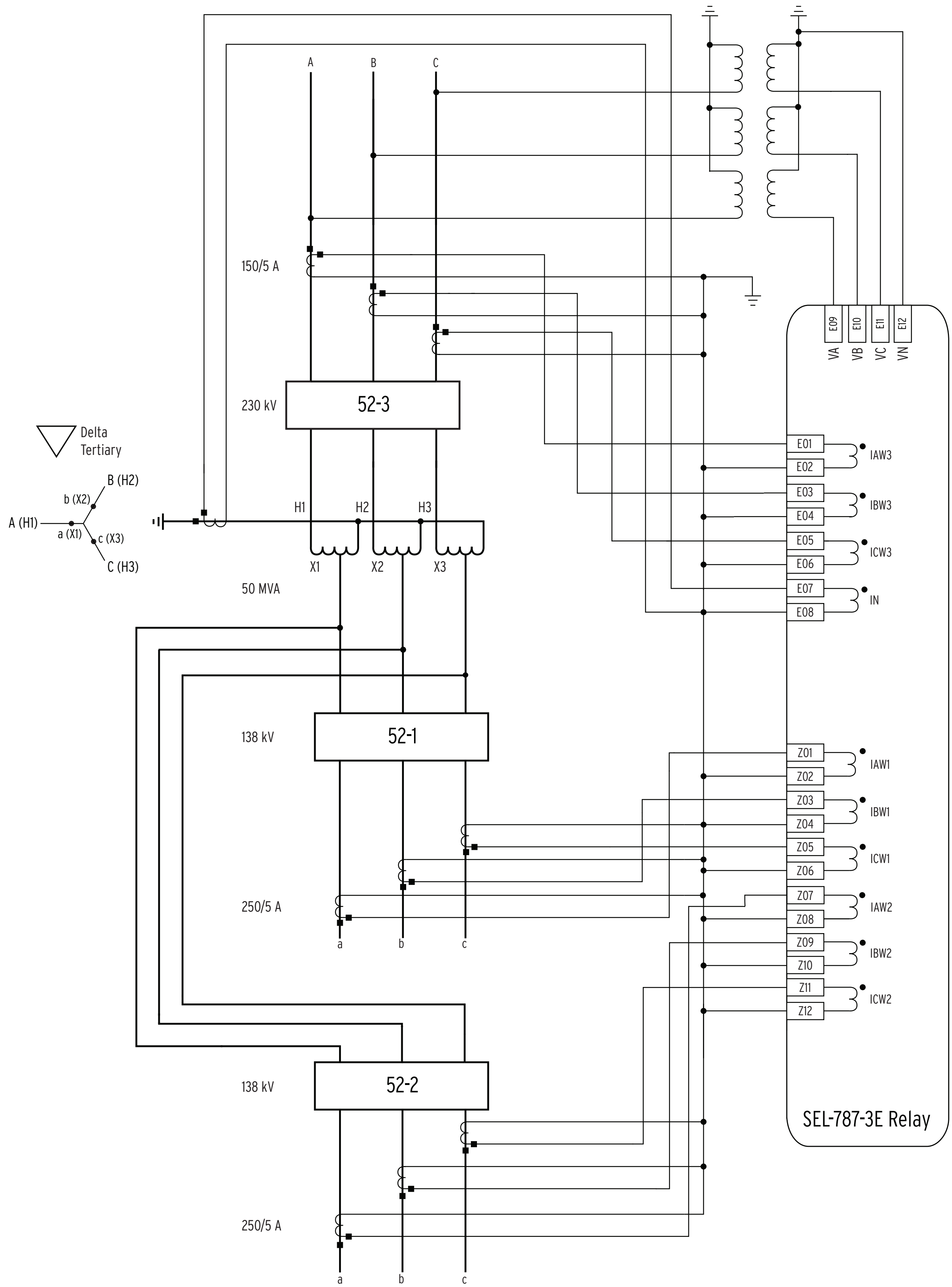
Figure 46 shows an SEL-787-3E Relay protecting an autotransformer with three terminals. You can configure Windings 1, 2, and 3 on the relay for differential protection, and you can apply the 50/51 elements associated with each winding towards overcurrent protection. You can configure Channel IN on the relay for REF protection. You can use the three-phase voltage inputs for V/Hz, over- and undervoltage, over- and underfrequency, and directional power protection.

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.



Note: The CT secondary circuit should be grounded in the relay cabinet.

Figure 45 SEL-787-4X Provides 3-Winding Transformer Differential Protection, REF Protection, Overcurrent Protection, and Fan Bank Control With LTC Monitoring



Note: The CT secondary circuit should be grounded in the relay cabinet.

Figure 46 SEL-787-3E Provides Auto-Transformer Differential Protection, REF Protection, Overcurrent Protection, and Voltage-Based Protection

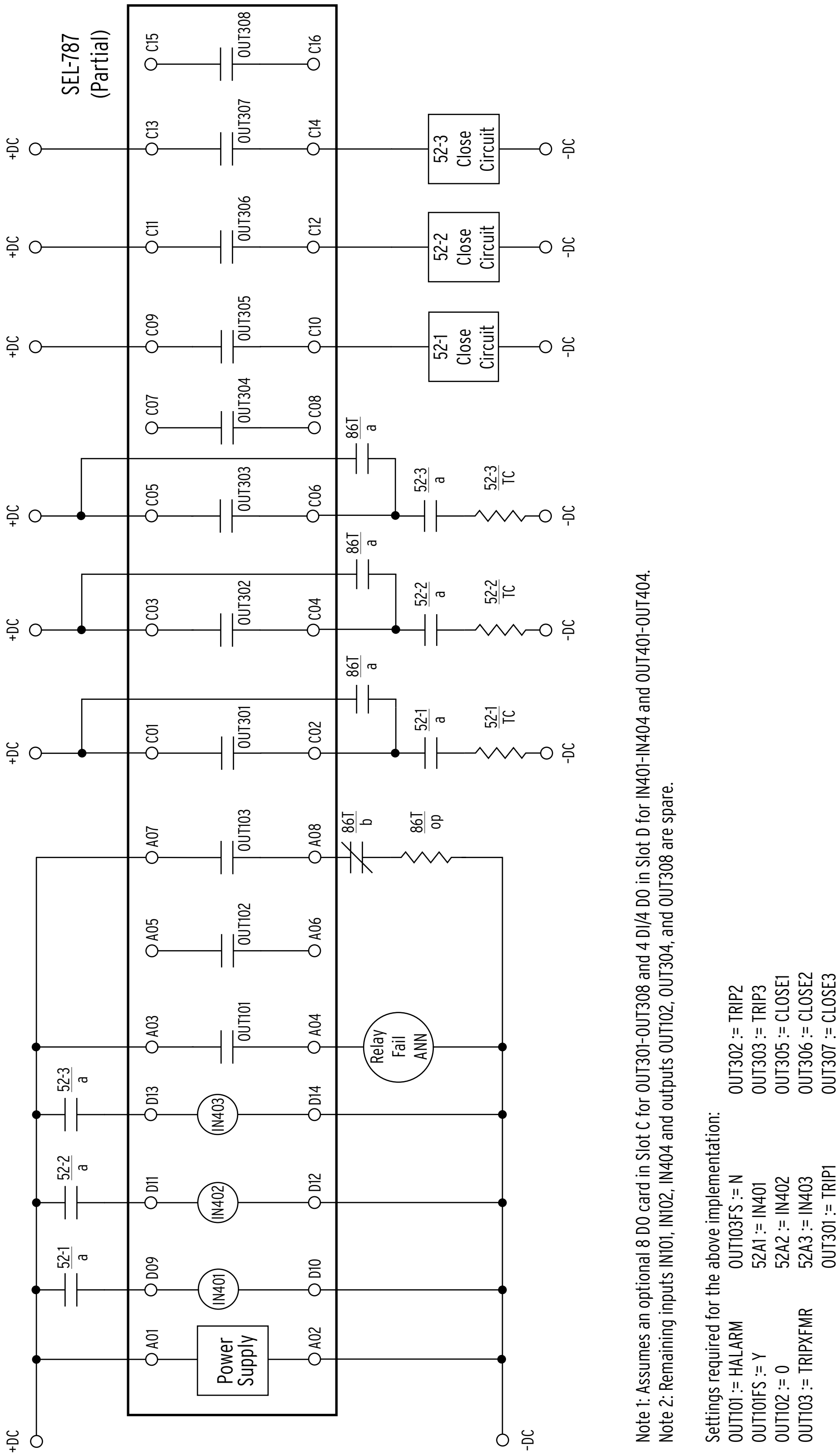


Figure 47 Typical DC Control Connection Diagram for the Three Terminal Applications

Specifications

Compliance

Designed and manufactured under an ISO 9001 certified quality management system

49 CFR 15B, Class A

Note: 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.

CE Mark in accordance with the requirements of the European Union

RCM Mark in accordance with the requirements of Australia

UKCA Mark in accordance with the requirements of United Kingdom

Normal Locations

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

Hazardous Locations

UL Certified Hazardous Locations to U.S. and Canadian standards CL 1, DIV 2; GP A, B, C, D; T3C, maximum surrounding air temperature of 50°C (File E470448)

EU

Ex SEL 19 ATEX 0001X
II 3 G
Ex ec nC IIC T3 Gc

EN 60079-0:2012 + A11:2013, EN 60079-7:2015, EN 60079-15:2010, EN 60079-11:2012

Ambient air temperature shall not exceed –20°C ≤ Ta ≤ +50°C.

Note: Where 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

I_{NOM} = 1 A or 5 A secondary depending on the model

Measurement Category:	II

Phase and Neutral Currents

I_{NOM} = 5 A

Continuous Rating:	3 • I_{NOM} @ 85°C 4 • I_{NOM} @ 55°C
A/D Measurement Limit:	217 A peak (154 A rms symmetrical)
Saturation Current Rating:	Linear to 96 A symmetrical
1-Second Thermal:	500 A
Burden (per phase):	<0.1 VA @ 5 A

I_{NOM} = 1 A

Continuous Rating:	3 • I_{NOM} @ 85°C 4 • I_{NOM} @ 55°C
A/D Measurement Limit:	43 A peak (31 A rms symmetrical)
Saturation Current Rating:	Linear to 19.2 A symmetrical
1-Second Thermal:	100 A
Burden (per phase):	<0.01 VA @ 1 A

AC Voltage Inputs

V_{NOM} (kV L-L)/PT Ratio Range:	100–250 V (if DELTA_Y := DELTA) 100–440 V (if DELTA_Y := WYE)
Rated Continuous Voltage:	300 Vac
10-Second Thermal:	600 Vac
Burden:	<0.1 VA
Input Impedance:	4 MΩ differential (phase-to-phase) 7 MΩ common mode (phase-to-chassis)

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 110–250 Vdc
Input Voltage Range (Design Range):	85–264 Vac 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

Output Contacts

General

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

Dielectric Test Voltage:	2500 Vac
Impulse Withstand Voltage (U_{IMP}):	5000 V
Mechanical Durability:	100,000 no-load operations

Standard Contacts

Pickup/Dropout Time:	≤8 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 (U_e) Rating: 240 Vac

Insulation Voltage (U_i) Rating (excluding EN 61010-1): 300 Vac

1-Second Thermal: 50 A

Contact Rating Designation: B300

B300 (5 A Thermal Current, 300 Vac Max)			
	Maximum Current		Max VA
Voltage	120 Vac	240 Vac	—
Make	30 A	15 A	3600
Break	3 A	1.5 A	360
PF <0.35, 50–60 Hz			

Utilization Category: AC-15

AC-15		
Operational Voltage (Ue)	120 Vac	240 Vac
Operational Current (Ie)	3 A	1.5 A
Make Current	30 A	15 A
Break Current	3 A	1.5 A
Electromagnetic loads >72 VA, PF <0.3, 50–60 Hz		

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

Pickup/Dropout Time: Depends on the input debounce settings

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 below 5 Vdc

When Used With AC Control Signals

Pickup Time: 2 ms

Dropout Time: 16 ms

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)

	1A0	4A0
Current:	4–20 mA	±20 mA
Voltage:	—	±10 V
Load at 1 mA:	—	0–15 kΩ
Load at 20 mA:	0–300 Ω	0–750 Ω
Load at 10 V:	—	>2000 Ω
Refresh Rate:	100 ms	100 ms
% Error, Full Scale, at	<±1%	<±0.55%
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:	15–70 Hz (requires ac voltage inputs)

Time-Code Input

Format:	Demodulated IRIG-B
On (1) State:	$V_{ih} \geq 2.2$ V
Off (0) State:	$V_{il} \leq 0.8$ V
Input Impedance:	2 kΩ

Synchronization Accuracy

Internal Clock:	±1 µs
Synchrophasor Reports (e.g., **MET PM**):	±10 µs
All Other Reports:	±5 ms
SNTP Accuracy:	±1 ms (in an ideal network)
PTP Accuracy:	±1 ms
Unsynchronized Clock Drift Relay Powered:	2 minutes per year, typically

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)

Standard Multimode Fiber-Optic Port

Location:	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 µm
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 µm
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 (the DeviceNet option has been discontinued and is no longer available as of September 25, 2017)

Communications Protocols

SEL, Modbus RTU and TCP/IP, DNP3 serial and LAN/WAN, FTP, Telnet, SNTP, IEEE 1588-2008 firmware-based PTP, IEC 61850 Edition 2, IEC 60870-5-103, EtherNet/IP, PRP, IEEE 802.1Q-2014 RSTP, MIRRORED BITS Communications, EVMSG, IEEE C37.118 (synchrophasors), and DeviceNet

Operating Temperature

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

Note: Not applicable to UL applications.

Note: The front-panel display is impaired for temperatures below –20°C and above +70°C.

DeviceNet Communications Card Rating:	+60°C (140°F) maximum
Optoisolated Control Inputs:	As many as 26 inputs are allowed in ambient temperatures of 85°C or less. As many as 34 inputs are allowed in ambient temperatures of 75°C or less. As many as 44 inputs are allowed in ambient temperatures of 65°C or less.

Operating Environment

Insulation Class:	I
Pollution Degree:	2
Overvoltage Category:	II
Atmospheric Pressure:	80–110 kPa
Relative Humidity:	5%–95%, noncondensing
Maximum Altitude Without Derating (Consult the Factory for Higher Altitude Rating):	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 Compatibility:	IEC 60255-26:2013 IEC 60255-27:2013 UL 508 CSA C22.2 No. 14-05

Type Tests

Environmental Tests

Enclosure Protection:	IEC 60529:2001 + CRDG:2003 IP65 enclosed in panel (2-line display models) IP54 enclosed in panel (touchscreen models) IP50-rated terminal dust protection assembly (SEL Part #915900170). The 10°C temperature derating applies to the temperature specifications of the relay. IP20 for terminals and the relay rear panel
Vibration Resistance:	IEC 60255-21-1:1988 IEC 60255-27:2013, Section 10.6.2.1 Endurance: Class 2 Response: Class 2
Shock Resistance:	IEC 60255-21-2:1988 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 IEC 60255-27:2013, Section 10.6.1.4 –40°C, 16 hours
Dry Heat:	IEC 60068-2-2:2007 IEC 60255-27:2013, Section 10.6.1.1 IEC 60255-27:2013, Section 10.6.1.3 85°C, 16 hours
Damp Heat, Steady State:	IEC 60068-2-78:2001 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
Change of Temperature:	IEC 60068-2-14:2009 IEC 60255-1:2010, Section 6.12.3.5 –40° to +85°C, ramp rate 1°C/min, 5 cycles

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, current, and voltage inputs
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 C37.90.2-2004 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 **Note:** Front port serial cable (non-fiber) length assumed to be <3 m. **Note:** Voltage elements (27, 59) time delay ≥ 30 ms.
Surge Withstand Capability Immunity:	IEC 61000-4-18:2010 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 **Note:** Front port serial cable (non-fiber) length assumed to be <3 m.
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 60225-26:2013, 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 Canada ICES-001 (A) / NMB-001 (A) 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 Canada ICES-001 (A) / NMB-001 (A) 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:	32 samples per power system cycle
Frequency Tracking Range:	15–70 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 25 ms). The 51 elements are processed 2 times per power system cycle. Analog quantities for rms data are determined through use of data averaged over the previous 8 cycles.

Oscillography

Length:	15, 64, or 180 cycles
Sampling Rate:	32 samples per cycle unfiltered
	4 samples per cycle filtered
Trigger:	Programmable with Boolean expression
Format:	ASCII and Compressed ASCII Binary COMTRADE (32 samples/cycle unfiltered)
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) for all Relay Word bits except those corresponding to digital inputs (IN*xxx*):	±5 ms
Time-Stamp Accuracy (With Respect to Time Source) for Relay Word bits corresponding to digital inputs (IN*xxx*):	1 ms

Functional Requirements

Over- and Undercurrent Protection:	IEC 60255-151:2009
Over- and Undervoltage Protection:	IEC 60255-127:2010
Frequency Protection:	IEC 60255-181:2019
Differential Protection:	IEC 60255-187-1:2021

Relay Elements

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

Supported and Effective Setting Range, A secondary	
5 A Model:	0.50–96.00 A, 0.01 A steps
1 A Model:	0.10–19.20 A, 0.01 A steps
Accuracy:	±3% of setting plus ±0.02 • I_{NOM} A secondary (steady state) ±5% of setting plus ±0.02 • I_{NOM} A secondary (transient) ±6% of setting plus ±0.02 • I_{NOM} A secondary (transient for 50Q)
Time Delay:	0.00–5.00 seconds, 0.01-second steps 0.00–120.00 seconds, 0.01-second steps (50Q) ±0.5% plus ±0.25 cycle
Pickup/Dropout Time:	<1.75 cycles (with fast hybrid output contacts)
Reset Ratio:	95% for setting ≥ 0.1 • INOM 90% for setting < 0.1 • INOM
Transient Overreach:	<15% for X/R = 10–120
Overshoot Time:	5 ms

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

Supported Setting Range, A secondary	
5 A Model:	0.50–16.00 A, 0.01 A steps
1 A Model:	0.10–3.20 A, 0.01 A steps
Effective Setting Range (IEC), A secondary	
5 A Model:	0.500–5.165 A, 0.01 A steps
1 A Model:	0.10–1.03 A, 0.01 A steps
Lowest Value of Input Energizing Quantity for which the Relay Is Guaranteed to Operate (GT):	1.20 • setting
Threshold at which the Relay Switches from Dependent Time Operation to Independent Time Operation (GD):	>30 • setting
Accuracy:	±5% of setting plus ±0.02 • I_{NOM} A secondary (steady-state pickup)
Time Dial	
U.S.:	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 A/D measurement limit)
Accuracy (Reset Time):	±1.5 cycles, ±4% between 0.5 and 0.0 multiple of pickup
Reset Ratio:	95% for setting ≥ 0.1 • I_NOM 90% for setting < 0.1 • I_NOM
Transient Overreach:	<15% for X/R = 10–120
Overshoot Time:	5–30 ms

Differential (87)

Unrestrained Pickup Range:	1.0–20.0 in per unit of TAP
Restrained 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:	1.05/1.25/2.15 cycles (Min/Typ/Max) (with fast hybrid output contacts)

Restrained Element (With Harmonic Blocking)

Pickup Time:	1.75/1.85/2.45 cycles (Min/Typ/Max) (with fast hybrid output contacts)

Restrained Element (With Harmonic Restraint)

Pickup Time:	2.87/2.97/3.11 cycles (Min/Typ/Max) (with fast hybrid output contacts)

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% plus ±0.25 cycle

Restricted Earth Fault (REF)

Pickup Range (per unit of I_{NOM} of neutral current inputs, IN, and/or Winding 3):	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 Maximum Pickup/Dropout Time:	<2.0 cycles (with fast hybrid output contacts)
ANSI Extremely Inverse TOC Curve (U4 With 0.5 Time Dial):	±5 cycles plus ±5% between 2 and 30 multiples of pickup (within rated range of current)

Undervoltage (27P, 27PP, 27S)

Supported and Effective Setting Range:	OFF, 12.50–300.00 V (phase elements, phase-to-phase elements with delta inputs or synchronism voltage input) OFF, 12.50–520.00 V (phase-to-phase elements with wye inputs)
Accuracy:	±1% of setting plus ±0.5 V
Pickup/Dropout Time:	<1.75 cycles (with fast hybrid output contacts)
Time Delay:	0.00–120.00 seconds, 0.01-second steps
Accuracy:	±0.5% plus ±0.25 cycle
Reset Ratio:	106% for setting ≤ 10 V 101% for setting > 10 V
Overshoot Time:	35 ms

Overvoltage (59P, 59PP, 59G, 59Q, 59S)

Supported and Effective Setting Range:	OFF, 12.50–300.00 V (phase elements, phase-to-phase elements with delta inputs or synchronism voltage input) OFF, 12.50–520.00 V (phase-to-phase elements with wye inputs)
Accuracy:	±1% of setting plus ±0.5 V
Pickup/Dropout Time:	<1.75 cycles (with fast hybrid output contacts)
Time Delay:	0.00–120.00 seconds, 0.01-second steps
Accuracy:	±0.5% plus ±0.25 cycle
Reset Ratio:	96% for setting ≤ 10 V 99% for setting > 10 V
Overshoot Time:	35 ms

Inverse-Time Undervoltage (27I)

Supported and Effective Setting Range	OFF, 2.00-300.00 V (phase elements, positive-sequence elements with delta inputs or synchronism-check voltage input) OFF, 2.00-520.00 V (phase-to-phase elements with wye inputs)
Accuracy:	±1% of setting plus ±0.5 V
Pickup/Dropout Time:	<1.75 cycles (with fast hybrid output contacts)
Time Dial:	0.00–16.00 s
Accuracy:	±1.5 cyc plus ±4% between 0.95 and 0.1 multiples of pickup
Pickup/Dropout Time:	<1.75 cycles (with fast hybrid output contacts)
Reset Ratio:	103% for setting ≤ 10 V 102% for setting > 10 V
Overshoot Time:	5–30 ms

Inverse-Time Overvoltage (59I)

Supported and Effective Setting Range:	OFF, 2.00–300.00 V (phase elements, sequence elements, or phase-to-phase elements with delta inputs or synchronism voltage input) OFF, 2.00–520.00 V (phase-to-phase elements with wye inputs)
Accuracy:	±1% of setting plus ±0.5 V
Pickup/Dropout Time:	<1.75 cycles (with fast hybrid output contacts)
Time Dial:	0.00–16.00 s
Accuracy:	±1.5 cyc plus ±4% between 1.05 and 5.5 multiples of pickup
Reset Ratio:	96% for setting ≤ 10 V 99% for setting > 10 V
Overshoot Time:	5–30 ms

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% plus ±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:	±0.10 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) ±0.02 A • (L-L voltage secondary) and ±5% of setting at unity power factor for power elements and zero power factor for reactive power element (1 A nominal)
Pickup/Dropout Time:	<10 cycles
Time Delay:	0.00–240.00 seconds, 0.01-second steps
Accuracy:	±0.5% plus ±0.25 cycle

Frequency (81)

Setting Range:	OFF, 15.00–70.00 Hz
Accuracy:	±0.01 Hz (V1 > 60 V) with voltage tracking
Pickup/Dropout Time:	<5.5 cycles (with fast hybrid output contacts)
Time Delay:	0.00–400.00 seconds, 0.01-second steps
Accuracy:	±0.5% plus ±0.25 cycle
Reset Hysteresis:	<0.02 Hz

RTD Protection

Setting Range:	OFF, 1°–250°C
Accuracy:	±2°C
RTD Open-Circuit Detection:	>250°C
RTD Short-Circuit Detection:	<–50°C
RTD Types:	PT100, NI100, NI120, CU10
RTD Lead Resistance:	25 ohm max. per lead
Update Rate:	<3 s
Noise Immunity on RTD Inputs:	To 1.4 Vac (peak) at 50 Hz or greater frequency
RTD Fault/Alarm/Trip Time Delay:	Approx. 12 s

Synchronism Check (25)

Pickup Range, Secondary Voltage:	0.00–300.00 V
Pickup Accuracy, Secondary Voltage:	±1% plus ±0.5 volts (over the range of 2.00–300.00 V)
Slip Frequency Pickup Range:	0.05 Hz–0.50 Hz
Slip Frequency Pickup Accuracy:	±0.02 Hz
Phase Angle Range:	0°–80°
Phase Angle Accuracy:	±4°

Station Battery Voltage Monitor

Operating Range:	0–350 Vdc (300 Vdc for UL purposes)
Pickup Range:	20.00–300.00 Vdc
Pickup Accuracy:	±2% of setting plus ±2 Vdc

Timers

Setting Range:	Various
Accuracy:	±0.5% of setting plus ±1/4 cycle

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.

Phase Currents

Magnitude Accuracy:	±1.0% (I_{NOM} = 1 A or 5 A)
Phase Accuracy:	±1.0° (I_{NOM} = 5 A), ±1.0° at 0.5–20.0 times I_{NOM} (I_{NOM} = 1 A), ±2.5° at 0.2–0.5 times I_{NOM} (I_{NOM} = 1 A)
Differential Quantities:	±5% of reading plus ±0.1 A (5 A nominal), ±0.02 A (1 A nominal)
Current Harmonics:	±5% of reading plus ±0.1 A (5 A nominal), ±0.02 A (1 A nominal)
I1 Positive-Sequence Current:	±2% of reading
IG (Residual Current):	±2% of reading, ±2° (±5.0° at 0.2–0.5 A for relays with I_{NOM} = 1 A)
IN (Neutral Current):	±1% of reading, ±1° (±2.5° at 0.2–0.5 A for relays with I_{NOM} = 1 A)
3I2 Negative-Sequence Current:	±2% of reading
System Frequency:	±0.01 Hz of reading for frequencies within 15–70 Hz (requires ac voltage inputs, V1 > 60 V)
Line-to-Line Voltages:	±1% of reading, ±1° for voltages within 24–264 V
Line-to-Ground Voltages:	±1% of reading, ±1° for voltages within 24–264 V
Voltage Harmonics:	±5% of reading plus ±0.5 V
V1 Positive-Sequence Voltage:	±2% of reading for voltages within 24–264 V
3V2 Negative-Sequence Voltage:	±2% of reading for voltages within 24–264 V
Real Three-Phase Power (kW):	±3% of reading for 0.10 < pf < 1.00
Reactive Three-Phase Power (kVAR):	±3% of reading for 0.00 < pf < 0.90
Apparent Three-Phase Power (kVA):	±3% of reading
Power Factor:	±2% of reading for 0.86 ≤ pf ≤ 1
RTD Temperatures:	±2°C

Synchrophasor Accuracy

Maximum Message Rate

Nominal 60 Hz System: 60 messages per second

Nominal 50 Hz System: 50 messages per second

The following are the accuracy specifications for voltages and currents for the SEL-787-3E and SEL-787-3S models. Note that the SEL-787-4X model does not track frequency, so the accuracy specifications are only applicable when the applied signal frequency equals FNOM.

Accuracy for Voltages

Level 1 compliant as specified in IEEE C37.118 under the following conditions for the specified range.

Conditions

- At maximum message rate
- When phasor has the same frequency as the positive-sequence voltage
- Frequency-based phasor compensation is enabled (PHCOMP := Y)
- The narrow bandwidth filter is selected (PMAPP := N)

Range

Frequency: ±5.0 Hz of nominal (50 or 60 Hz)

Magnitude: 30 V–250 V

Phase Angle: –179.99° to 180°

Out-of-Band Interfering Frequency (Fs): 10 Hz ≤ Fs ≤ (2 • FNOM)

Accuracy for Currents

Level 1 compliant as specified in IEEE C37.118 under the following conditions for the specified range.

Conditions

- At maximum message rate
- When phasor has the same frequency as the positive-sequence voltage
- Frequency-based phasor compensation is enabled (PHCOMP := Y)
- The narrow bandwidth filter is selected (PMAPP := N)

Range

Frequency: ±5.0 Hz of nominal (50 or 60 Hz)

Magnitude: (0.4–2) • I_{NOM} (I_{NOM} = 1 A or 5 A)

Phase Angle: –179.99° to 180°

Out-of-Band Interfering Frequency (Fs): 10 Hz ≤ Fs ≤ (2 • FNOM)

Notes

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WORLDWIDE 10 years WARRANTY

PDS787-02