SEL-487E-3, -4 Transformer Protection Relay

Three-Phase Transformer Protection, Automation, and Control System

Key Features and Benefits

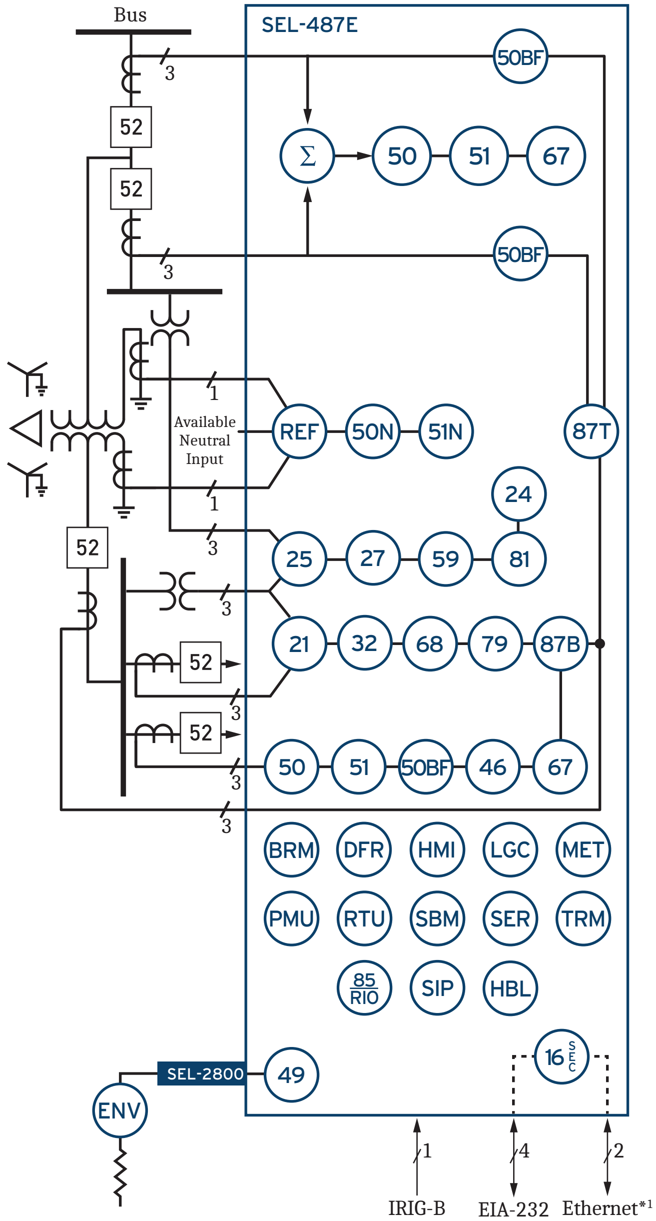
The SEL-487E Transformer Protection Relay provides three-phase differential protection for transformer applications with as many as six three-phase restraint current inputs. A second three-phase differential element is also supported for busbar protection.

- **High-Speed Differential Protection.** A two-stage slope adapts automatically to external fault conditions, providing fast, sensitive, dependable, and secure differential protection, even for CT saturation and heavily distorted waveforms. Two independent differential zones are available, one of which supports additional features that accommodate transformer differential protection.
- **Inrush and Overexcitation Detection.** Combined harmonic blocking and restraint features provide maximum security during transformer magnetizing inrush conditions. Waveshape-based inrush detection addresses inrush conditions that contain low second and fourth harmonic content.
- **Turn-to-Turn Winding Fault Protection.** Innovative negative-sequence differential elements provide transformer windings protection from as little as two percent turn-to-turn winding faults.
- **Restricted Earth Fault Protection.** Three independent REF elements provide sensitive protection for faults close to the winding neutral in grounded wye-connected transformers.

- **Combined Overcurrent.** Configurations exist for a wide variety of transformer applications. Use the combined overcurrent elements for transformers connected to ring-bus or breaker and one-half systems. This feature mathematically sums two terminal current inputs to form a single operating quantity.
- **Distance Protection.** Mho or quadrilateral characteristics protect transformers and transmission lines with four zones of phase distance and ground distance elements. Line harmonic blocking, load-encroachment, coupling capacitor voltage transformer (CCVT) detection, and out-of-step blocking logic add security to your distance protection scheme.
- **Transformer and Feeder Backup Protection.** Adaptive time-overcurrent elements with selectable operating quantity, programmable pickup, and time-delay settings provide transformer and feeder backup protection.
- **Reclosing Control.** You can incorporate programmable three-pole trip and reclose of as many as six independent breakers into an integrated substation control system.
- **Reverse Power Flow and Overload Condition Protection.** The SEL-487E directional real- and reactive-power elements guard against reverse power flow and overload conditions.
- **Synchronism Check.** Synchronism check can prevent circuit breakers from closing if the corresponding phases across the open circuit breaker are excessively out of phase, magnitude, or frequency. The synchronism-check function has a user-selectable synchronizing voltage source and incorporates slip frequency, two levels of maximum angle difference, and breaker close time into the closing decision.
- **Input/Output Scaling.** The SEL-2600 RTD Module provides as many as 12 temperature inputs, and the SEL-2505/SEL-2506 Remote I/O Modules provide a scalable number of discrete I/O points.
- **Two CT Input Levels.** Selectable 1 A or 5 A nominal secondary input levels are available for any three-phase winding input.
- **Large CT Mismatch Ratio.** The relay can accommodate CT ratio mismatch as great as 35:1.
- **Breaker Failure.** High-speed (less than one cycle) open-pole detection logic reduces coordination times for critical breaker failure applications. Apply the relay to supply breaker failure protection for all supported breakers. Logic for breaker failure retrip and initiation of transfer tripping is included.
- **IEC 60255-149 Compliant Thermal Model.** The relay can provide a configurable thermal model for the protection of a wide variety of devices. This function can activate a control action or issue an alarm or trip when equipment overheats as a result of adverse operation conditions. A separate resistance temperature detector (RTD) module is required for this application.
- **Ethernet Access.** The optional Ethernet card grants access to all relay functions. Use IEC 61850 Manufacturing Message Specification (MMS) or DNP3 protocol directly to interconnect with automation systems. You can also connect to DNP3 networks through a communications processor. Use File Transfer Protocol (FTP) for high-speed data collection. Connect to substation or corporate LANs to transmit synchrophasors by using TCP or UDP internet protocols.
- **Serial Data Communication.** The relay can communicate serial data through SEL ASCII, SEL Fast Message, SEL Fast Operate, MIRRORED BITS®, and DNP3 protocols. Synchrophasor data are provided in either SEL Fast Message or IEEE C37.118 format.
- **Automation.** The enhanced automation features include programmable elements for local control, remote control, protection latching, and automation latching. Local metering on the large front-panel LCD eliminates the need for separate panel meters. Serial and Ethernet links efficiently transmit key information, including metering data, protection element and control I/O status, synchrophasor data, IEC 61850 Edition 2 GOOSE messages, Sequential Events Recorder (SER) reports, breaker monitoring, relay summary event reports, and time synchronization. Apply expanded SELOGIC® control equations with math and comparison functions in control applications. Incorporate as many as 1000 lines of automation logic to accelerate and improve control actions.
- **Synchrophasors.** You can make informed load dispatch decisions based on actual real-time phasor measurements from relays across your power system. Record streaming synchrophasor data from the relay for system-wide disturbance recording. Control the power system by using local and remote synchrophasor data.
- **Breaker and Battery Monitoring.** You can schedule breaker maintenance when accumulated breaker duty (independently monitored for each pole) indicates possible excess contact wear. The relay records electrical and mechanical operating times for both the last operation and the average of operations since function reset. Alarm contacts provide notification of substation battery voltage problems (as many as two independent battery monitors in some SEL-400 series relays) even if voltage is low only during trip or close operations.
- **Six Independent Settings Groups.** The relay includes group logic to adjust settings for different operating conditions, such as station maintenance, seasonal operations, emergency contingencies, loading, source changes, and adjacent relay settings changes. Select the active group settings by control input, command, or other programmable conditions.

- **Software-Invertible Polarities.** Inverting individual or grouped CT and PT polarities allows you to account for field wiring or zones of protection changes. CEV files and all metering and protection logic use the inverted polarities, whereas COMTRADE event reports do not use inverted polarities but rather record signals as applied to the relay.
- **Parallel Redundancy Protocol (PRP).** PRP provides seamless recovery from any single Ethernet network failure. The Ethernet network and all traffic are fully duplicated with both copies operating in parallel.
- **IEC 61850 Operating Modes.** The relay supports IEC 61850 standard operating modes such as Test, Blocked, On, and Off.
- **IEEE 1588, Precision Time Protocol (PTP).** PTP provides high-accuracy timing over an Ethernet network.
- **Digital Relay-to-Relay Communications.** MIRRORED BITS communications can monitor internal element conditions between bays within a station, or between stations, using SEL fiber-optic transceivers. Send digital, analog, and virtual terminal data over the same MIRRORED BITS channel.
- **Sequential Events Recorder (SER).** The SER records the last 1000 events, including setting changes, startups, and selectable logic elements.
- **Oscillography and Event Reporting.** The relay records voltages, currents, and internal logic points at a sampling rate as fast as 8 kHz. Offline phasor and harmonic-analysis features allow investigation of bay and system performance. Time-tag binary COMTRADE event reports with high-accuracy time stamping for accuracy better than 10 µs.
- **Digitally Signed Upgrades.** The relay supports upgrading the relay firmware with a digitally signed upgrade file. The digitally signed portion of the upgrade file helps ensure firmware and device authenticity after it is sent over a serial or Ethernet connection.
- **Increased Security.** The relay divides control and settings into seven relay access levels; the relay has separate breaker, protection, automation, and output access levels, among others. Set unique passwords for each access level.
- **Rules-Based Settings Editor.** You can communicate with and set the relay by using an ASCII terminal or use QuickSet to configure the relay and analyze fault records with relay element response. Use as many as 200 aliases to rename any digital or analog quantity in the relay.

Functional Overview



ANSI NUMBERS/ACRONYMS AND FUNCTIONS	
16 SEC	Access Security (Serial, Ethernet)
21*	Phase and Ground Distance
24	Volts/Hertz
25	Synchronism Check
27	Undervoltage
32	Directional Power
46	Current Unbalance
49	IEEE C59.71 and IEC 60255-Compliant Thermal Model
50BF	Dual Breaker Failure Overcurrent
50N	Neutral Overcurrent
50	Overcurrent (Phase, Zero-Sequence, and Negative-Sequence)
51N	Neutral Time-Overcurrent
51	Time-Overcurrent (Phase, Zero-Sequence, and Negative-Sequence)
59	Overvoltage
67	Directional Overcurrent (Phase, Zero-Sequence, and Negative-Sequence)
68*	Out-of-Step Block
79*	Autoreclosing
81	Over- and Underfrequency
85 RIO	SEL MIRRORED BITS Communications
87T	Transformer Differential (Unrestrained, Restrained, Neg. Seq.)
87B*	Bus Differential (Restrained)

ADDITIONAL FUNCTIONS	
BRM	Breaker Wear Monitor
DFR	Event Reports
ENV	SEL-2600 RTD Module*
HBL	Harmonic Blocking
HMI	Operator Interface
LDP	Load Data Profiling
LGC	SELOGIC Control Equations
MET	High-Accuracy Metering
PMU	Synchrophasors
REF	Restricted Earth Fault
RTU	Remote Terminal Unit
SER	Sequential Events Recorder
SBM	Station Battery Monitor
SIP	Software-Invertible Polarities
TRM	Transformer Monitor

[1] Copper or Fiber Optic * Optional Feature

Figure 1 Functional Diagram

Protection Features

Differential Element

In the SEL-487E, the phase differential elements employ operate (IOP*n*, where *n* = A, B, C) and restraint (IRT*n*) quantities that the relay calculates from the selected winding input currents. *Figure 2* shows the characteristic of the filtered differential element as a straight line through the origin of the form:

$$IOPA\ (IRTA) = SLPc \bullet IRTA$$

For operating quantities (IOPA) exceeding the threshold level O87P and falling in the operate region of *Figure 2*, the filtered differential element issues an output. There are two slope settings, namely Slope 1 (SLP1) and Slope 2 (SLP2). Slope 1 is effective during normal operating conditions, and Slope 2 is effective when the fault detection logic detects an external fault condition. In general, the relay uses filtered and unfiltered (instantaneous) analog quantities in two separate algorithms to form the differential element. The adaptive differential element responds to most internal fault conditions in less than one and a half cycles.

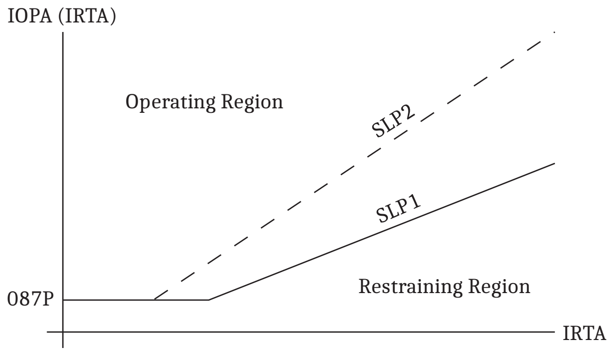


Figure 2 Adaptive Slope Differential Characteristics

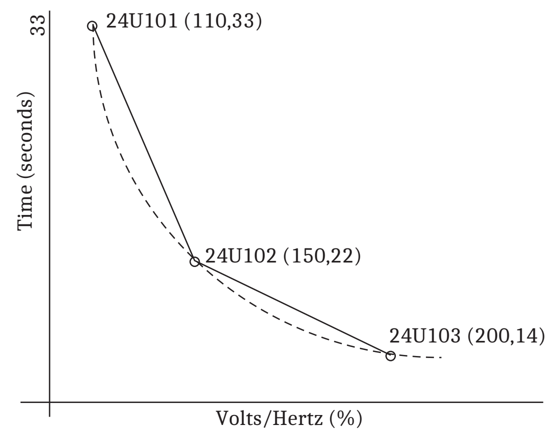
The differential element includes one harmonic blocking and one harmonic restraint element; select either one or both of them. The combination of harmonic blocking and restraint elements provides optimum operating speed and security during inrush conditions. Waveshape-based inrush detection addresses inrush conditions that contain low second- and fourth-harmonic content. Fast subcycle external fault detection supervision adds security during external faults with CT saturation. The harmonic blocking element includes common or independent second- and fourth-harmonic blocking and independent fifth-harmonic blocking.

Negative-Sequence Differential Element

Turn-to-turn internal faults on transformer windings may not cause enough additional current flow at the transformer bushing CTs to assert a phase-current differential element, but left undetected can be very destructive to the transformer. When turn-to-turn faults occur, the autotransformer effect on the shorted section of winding causes a very large current flow relative to the shorted windings but small compared to the remainder of the unaffected winding. To detect these destructive internal faults, the SEL-487E uses a sensitive negative-sequence current differential element. This element detects the phase-current unbalance caused by internal fault by using a single-slope characteristic. Using negative-sequence restraint, the differential element is not affected by fluctuating negative-sequence quantities on the power system and is able to detect turn-to-turn short circuit conditions in as little as two percent of the total transformer winding. External fault detection logic from the phase-differential element is used to block the negative-sequence differential element, keeping it secure during external faults and inrush conditions when CT saturation may occur.

V/Hz Elements

The SEL-487E provides comprehensive V/Hz protection (24). The SEL-487E maintains frequency tracking from 40.0 to 65.0 Hz when voltage inputs are provided to the relay. Two independent V/Hz curves with definite and custom 20-point curve characteristics can be selected using programmable logic. Use the two independent V/Hz curves for loaded versus unloaded transformer protection, allowing maximum sensitivity to overexcitation conditions during all modes of transformer operation. The single V/Hz element in the relay can be assigned to either set of three-phase voltage inputs.



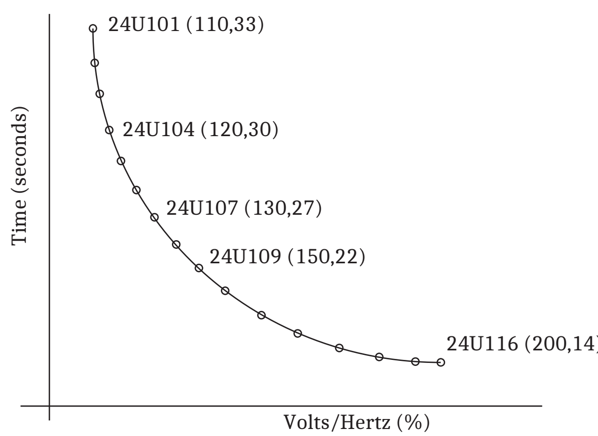


Figure 3 Volts/Hertz Curve Diagrams

Distance Elements

The SEL-487E protects transformers and transmission lines with as many as four zones of phase distance and ground distance elements with either mho or quadrilateral characteristics. You can set all four zones independently in the forward or reverse direction. The distance elements are secured with load-encroachment logic, which prevents operation of the phase distance elements under high load conditions; line harmonic-blocking logic, which prevents element operation when a transformer in the protection zone is being energized or experiencing an overexcitation condition; and CCVT transient detection, which blocks the distance elements when there is transient on the system with CCVTs that may cause the distance element to overreach. All mho elements use positive-sequence memory polarization that expands the operating characteristic in proportion to the source impedance. This provides dependable and secure operation for close-in faults. The quadrilateral phase and ground distance elements provide improved fault and arc resistance coverage, including application on short lines.

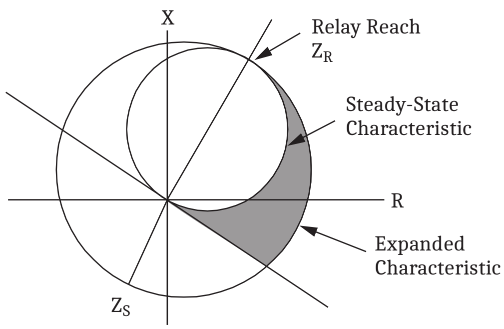


Figure 4 Mho Characteristics

Out-of-Step Detection

The SEL-487E supports out-of-step detection by using timers and blinders that are set outside any of the distance elements. A power swing is declared when an impedance locus travels through the blinders slower than a preset time. This logic blocks the distance elements in case of a stable power swing.

Adaptive Time-Overcurrent Elements (51S)

The relay supports 20 adaptive time-overcurrent elements with selectable operate quantity and programmable time-delay and pickup levels. Choose from the ten time-overcurrent curves shown in *Table 1* (five IEC and five U.S.). Each torque-controlled time-overcurrent element has two reset characteristics. One choice resets the elements if current drops below pickup for one cycle while the other choice emulates the reset characteristic of an electromechanical induction disk relay.

Table 1 Supported Time-Overcurrent Curves

U.S. Curves	IEC Curves
U1 (moderately inverse)	C1 (standard inverse)
U2 (inverse)	C2 (very inverse)
U3 (very inverse)	C3 (extremely inverse)
U4 (extremely inverse)	C4 (long-time inverse)
U5 (short-time inverse)	C5 (short-time inverse)

The adaptive time-overcurrent elements in the SEL-487E allow the selection of a wide variety of current sources as operate quantities to the element. Select the time-overcurrent element operate quantity from any one of the following current sources:

- Filtered phase currents: IA*m*FM, IB*m*FM, IC*m*FM
- Maximum filtered phase current: IMAX*m*F
- Combined filtered phase currents (any two terminals): IA*mm*FM, IB*mm*FM, IC*mm*FM
- Maximum filtered combined phase current: IMAX*mm*F
- Filtered positive-, negative-, and zero-sequence: I1*m*FM, 3I2*m*FM, 3I0*m*FM, I1*mm*M, 3I2*mm*M, 3I0*mm*M
- RMS currents: IA*m*RMS, IB*m*RMS, IC*m*RMS, IMAX*m*R IA*mm*RMS, IB*mm*RMS, IC*mm*RMS, IMAX*mm*R

where:

m = Relay current terminals S, T, U, W, X, Y

mm = Relay current terminals ST, TU, UW, WX

F = Filtered

M = Magnitude

MAX = Maximum magnitude A-, B-, C-phase currents

In addition to the selectable operate quantity, the 51S element time-delay and pickup level inputs are SELOGIC-programmable settings. This flexibility allows these inputs to be set to fixed numerical values to operate as standard time overcurrent elements, or the pickup and time-dial settings can be programmed as SELOGIC math variables. Programming the time-delay and pickup levels as math variables allows the numeric value of the pickup and time-delay settings to change based on system conditions without the added delay of having to change relay setting groups. For example, change pickup and time-delay settings dynamically in a parallel transformer application based upon single or parallel transformer configurations. Another example would be changing feeder time-overcurrent element pickup and coordination delays based upon distributed generation being connected downstream of a transformer.

REF Protection

Apply the REF protection feature to provide sensitive detection of internal ground faults on grounded wye-connected transformer windings and autotransformers. Use single-phase neutral current inputs for providing neutral CT operating current for as many as three windings. Polarizing current is derived from the residual current calculated for the corresponding protected winding. A directional element determines whether the fault is internal or external. Zero-sequence current thresholds supervise tripping. The relay can accommodate CT ratio mismatch as great as 35:1.

Synchronism Check

Synchronism-check elements prevent circuit breakers from closing if the corresponding phases across the open circuit breaker are excessively out of phase, magnitude, or frequency. The SEL-487E synchronism-check elements selectively close circuit breaker poles under the following criteria:

- ➤ The systems on both sides of the open circuit breaker are in phase (within a settable voltage angle difference).
- ➤ The voltages on both sides of the open circuit breaker are healthy (within a settable voltage magnitude window).

The synchronism-check function is available for as many as six breakers with a user-selectable reference voltage. Each element has a user-selectable synchronizing voltage source and incorporates slip frequency, two levels of maximum angle difference, and breaker close time into the closing decision. Include the synchronism-check element outputs in the close SELOGIC control equations to program the relay to supervise circuit breaker closing.

Current Unbalance Elements

The current unbalance logic uses the average terminal current to calculate the percentage difference between the individual phase current and the terminal median current. If the percentage difference is greater than the pickup value setting, the phase unbalance element is asserted. To prevent this element from asserting during fault conditions and after a terminal circuit breaker has closed, the final terminal unbalance output is supervised using current, fault detectors, and the open-phase detection logic.

Fault Identification Logic

The purpose of the fault identification logic is to determine, on a per-terminal basis, which phase(s) was involved in a fault for which the transformer tripped. Determining the faulted phase is based on current inputs from wye-connected CTs. The logic does not determine the faulted phase for the following cases:

- ➤ Delta-connected CTs (CTCON*m* = D)
- ➤ Where only zero-sequence current flows through the relay terminal (no negative-sequence current and no positive-sequence current)

This logic identifies a sector in which a faulted phase(s) can appear by comparing the angle between the negative- and zero-sequence currents I2*m* and I0*m* (*m* = S, T, U, W, X, Y).

Applications

The SEL-487E offers comprehensive transformer protection features. Around the clock winding phase compensation simplifies setting the transformer protection elements. Harmonic restraint and blocking by using second- and fourth-harmonic quantities provide secure operation during transformer energization, while maintaining sensitivity for internal faults. Waveshape-based inrush detection addresses inrush conditions that contain low second- and fourth-harmonic content. For applications without voltage inputs (therefore no V/Hz element), use the fifth-harmonic monitoring to detect and alarm on overexcitation conditions.

Flexible ordering options allow either 1 A or 5 A CT inputs for each transformer winding to configure the SEL-487E for a variety of CT configurations.

Configure the SEL-487E for transformer differential protection for transformer applications by using as many as six three-phase restraint current inputs. This includes single transformers with tertiary windings. *Figure 5* shows the SEL-487E in a typical two-winding transformer application. Use the remaining three-phase current inputs for feeder backup protection.

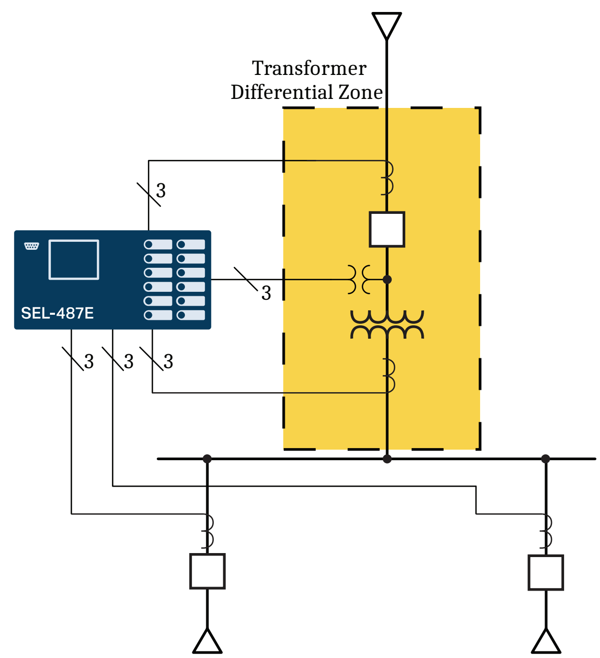


Figure 5 Two-Winding Transformer Application

Use the negative-sequence differential element for sensitive detection of interturn faults within the transformer winding.

Phase-, negative-, and zero-sequence overcurrent elements provide backup protection. Use breaker-failure protection with subsidence detection to detect breaker failure and minimize system coordination times.

When voltage inputs are provided to the SEL-487E, voltage-based protection elements and frequency tracking are made available. Frequency tracking from 40.0 to 65.0 Hz over- and undervoltage, and frequency elements, along with V/Hz elements provide the SEL-487E with accurate transformer protection for off-frequency events and overexcitation conditions.

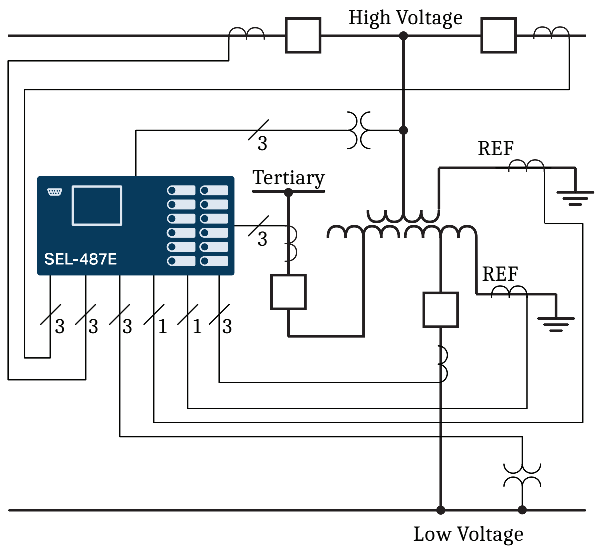


Figure 6 Single Transformer REF Application

Use the SEL-487E for complete protection of generator step-up (GSU) transformer applications. Use built-in thermal elements for monitoring both generator and transformer winding temperatures. Apply the V/Hz element with two level settings for overexcitation protection of loaded and unloaded generator operating conditions. Set the directional power elements to detect forward and reverse power flow conditions for monitoring and protection of the GSU transformer in prime power, standby, base load, and peak shaving applications. *Figure 7* shows the SEL-487E in a typical GSU application.

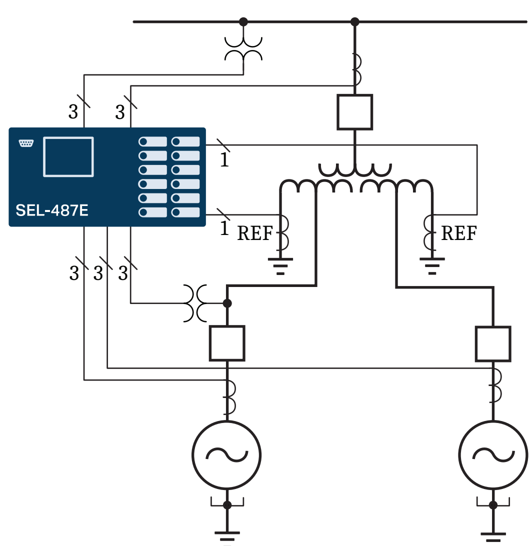


Figure 7 Generator Step-Up Application

Distance Protection

The SEL-487E simultaneously supports as many as four zones of phase and ground distance protection by using mho or quadrilateral characteristics. You can use expanded SELOGIC control equations to tailor the relay further to your particular application. The SEL-487E distance elements are flexible enough to be used for transmission line or transformer winding protection, as shown in *Figure 8* and *Figure 9*.

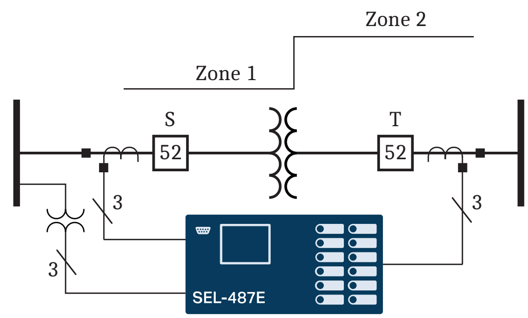


Figure 8 Transformer Distance Application

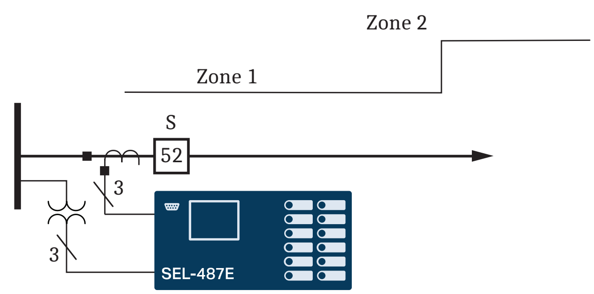


Figure 9 Transmission Line Distance Application

Six Terminal Feeder Protection

Use the six three-phase current terminals on the SEL-487E to provide comprehensive feeder protection and control including overcurrent, directional overcurrent, reclosing, and breaker failure protection for six feeders. *Figure 10* shows a single SEL-487E can provide full feeder functionality of six single function feeder relays thereby reducing the device count within the system.

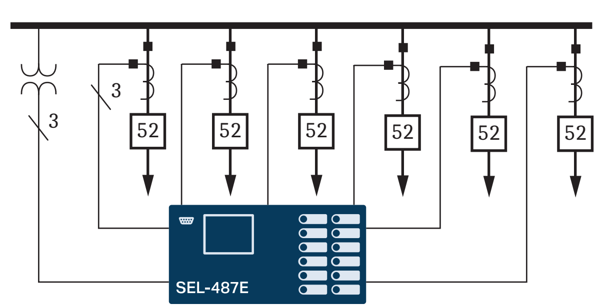


Figure 10 Six Terminal Feeder Application

Synchrophasor Applications

Use the SEL-487E as a station-wide synchrophasor measurement and recording device. The SEL-487E provides as many as 24 analog channels of synchrophasor data and can serve as a central phasor measurement unit in any substation or power generation facility. The SEL-487E can be configured to send five unique synchrophasor data streams over serial and Ethernet ports. Measure voltage and current phase angle relationships at generators and transformers, key source nodes for stability studies and load angle measurements. Use the SEL-487E to store as much as 120 seconds of IEEE C37.118 binary synchrophasor data for all 24 analog channels at a recording rate of 60 messages per second. A SELOGIC control equation triggers storage of data. Capture data as necessary, and then store this information in SEL-487E nonvolatile memory. Use this capability to record system transients for comparison to state machine estimations.

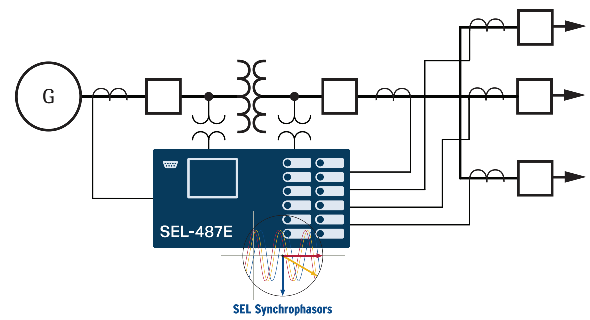


Figure 11 Station-Wide Synchrophasor Application

Additional Features

Front-Panel Display

The LCD shows event, metering, setting, and relay self-test status information. The target LEDs display relay target information as shown in *Figure 12*.

The LCD is controlled by the navigation pushbuttons (*Figure 13*), automatic messages the relay generates, and user-programmed analog and digital display points. The rotating display scrolls through alarm points, display points, and metering screens. If none are active, the relay scrolls through displays of the fundamental and rms metering screens. Each display remains for a user-programmed time (1–15 s) before the display continues scrolling. Any message the relay generates because of an alarm condition takes precedence over the rotating display.

Figure 12 and *Figure 13* show close-up views of the front panel of the SEL-487E. The front panel includes a 128 x 128 pixel, 3" x 3" LCD screen; LED target indicators; and pushbuttons with indicating LEDs for local control functions. The asserted and deasserted colors for the LEDs are programmable. Configure any of the direct-acting pushbuttons to navigate directly to any HMI menu item for fast viewing of events, alarm points, display points, or the SER.

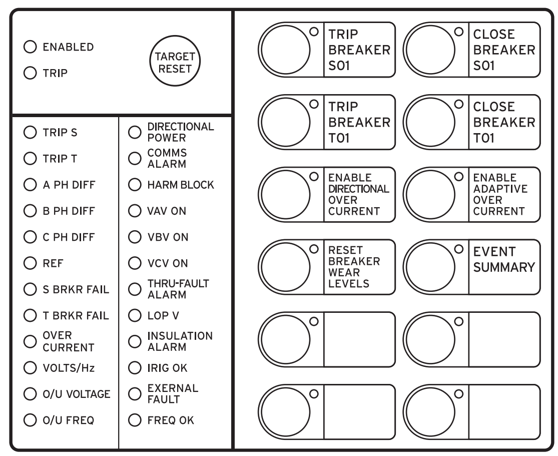


Figure 12 Factory-Default Status and Trip Target LEDs (12 Pushbutton, 24 Target LED Option)

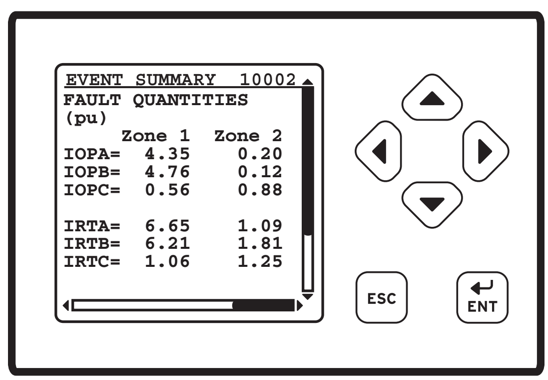


Figure 13 Factory-Default Front-Panel Display and Pushbuttons

Bay Control

The SEL-487E provides dynamic bay one-line diagrams on the front-panel screen with disconnect and breaker control capabilities for user-selectable bay types. You can download the QuickSet interface from selinc.com to obtain additional user-selectable bay types. The bay control can control as many as ten disconnects and two breakers, depending on the one-line diagram selected. Certain one-line diagrams provide status for as many as three breakers and five disconnect switches. Operate disconnects and breakers with ASCII commands, SELOGIC control equations, Fast Operate Messages, and from the one-line diagram. The one-line diagram includes user-configurable apparatus labels and as many as six user-definable analog quantities.

One-Line Bay Diagrams

The SEL-487E offers a variety of preconfigured one-line diagrams for common bus configurations. Once you select a one-line diagram, you can customize the names for all of the breakers, disconnect switches, and buses. Most one-line diagrams contain analog display points. You can set these display points to any of the available analog quantities (including remote 87L currents) with labels, units, and scaling. The SEL-487E updates these values along with the breakers and switch position in real time to give instant status and complete control of a bay. The following diagrams demonstrate some of the preconfigured bay arrangements available in the SEL-487E.

Programmable interlocks help prevent operators from incorrectly opening or closing switches or breakers. The SEL-487E not only prevents operators from making an incorrect control decision, but it can notify and/or alarm upon initiation of an incorrect operation.

Circuit Breaker Operations From the Front Panel

Figure 14–Figure 17 are examples of some of the selectable one-line diagrams in the SEL-487E. Select the one-line diagram from the Bay settings. Additional settings for defining labels and analog quantities are also found in the Bay settings. One-line diagrams are composed of the following:

- ➤ Bay names and bay labels
- ➤ Busbar and busbar labels
- ➤ Breaker and breaker labels
- ➤ Disconnect switches and disconnect switch labels
- ➤ Analog display points

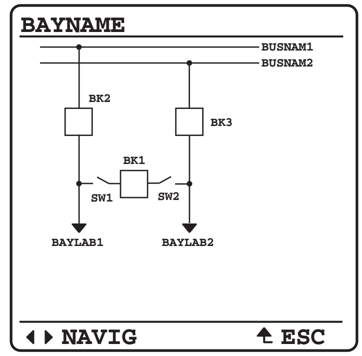


Figure 14 Breaker-and-a-Half

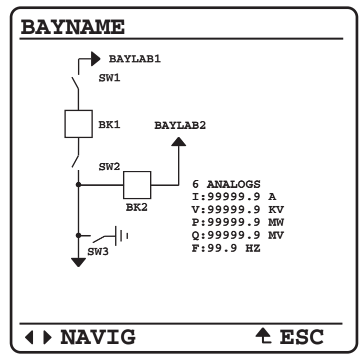


Figure 15 Ring Bus With Ground Switch

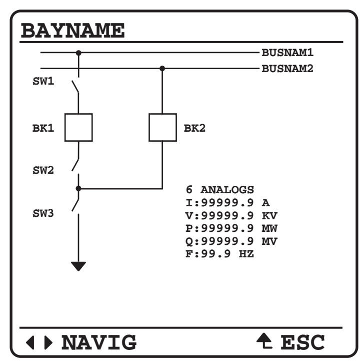


Figure 16 Double Bus/Double Breaker

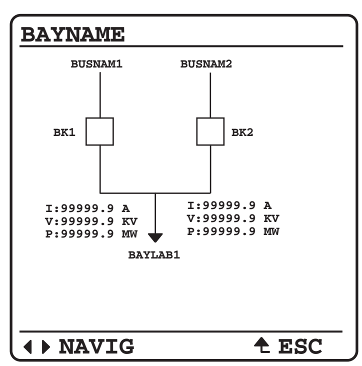


Figure 17 Source Transfer Bus

Figure 18 shows the breaker control screens available when the ENT pushbutton is pressed with the circuit breaker highlighted as shown in *Figure 18(a)*.

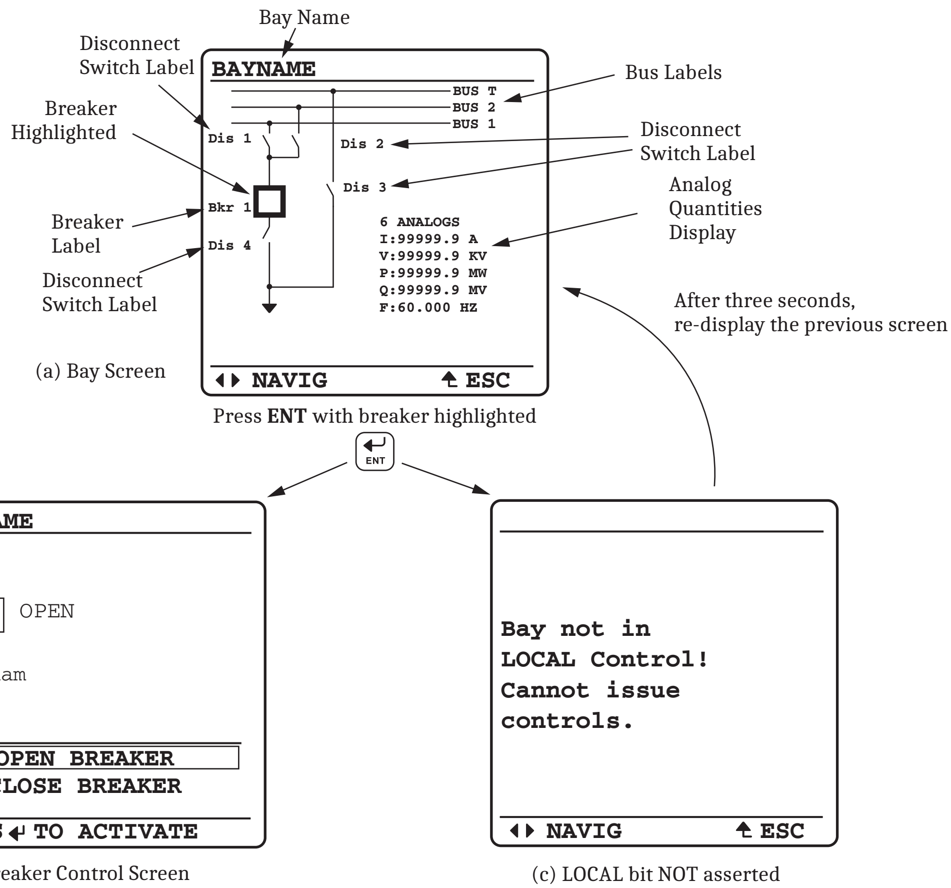


Figure 18 Screens for Circuit Breaker Selection

Rack-Type Breakers Mosaics

The SEL-487E supports the display of rack-type (also referred to as truck-type) circuit breakers. The rack-type breakers have three positions: racked out, test, and racked in. When in the test or racked-in positions, the breaker can be displayed as open or closed. When racked out, no breaker open/close display are available. The rack-type breakers are a display-only functionality and do not impact any circuit breaker control capabilities.

Status and Trip Target LEDs

The SEL-487E includes programmable status and trip target LEDs, as well as programmable direct-action control pushbuttons on the front panel. *Figure 12* shows these targets.

The SEL-487E features a versatile front panel that you can customize to fit your needs. 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. The blank slide-in label set is included with the SEL-487E. You can use templates supplied with the relay or hand label supplied blank labels and print label sets from a printer.

Alarm Points

You can display messages on the SEL-487E front-panel LCD that indicate alarm conditions in the power system. The relay uses alarm points to place these messages on the LCD.

Figure 19 shows a sample alarm points screen. The relay can display as many as 66 alarm points. The relay automatically displays new alarm points while in manual-scrolling mode and in autoscrolling mode. You can configure the alarm points message and trigger it either immediately by using inputs, communications, or conditionally by using powerful SELOGIC control equations. The asterisk next to the alarm point indicates an active alarm. Use the front-panel navigation pushbuttons to clear inactive alarms.

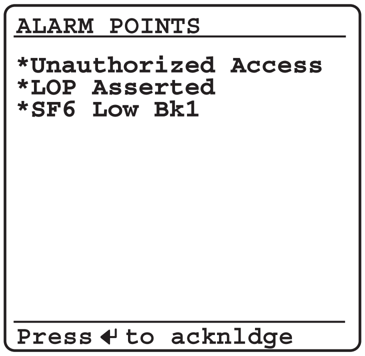


Figure 19 Sample Alarm Points Screen

Advanced Display Points

Create custom screens showing metering values, special text messages, or a mix of analog and status information. *Figure 20* shows an example of how you can use display points to show circuit breaker information and current metering. You can create as many as 96 display points. All display points occupy only one line on the display at all times. The height of the line is programmable as either single or double, as shown in *Figure 20*. These screens become part of the autoscrolling display when the front panel times out.

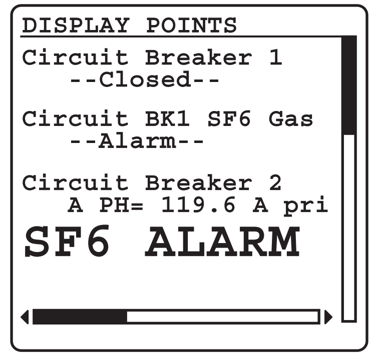


Figure 20 Sample Display Points Screen

Communications Features

See *Specifications on page 25* for specific supported protocols.

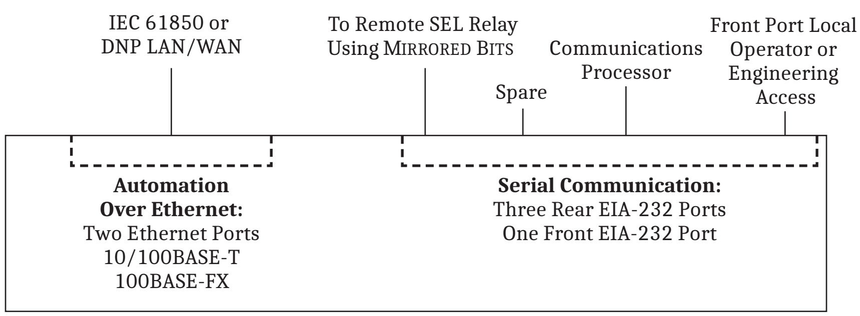


Figure 21 System Functional Overview

The relay offers the following communications features:

- ➤ Four independent EIA-232 serial ports.
- ➤ Access to event history, relay status, and meter information from the communications ports.
- ➤ Password-controlled settings management and automation features.
- ➤ SCADA interface capability, including FTP, IEC 61850, DNP3 LAN/WAN (via Ethernet), and DNP3 (via serial port). The relay does not require special communications software. You only need ASCII terminals, printing terminals, or a computer supplied with terminal emulation and a serial communications port.
- ➤ Synchrophasor data at 60 message-per-second data format.

Ethernet Card

Use popular Telnet applications for easy terminal communications with SEL relays and other devices. Transfer data at high speeds for fast file uploads. The Ethernet card communicates using FTP applications for easy and fast file transfers.

Communicate with SCADA by DNP3 and other substation IEDs by using IEC 61850 Manufacturing Message Specification (MMS) and GOOSE messaging.

Choose Ethernet connection media options for primary and standby connections:

- ➤ 10/100BASE-T twisted pair network
- ➤ 100BASE FX fiber-optic network

Telnet and FTP

Use Telnet to access relay settings, metering, and event reports remotely by using the ASCII interface. Use FTP to transfer settings files to and from the relay via the high-speed Ethernet port.

DNP3 LAN/WAN

DNP3 LAN/WAN provides the relay with DNP3 Level 2 Outstation functionality over Ethernet. Configure DNP3 data maps for use with specific DNP3 masters.

PTP

The Ethernet card provides the ability for the relay to accept IEEE 1588 PTPv2 for data time synchronization. PTP support includes the Default, Power System, and Power Utility Automation Profiles. When connected directly to a grandmaster clock providing PTP at 1-second synchronization intervals, the relay can be synchronized to an accuracy of ±100 ns in the PTP time scale.

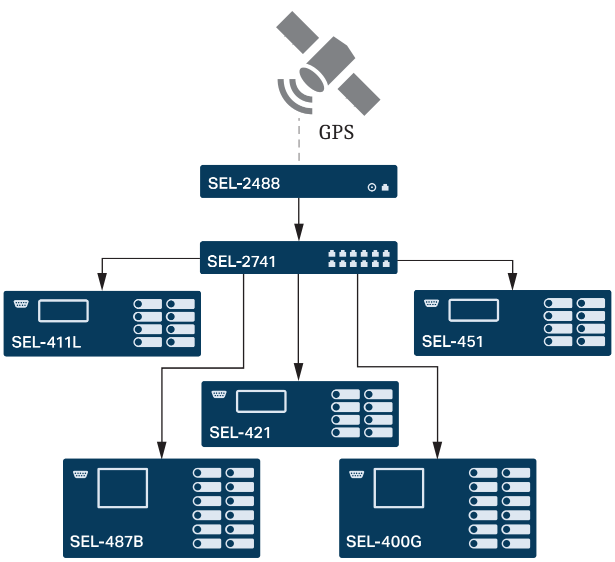


Figure 22 Example PTP Network

SNTP Time Synchronization

Use SNTP to synchronize relays to as little as ±1 ms with no time source delay. Use SNTP as a primary time source, or as a backup to a higher accuracy time input to the relay.

PRP

Use PRP to provide seamless recovery from any single Ethernet network failure, in accordance with IEC 62439-3. The Ethernet network and all traffic are fully duplicated with both copies operating in parallel.

HTTP Web Server

The relay can serve read-only webpages displaying certain settings, metering, and status reports. The web server also allows quick and secure firmware upgrades over Ethernet. As many as four users can access the embedded HTTP server simultaneously.

IEC 61850 Ethernet Communications

IEC 61850 Ethernet-based communication protocols provide interoperability between intelligent devices within the substation. Standardized logical nodes allow interconnection of intelligent devices from different manufacturers for monitoring and control of the substation.

Eliminate system RTUs by streaming monitor and control information from the intelligent devices directly to remote SCADA client devices.

You can order the relay with IEC 61850 protocol for relay monitor and control functions, including:

- ➤ As many as 128 incoming GOOSE messages. You can use the incoming GOOSE messages to control as many as 256 control bits in the relay with <3 ms latency from device to device depending on network design. These messages provide binary control inputs to the relay for high-speed control functions and monitoring.
- ➤ As many as eight outgoing GOOSE messages. Configure outgoing GOOSE messages for Boolean or analog data such as high-speed control and monitoring of external breakers, switches, and other devices. Boolean data are provided with <3 ms latency from device to device depending on network design.
- ➤ IEC 61850 Data Server. The relay equipped with embedded IEC 61850 Ethernet protocol provides data according to predefined logical node objects. Each relay supports as many as seven unbuffered MMS report client associations. Relevant Relay Word bits are available within the logical node data, so status of relay elements, inputs, outputs, or SELOGIC control equations can be monitored.
- ➤ As many as 256 virtual bits. Configure the virtual bits within GOOSE messaging to represent a variety of Boolean values available within the relay. These bits that the relay receives are available for use in SELOGIC control equations.
- ➤ As many as 64 remote analog outputs. Assign the remote analog outputs to virtually any analog quantity available in the relay. You can also use SELOGIC math variables to develop custom analog quantities for assignment as remote analog outputs. Remote

analog outputs that use GOOSE messages provide peer-to-peer transmission of analog data. Each relay can receive as many as 256 remote analog inputs and use those inputs as analog quantities within SELOGIC control equations.

➤ IEC 61850 standard operating modes. The relay supports Test, Blocked, On, and Off. The relay also supports Simulation mode for added flexibility.

MMS File Services

This service of IEC 61850 MMS provides support for file transfers completely within an MMS session. All relay files that can be transferred via FTP can also be transferred via MMS file services.

MMS Authentication

When enabled via a setting in the Configured IED Description (CID) file, the relay requires authentication from any client requesting to initiate an MMS session.

Architect Software

Use ACSELERATOR Architect SEL-5032 Software to manage the IEC 61850 configuration for devices on the network. This Windows-based software provides easy-to-use displays for identifying and binding IEC 61850 network data among logical nodes that use IEC 61850-compliant CID files. Architect uses CID files to describe the data available in each relay.

Serial Communications

MIRRORED BITS Communications

The SEL patented MIRRORED BITS technology provides bidirectional relay-to-relay digital communication.

Figure 23 shows two relays with SEL-2815 Fiber-Optic Transceivers that use MIRRORED BITS communications. MIRRORED BITS communications can operate simultaneously on any two serial ports. This bidirectional digital communication creates additional outputs (transmitted MIRRORED BITS) and additional inputs (received MIRRORED BITS) for each serial port operating in the MIRRORED BITS communications mode.

Communicated information can include digital, analog, and virtual terminal data. Virtual terminal allows operator access to remote relays through the local relay. You can use this MIRRORED BITS protocol to transfer information between stations to enhance coordination and achieve faster tripping.

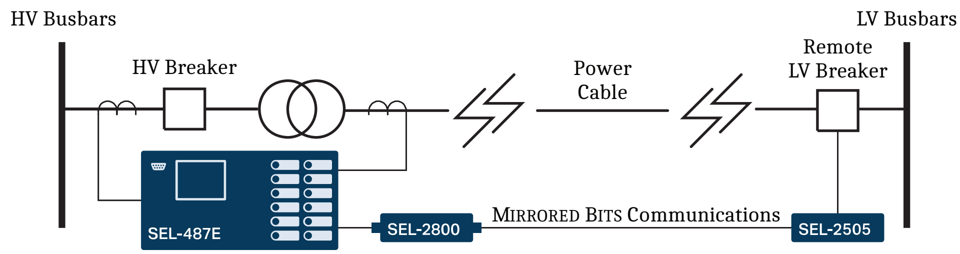


Figure 23 Integral Communication Provides Secure Protection, Monitoring, and Control as Well as Terminal Access to Both Relays Through One Connection

Open Communications Protocols

The relay does not require special communications software. ASCII terminals, printing terminals, or a computer supplied with terminal emulation and a serial communications port are all that is required. *Table 2* lists a brief description of the terminal protocols.

Table 2 Open Communications Protocol (Sheet 1 of 2)

Type	Description
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 bay data in an appropriate format for direct import into spreadsheets and database programs. Data are checksum protected.
Extended Fast Meter, Fast Operate, and Fast SER	Binary protocol for machine-to-machine communications. Quickly updates SEL-2032 Communications Processors, RTUs, and other substation devices with metering information, bay 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 that control operator metering information is not lost while a technician is transferring an event report.

Table 2 Open Communications Protocol (Sheet 2 of 2)

Type	Description
Ymodem	Support for reading event, settings, and oscillography files.
Optional DNP3 Level 2 Outstation	DNP with point remapping. Includes access to metering data, protection elements, contact I/O, targets, SER, relay summary event reports, and settings groups.
IEEE C37.118	Phasor measurement protocol.
MIRRORED BITS	SEL protocol for exchanging digital and analog information among SEL relays and for use as low-speed terminal connection.
IEC 61850	Ethernet-based international standard for interoperability between intelligent devices in a substation.
PRP	PRP provides redundant Ethernet network capabilities for seamless operation in the event of loss to one network.
SNTP	Ethernet-based SNTP for time synchronization among relays.
FTP and Telnet	Use Telnet to establish a terminal-to-relay connection over Ethernet. Use FTP to move files in and out of the relay over Ethernet.

Automation

Flexible Control Logic and Integration Features

Use the control logic to perform the following:

- ➤ Replace traditional panel control switches
- ➤ Eliminate remote terminal unit (RTU)-to-bay wiring
- ➤ Replace traditional latching relays
- ➤ Replace traditional indicating panel lights

Eliminate traditional panel control switches with 96 local control points. Set, clear, or pulse local control points with the front-panel pushbuttons and display. Program the local control points to implement your control scheme via SELOGIC control equations. Use the local control points for such functions as trip testing, enabling/disabling reclosing, and tripping/closing circuit breakers.

Eliminate RTU-to-bay wiring with 64 remote control points per relay. Set, clear, or pulse remote control points via serial port commands. Incorporate the remote control points into your control scheme via SELOGIC control equations. Use remote control points for SCADA-type control operations (e.g., trip, close, settings group selection).

Replace traditional latching relays for such functions as remote control enable with 64 latching control points. Program latch set and latch reset conditions with SELOGIC control equations. Set or reset the latch control points via control inputs, remote control points, local control points, or any programmable logic condition. The relay retains the states of the latch control points after turning on following a power interruption.

Replace traditional indicating panel lights and switches with as many as 24 latching target LEDs and as many as 12 programmable pushbuttons with LEDs. Define custom messages (i.e., `BREAKER OPEN`, `BREAKER CLOSED`, `RECLOSER ENABLED`) to report power system or relay conditions on the large format LCD. Control displayed messages with SELOGIC control equations by driving the LCD via any logic point in the relay.

SELOGIC Control Equations With Expanded Capabilities and Aliases

Expanded SELOGIC control equations put relay logic in the hands of the engineer. Assign inputs to suit your application, logically combine selected bay elements for various control functions, and assign outputs to your logic functions.

Programming SELOGIC control equations consists of combining relay elements, inputs, and outputs with SELOGIC control equation operators (*Table 3*). Any element in the Relay Word can be used in these equations. For complex or unique applications, these expanded SELOGIC functions allow superior flexibility.

Table 3 SELOGIC Control Equation Operators (Sheet 1 of 2)

Operator Type	Operators	Comments
Boolean	AND, OR, NOT	Allows combination of measuring units.
Edge Detection	F_TRIG, R_TRIG	Operates at the change of state of an internal function.
Comparison	>, >=, =, <=, <, < >	
Arithmetic	+, –, *, /	Uses traditional math functions for analog quantities in an easily programmable equation.

Table 3 SELOGIC Control Equation Operators (Sheet 2 of 2)

Operator Type	Operators	Comments
Numerical	ABS, SIN, COS, LN, EXP, SQRT, LOG	
Precedence Control	( )	Allows multiple and nested sets of parentheses.
Comment	#, (* *)	Provides for easy documentation of control and protection logic.

Use the relay alias capability to assign more meaningful names to analog and Boolean quantities. This improves the readability of customized programming. Use as many as 200 aliases to rename any digital or analog quantity. The following is an example of possible applications of SELOGIC control equations that use aliases.

```
=>>SET T <Enter>
1: PMV01,THETA
```

(assign the alias "THETA" to math variable PMV01)

```
2: PMV02,TAN
```

(assign the alias "TAN" to math variable PMV02)

```
=>>SET L <Enter>
1: # CALCULATE THE TANGENT OF THETA
2: TAN:=SIN(THETA)/COS(THETA)
```

(use the aliases in an equation)

Add programmable control functions to your relay and automation systems. New functions and capabilities enable using analog values in conditional logic statements. The following are examples of possible applications of SELOGIC control equations with expanded capabilities.

- ➤ Emulate a motor-driven reclose timer, including stall, reset, and drive-to-lockout conditions.
- ➤ Scale analog values for SCADA retrieval.
- ➤ Initiate remedial action sequence based on load flow before fault conditions.
- ➤ Interlock breakers and disconnect switches.
- ➤ Restrict breaker tripping in excessive duty situations without additional relays.
- ➤ Hold momentary change-of-state conditions for SCADA polling.

Metering and Monitoring

Access a range of useful information in the relay with the metering function. Metered quantities include fundamental primary and secondary current and voltage magnitudes and angles for each terminal. RMS voltage and current metering is also provided. Fundamental phase and real and reactive power, per-phase voltage magnitude, angle, and frequency are displayed in the metering report for applications that use the relay voltage inputs.

Table 4 Metering Capabilities (Sheet 1 of 2)

Capabilities	Description
Instantaneous Quantities	
Voltages $V_{A, B, C}$ (V, Z), Vϕϕ, 3V0, V1, 3V2	Voltages measured at the fundamental frequency of the power system. The relay compensates for delta-connected CTs when reporting primary values.
RMS Voltages $V_{A, B, C}$ (V, Z), Vϕϕ	RMS voltages include fundamental plus all measurable harmonics.
Compensated Fundamental Currents $I_{A, B, C}$ (S, T, U, W, X, Y), 3I0, I1, 3I2 $I_{A, B, C}$ (ST, TU, UW, WX), 3I0, I1, 3I2	Currents measured at the fundamental frequency of the power system with transformer phase-compensation applied.
RMS Currents $I_{A, B, C}$ (S, T, U, W, X, Y) $I_{A, B, C}$ (ST, TU, UW, WX)	RMS currents include fundamental plus all measurable harmonics.

Table 4 Metering Capabilities (Sheet 2 of 2)

Capabilities	Description
Differential Metering	
Currents $I_{A, B, C}$, I1, $3I_2$, $3I_0$	Local terminal/all Remote Terminals
Differential Current $I_{A, B, C}$, I1, $3I_2$, $3I_0$	Local terminal/all Remote terminals
Alpha Plane k alpha	Alpha plane ratio Alpha plane angle
Power/Energy Metering Quantities	
Fundamental Power Quantities $S_{A, B, C}$, $P_{A, B, C}$, $Q_{A, B, C}$ (S, T, U, W, X, Y) $S_{A, B, C}$, $P_{A, B, C}$, $Q_{A, B, C}$ (ST, TU, UW, WX) $S_{3\phi}$, $P_{3\phi}$, $Q_{3\phi}$ (S, T, U, W, X, Y) $S_{3\phi}$, $P_{3\phi}$, $Q_{3\phi}$ (ST, TU, UW, WX)	Power quantities calculated using fundamental voltage and current measurements; S = MVA, P = MW, Q = MVAR.
Differential Metering	
Differential IOPA, IOPB, IOPC, IRTA, IRTB, IRTC IOPA2, IOPB2, IOPC2, IRTA2, IRTB2, IRTC2	IOP, Zone 1 operate current magnitude (per unit). IRT, Zone 1 restraint current magnitude (per unit). IOP2, Zone 2 operate current magnitude (per unit). IRT2, Zone 2 restraint current magnitude (per unit).
Harmonics 2nd: IOPAF2, IOPBF2, IOPCF2 4th: IOPAF4, IOPBF4, IOPCF4 5th: IOPAF5, IOPBF5, IOPCF5	Zone 1 differential harmonic quantities represent the effective harmonic content of the operate current. This content is what the relay uses for harmonic blocking and harmonic restraint.
Demand/Peak Demand Metering	
$I_{A, B, C}$, 3I2, 3I0 (S, T, U, W, X, Y) $I_{A, B, C}$, 3I2, 3I0 (ST, TU, UW, WX) IMAX (S, T, U, W, X, Y) IMAX (ST, TU, UW, WX)	Thermal or rolling interval demand.

Event Reporting and SER

Event reports and SER features simplify post-fault analysis and help improve your understanding of both simple and complex protective scheme operations. These features also aid in testing and troubleshooting relay settings and protective schemes.

Oscillography and Event Reporting

In response to a user-selected internal or external trigger, the voltage, current, and element status information contained in each event report confirms relay, scheme, and system performance for every fault. The relay provides sampling rates as fast as 8 kHz for analog quantities in a COMTRADE file format, as well as eight-sample-per-cycle and four-sample-per-cycle event reports. The relay stores as much as 3 seconds of 8 kHz event data. The relay supports inclusion of user-configurable analogs in the events. Reports are stored in nonvolatile memory. Relay settings operational in the relay at the time of the event are appended to each event report.

Each relay provides event reports for analysis with software such as SEL-5601-2 SYNCHROWAVE® Event Software. With SYNCHROWAVE Event, you can display events from several relays to make the fault analysis easier and more meaningful. Because the different relays time-stamp the events with values from their individual clocks, be sure to time synchronize the relay with an IRIG-B clock input or PTP source to use this feature.

Event Summary

Each time the relay generates a standard event report, it also generates a corresponding event summary. This is a concise description of an event that includes the following information:

- Relay/terminal identification
- Event date and time
- Event type
- Event number
- Time source
- Active settings group

- Targets asserted during the fault
- Current magnitudes and angles for each terminal
- Voltage magnitudes and angles
- Differential operate and restraint current magnitudes
- Breaker status (open/close)

With an appropriate setting, the relay sends an event summary in ASCII text automatically to one or more serial ports each time an event report is triggered.

SER

Use this feature to gain a broad perspective of relay element operation. Items that trigger an SER entry are selectable and can include as many as 250 monitoring points, such as I/O change-of-state and element pickup/dropout. The relay SER stores the latest 1000 events.

Analog Signal Profiling

The relay provides analog signal profiling for as many as 20 analog quantities. Select any analog quantity measured or calculated by the relay for analog signal profiling. You can select signal sampling rates of 1, 5, 15, 30, and 60 minutes through settings. The analog signal profile report provides a comma-separated variable (CSV) list that you can load into any spreadsheet or database for analysis and graphical display.

SELOGIC enable/disable functions can start and stop signal profiling based on Boolean or analog comparison conditions.

Substation Battery Monitor for DC Quality Assurance

The relay measures and reports the substation battery voltage for up to two battery systems. The SEL-411L, SEL-421, SEL-451 support two battery monitors while the SEL-487B, SEL-487E, and SEL-487V support one. Each battery monitor supports programmable threshold comparators and associated logic provides alarm and control for batteries and chargers. The relay also provides dual ground detection. Monitor dc system status alarms with an SEL communications processor and trigger messages, telephone calls, or other actions.

The measured dc voltage is reported in the `METER` display via serial port communications, on the LCD, and in the event report. Use the event report data to see an oscillographic display of the battery voltage. Monitor the substation battery voltage drops during trip, close, and other control operations.

Breaker Contact Wear Monitoring

Circuit breakers experience mechanical and electrical wear during each operation. Effective scheduling of breaker maintenance takes into account the manufacturer's published data of contact wear versus interruption levels and operation count.

- Every time the breaker trips, the relay integrates interrupted current. When the result of this integration exceeds the threshold set by the breaker wear curve (*Figure 24*), the relay can alarm via an output contact or the optional front-panel display. With this information, you can schedule breaker maintenance in a timely, economical fashion.
- The relay monitors last and average mechanical and electrical interruption time per pole. You can easily determine if operating time is increasing beyond reasonable tolerance and then schedule proactive breaker maintenance. You can activate an alarm point if operation time exceeds a preset value.

The relay also monitors breaker motor run time, pole discrepancy, and breaker inactivity.

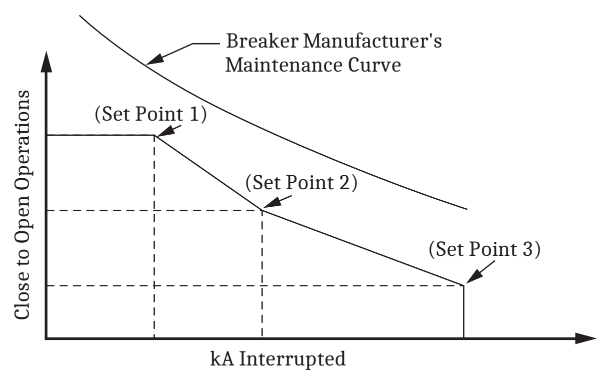


Figure 24 Breaker Contact Wear Curve and Settings

Transformer Thermal Monitoring

Transformer thermal monitoring for mineral-oil immersed transformers is a standard feature in the SEL-487E. Specify the SEL-487E to provide this capability for monitoring and protection of a single three-phase transformer, as well as for monitoring and protection of three independent single-phase units. Use the thermal element to activate a control action or issue a warning or alarm when your transformer overheats or is in danger of excessive insulation aging or loss of life.

The thermal element operates in one of three modes, depending upon the presence or lack of measured temperature inputs: 1) measured ambient and top-oil temperature inputs, 2) measured ambient temperature only, and 3) no measured temperature inputs. If the relay receives measured ambient and top-oil temperatures, the thermal element calculates hot-spot temperature. When the relay receives a measurement of ambient temperature without top-oil temperature, the thermal element calculates the top-oil temperature and hot-spot temperature. In the absence of any measured ambient or top-oil temperatures, the thermal element uses a default ambient temperature setting that you select and calculates the top-oil and hot-spot temperatures. The relay uses hot-spot temperature as a basis for calculating the insulation aging acceleration factor (FAA) and loss-of-life quantities. Use the thermal element to indicate alarm conditions and/or activate control actions when one or more of the following exceed settable limits:

- Top-oil temperature
- Winding hot-spot temperature
- Insulation FAA
- Daily loss-of-life
- Total loss-of-life

Generate a thermal monitor report that indicates the present thermal status of the transformer. Historical thermal event reports and profile data are stored in the relay in hourly format for the previous 24 hours and in daily format for the previous 31 days.

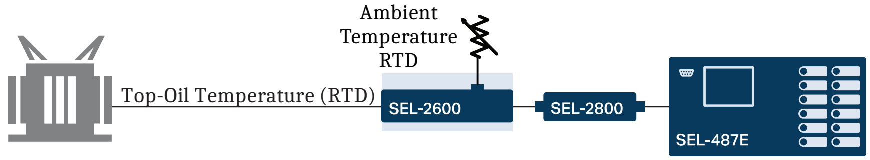


Figure 25 Typical One-Line Diagram for Collecting Transformer Temperature Data

Through-Fault Event Monitor

A through fault is an overcurrent event external to the differential protection zone. Though 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 because of mechanical stress of insulation components in the transformer. The SEL-487E through-fault event monitor gathers current level, duration, and date/time for each through fault. The monitor also calculates a I^2t and cumulatively stores these data per phase. The SEL-487E through-fault report also provides percent of total through-fault accumulated according to the *IEEE Guide for Liquid-Immersed Transformer Through-Fault-Current Duration*, IEEE C57.109-1993. Use through-fault event data to schedule proactive transformer bank maintenance and help justify through-fault mitigation efforts. Apply the accumulated I^2t alarm capability of the relay to indicate excess through-fault current over time.

Diagrams and Dimensions

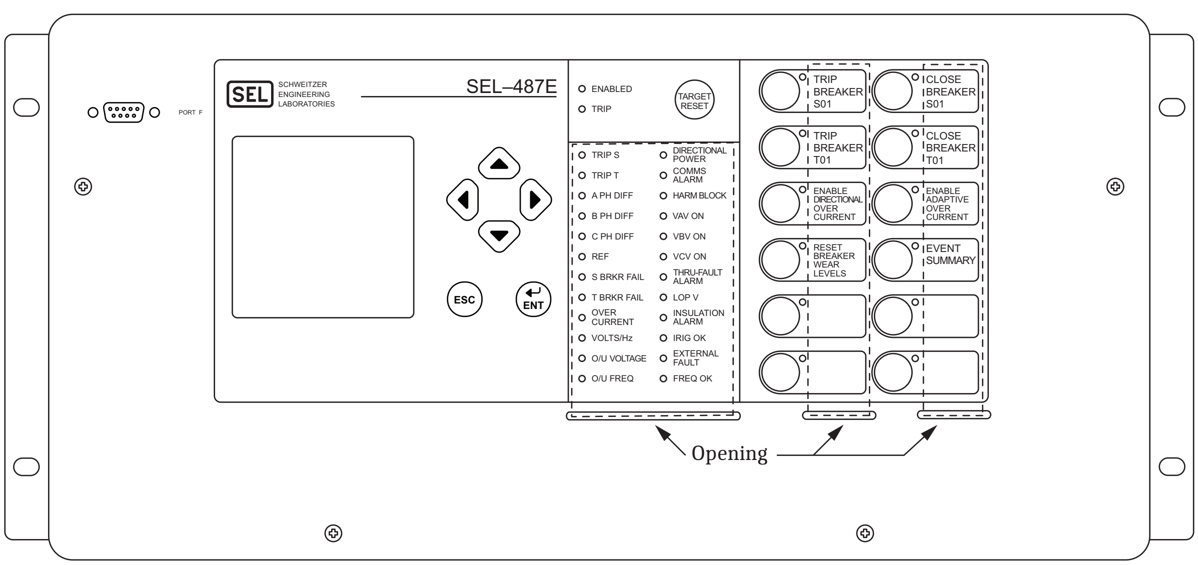


Figure 26 5U Front Panel, Rack-Mount Option

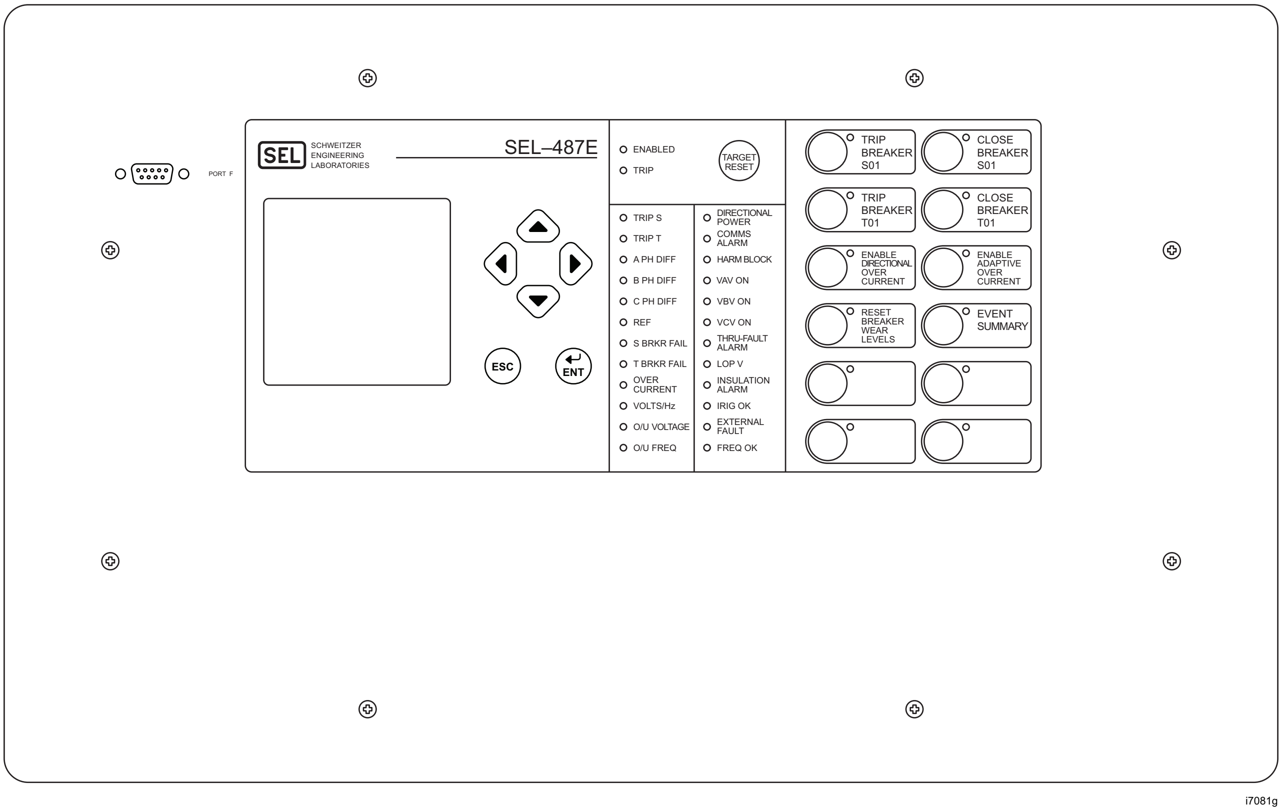


Figure 27 6U Front Panel, Panel-Mount Option

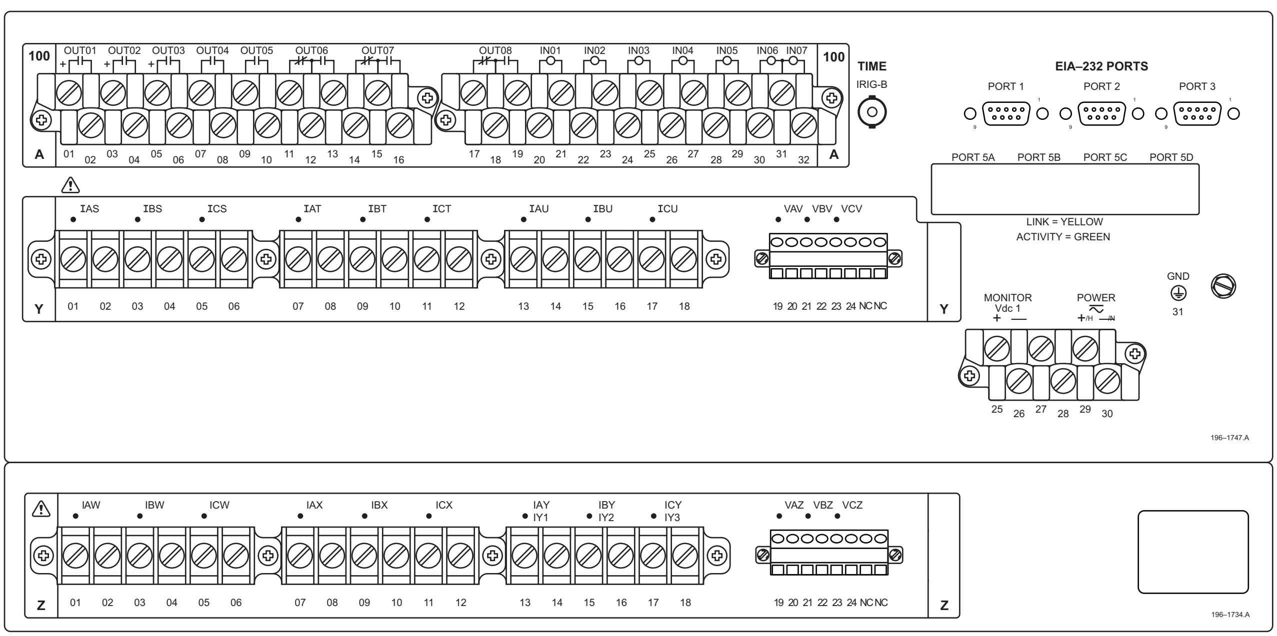


Figure 28 5U Rear Panel, Main Board, LEA Voltage Option

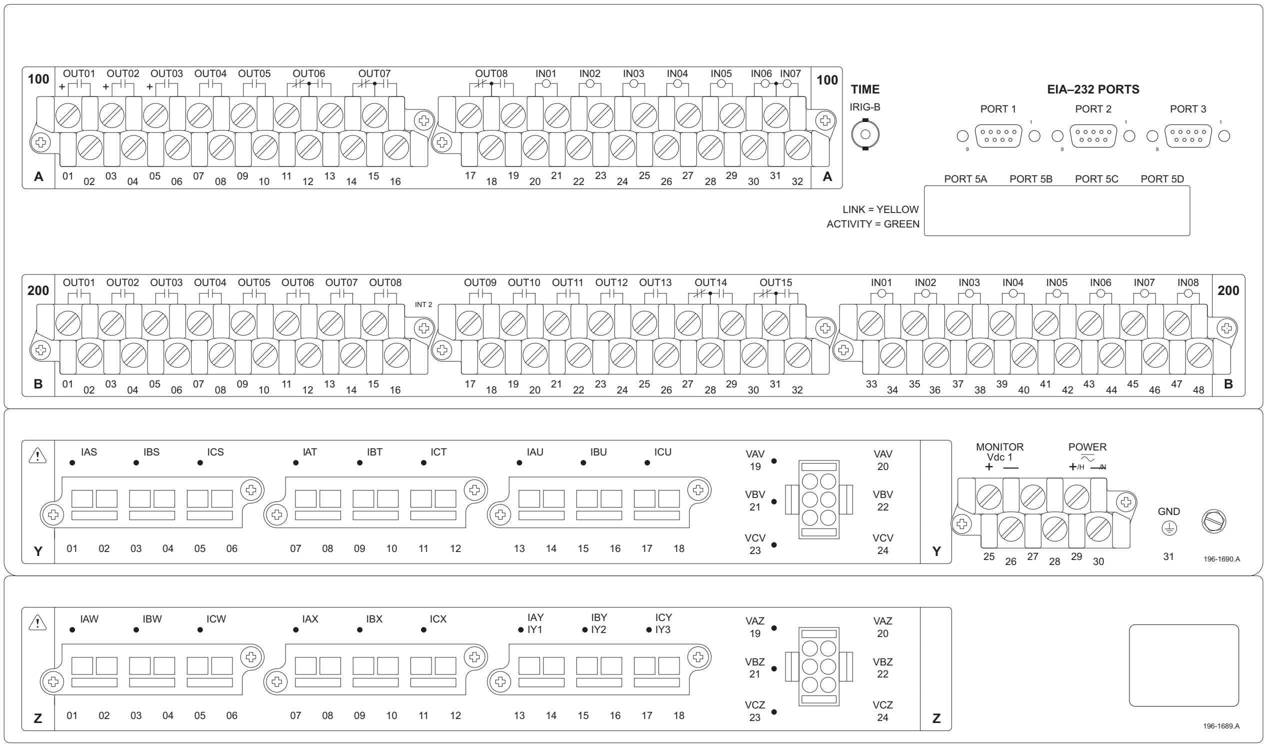


Figure 29 6U Rear Panel, Main Board, Connectorized® Option With One (INT2) I/O Board

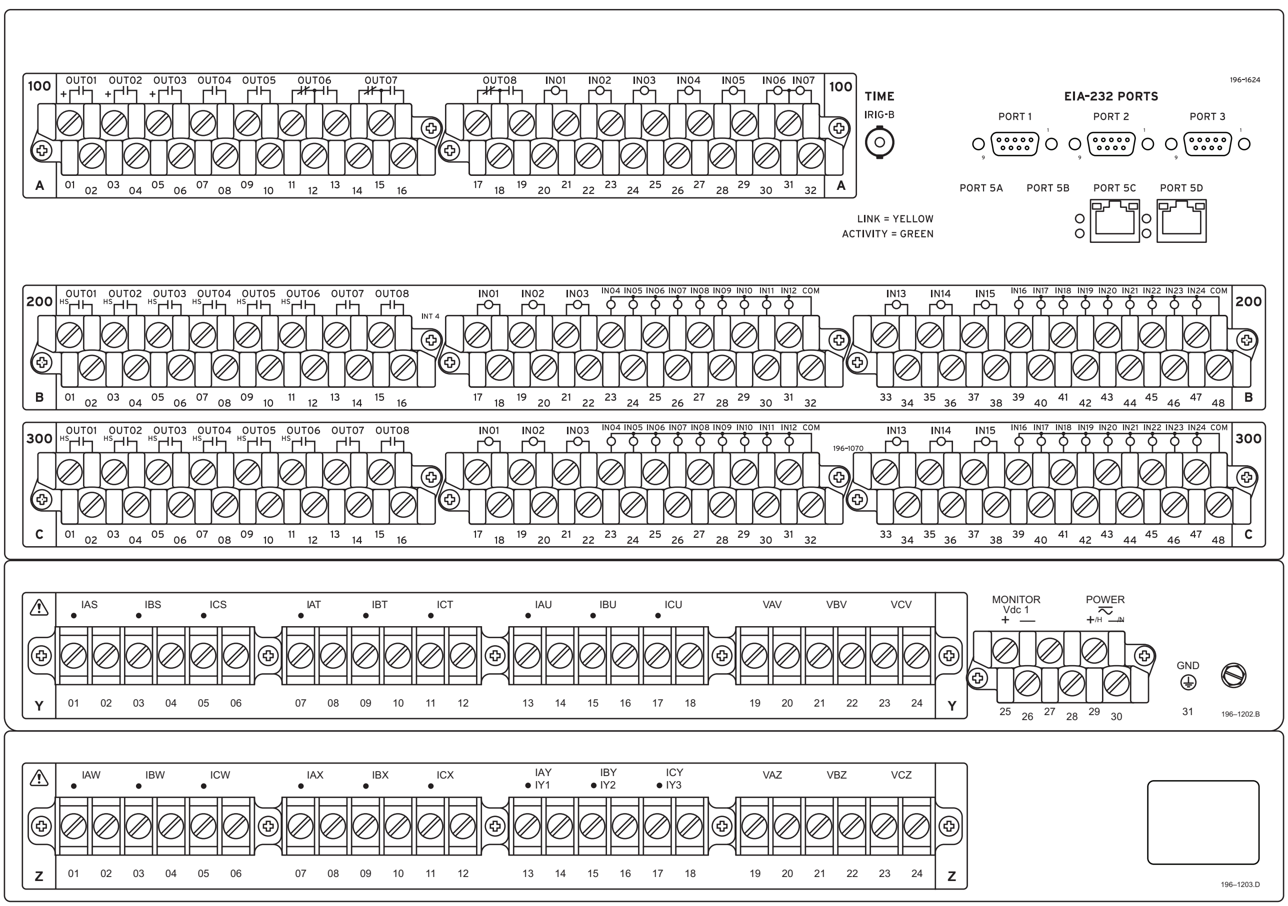


Figure 30 7U Rear Panel, Main Board, Terminal Block Option With Two (INT4) I/O Boards

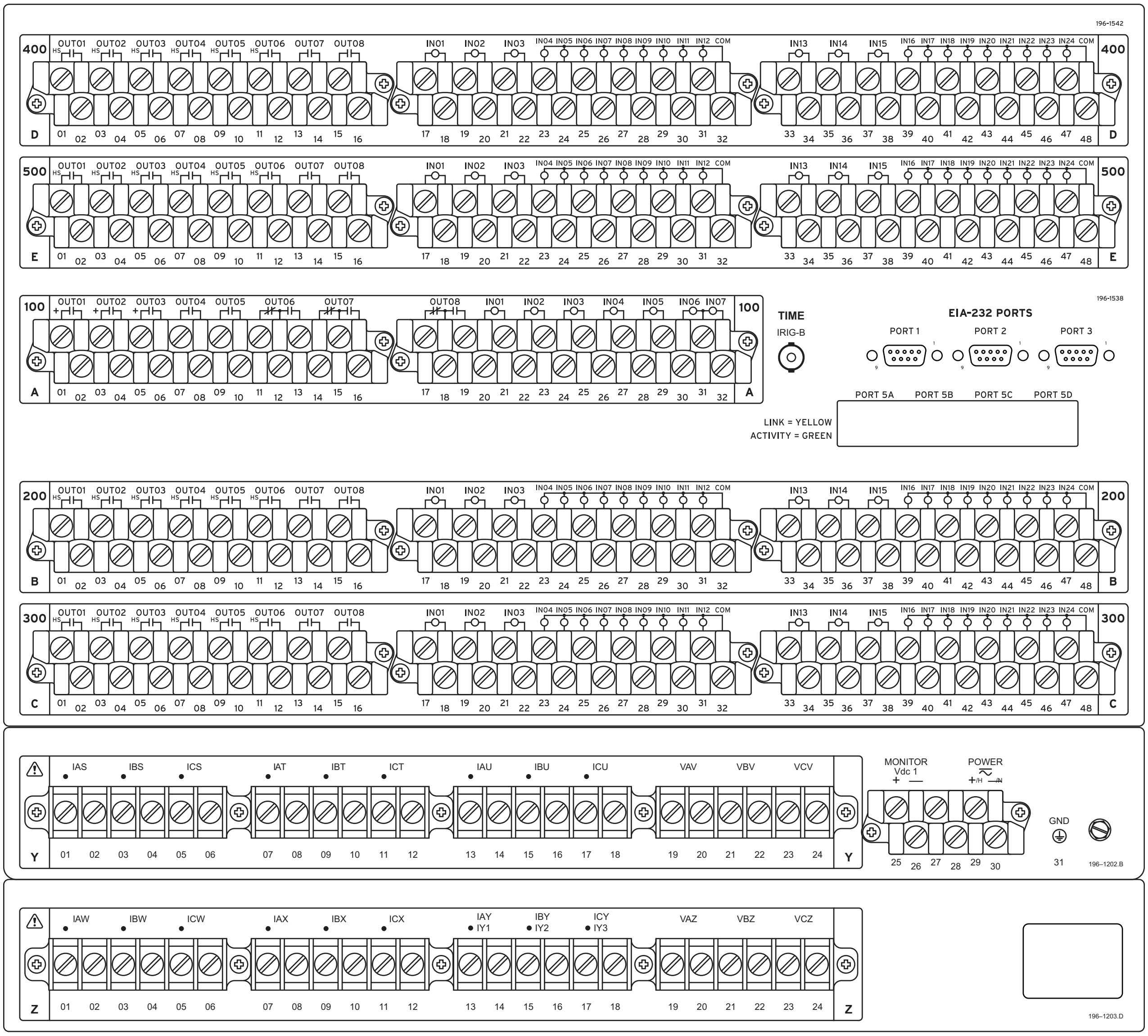
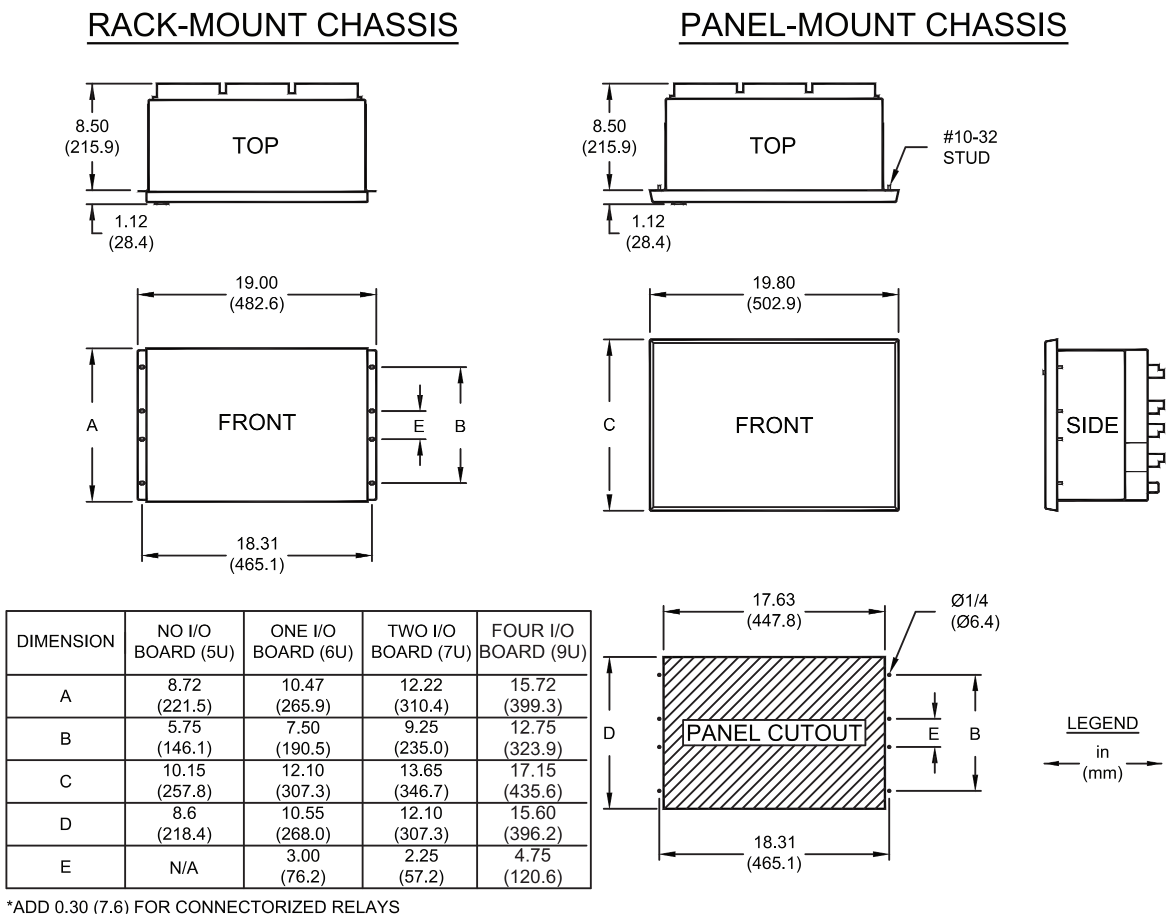


Figure 31 9U Rear Panel, Main Board, Terminal Blocks Option With Four (INT4) I/O Boards



DIMENSION	NO I/O BOARD (5U)	ONE I/O BOARD (6U)	TWO I/O BOARD (7U)	FOUR I/O BOARD (9U)
A	8.72 (221.5)	10.47 (265.9)	12.22 (310.4)	15.72 (399.3)
B	5.75 (146.1)	7.50 (190.5)	9.25 (235.0)	12.75 (323.9)
C	10.15 (257.8)	12.10 (307.3)	13.65 (346.7)	17.15 (435.6)
D	8.6 (218.4)	10.55 (268.0)	12.10 (307.3)	15.60 (396.2)
E	N/A	3.00 (76.2)	2.25 (57.2)	4.75 (120.6)

*ADD 0.30 (7.6) FOR CONNECTORIZED RELAYS

Figure 32 Dimensions for Rack- and Panel-Mount Models

Models and Options

Depending on the number of interface boards, the SEL-487E is available in 5U (no interface boards), 6U (one interface board), 7U (two interface boards), or 9U size (four interface boards) (U is one rack unit in height—44.45 mm or 1.75 in). Select I/O boards from a choice of four interface boards, each board designed to provide a wide range of input and output combinations to tailor the relay for your specific application. If your application requires more I/O, add contact I/O with the SEL-2505/SEL-2506 Remote I/O Module.

Firmware Options

The SEL-487E comes in two different ordering options: Transformer Protection Relay (SEL-487E-3) and Station Phasor Measurement Unit (SEL-487E-4). The only difference between the two options is the front overlay labeling. On the SEL-487E-3, the front overlay reads “Protection Automation Control.” On the SEL-487E-4, the front overlay reads “Station Phasor Measurement Unit.” All the relay functionality is the same in the two versions.

Current Channel Options

Select the CT secondary current for any one of the five windings (S, T, U, W, X) from 1 A or 5 A (all three phases 1 A or 5 A). For neutral windings (the three inputs of Winding Y), you can separately select the CT secondary current for each of the three inputs. For example, select 5 A secondary currents for the three phases of Winding S, 5 A secondary currents for the three phases of Winding T, 1 A secondary currents for the three phases of Winding U, 5 A secondary current for REF 1 (first neutral current input), and 1 A secondary current for REF 2 (second neutral current input). When Winding Y is ordered with matching rated nominal current inputs, you can use that terminal as a sixth set of three-phase CT inputs: IAY, IBY, and ICY.

Although each three-phase winding (S, T, U, W, and X) can be either 1 A or 5 A, and the Y-windings either 1 A or 5 A on a per-phase basis, the SEL-487E supports only the combinations shown in *Table 5*.

Table 5 Supported 1 A/5 A Windings Combinations (Sheet 1 of 2)

Windings S, T, U	Windings W, X, IY1, IY2, IY3
Winding S = 5 A Winding T = 5 A Winding U = 5 A	Winding W = 5 A Winding X = 5 A Winding IY1, IY2, IY3 = 5 A, 5 A, 5 A
Winding S = 5 A Winding T = 5 A Winding U = 1 A	Winding W = 5 A Winding X = 5 A Winding IY1, IY2, IY3 = 5 A, 5 A, 1 A
Winding S = 5 A Winding T = 1 A Winding U = 1 A	Winding W = 5 A Winding X = 5 A Winding IY1, IY2, IY3 = 5 A, 1 A, 1 A
Winding S = 1 A Winding T = 1 A Winding U = 1 A	Winding W = 5 A Winding X = 5 A Winding IY1, IY2, IY3 = 1 A, 1 A, 1 A
	Winding W = 1A Winding X = 1A Winding IY1, IY2, IY3 = 5 A, 5 A, 5 A

Table 5 Supported 1 A/5 A Windings Combinations (Sheet 2 of 2)

Windings S, T, U	Windings W, X, IY1, IY2, IY3
	Winding W = 1 A Winding X = 1 A Winding IY1, IY2, IY3 = 5 A, 5 A, 1 A
	Winding W = 1 A Winding X = 1 A Winding IY1, IY2, IY3 = 5 A, 1 A, 1 A
	Winding W = 1 A Winding X = 1 A Winding IY1, IY2, IY3 = 1 A, 1 A, 1 A

Interface Board (I/O) Options

Select from four interface boards to provide flexibility with the diverse I/O requirements when installing the SEL-487E at power plants, transmission and distribution networks. You can install the interface boards in any combination in the relay. *Table 6* provides I/O information about the main board and the four interface boards.

Table 6 Main Board and Interface Board Information

Board Name	Inputs	Description	Outputs	Description
Main	5	Optoisolated, independent, level-sensitive	3	High-current interrupting, Form A
	2	Optoisolated, common, level-sensitive	2	Standard Form A
			3	Standard Form C
INT2	8	Optoisolated, independent, level-sensitive	13	Standard Form A
			2	Standard Form C
INT4	18	Two sets of 9 common optoisolated, level-sensitive	6	High-speed, high-current interrupting, Form A
	6	Optoisolated, independent, level-sensitive	2	Standard Form A
INT7	8	Optoisolated, independent, level-sensitive	13	High-current interrupting, Form A
			2	Standard Form C
INT8	8	Optoisolated, independent, level-sensitive	8	High-speed, high-current interrupting, Form A

- Voltage ranges for the inputs on the main board as well as for the inputs on the four interface boards
  - 24 Vdc
  - 48 Vdc
  - 110 Vdc
  - 125 Vdc
  - 220 Vdc
  - 250 Vdc
- Connector type
  - Screw-terminal block inputs
  - Connectorized
- Conformal coat
  - Conformal coating provides an additional barrier to harsh environments, such as high humidity and airborne contaminants. See selinc.com/conformalcoating/ for more information.
- Power supply
  - 24–48 Vdc
  - 48–125 Vdc or 110–120 Vac
  - 125–250 Vdc or 110–240 Vac
- Voltage channel options
  - 300 V phase-to-neutral wye configuration PT inputs
  - Two three-phase, 8 Vac, C37.92-compliant LEA inputs

- Ethernet card options
  - Ethernet card with combinations of 10/100BASE-T and 100BASE-FX media connections on each of two ports.
- Ethernet communications protocols
  - Standard (FTP, Telnet, DNP3, PRP)
  - Standard plus IEC 61850

Contact the SEL factory or your local Technical Service Center for particular part number and ordering information (see *Technical Support on page 33*). You can also view the latest part number and ordering information on the SEL website at selinc.com.

Specifications

Note: TiDL (EtherCAT) technology is no longer offered in the SEL-487E-3, -4. TiDL (T-Protocol) is available in the SEL-487E-5. If the relay is using a TiDL (EtherCAT) system, such as TiDL, the operating times will be delayed by 1.5 ms. Use caution when setting the relay coordination times to account for this added delay. Element operate times will also have this small added delay.

Compliance

Designed and manufactured under an ISO 9001 certified quality management system

FCC Compliance Statement

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 in which case the user will be required to correct the interference at his own expense.

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

CE Mark

General

AC Analog Inputs

Sampling Rate:	8 kHz

AC Current Inputs (Secondary Circuits)

Note: Current transformers are Measurement Category II.

Input Current

5 A Nominal:	S, T, U, W, X, and Y terminals
1 A Nominal:	S. T, U, W, X, and Y terminals
1 A/5 A Nominal:	Y terminal only (REF)

Current Rating (With DC Offset at X/R = 10, 1.5 cycles)

5 A Nominal:	91.0 A
1 A Nominal:	18.2 A

Continuous Thermal Rating

5 A Nominal:	15 A 20 A (+55°C)
1 A Nominal:	3 A 4 A (+55°C)

Saturation Current (Linear) Rating

5 A Nominal:	100 A
1 A Nominal:	20 A

One-Second Thermal Rating

5 A Nominal:	500 A
1 A Nominal:	100 A

One-Cycle Thermal Rating

5 A Nominal:	1250 A-peak
1 A Nominal:	250 A-peak

Burden Rating

5 A Nominal:	≤0.5 VA at 5 A
1 A Nominal:	≤0.1 VA at 1 A

A/D Current Limit

Note: Signal clipping may occur beyond this limit.

5 A Nominal:	247.5 A
1 A Nominal:	49.5 A

AC Voltage Inputs

Three-phase, four-wire (wye) connections are supported.

Rated Voltage Range:	55–250 V_{LN}
Operational Voltage Range:	0–300 V_{LN}
Ten-Second Thermal Rating:	600 Vac
Burden:	≤0.1 VA @ 125 V

LEA Voltage Inputs

Rated Voltage Range:	4 $V_{L\text{-}N}$
Operational Voltage Range:	0–8 $V_{L\text{-}N}$
Ten-Second Thermal Rating:	300 Vac
Input Impedance:	1 MΩ

Frequency and Rotation

Rotation:	ABC ACB
Nominal Frequency Rating:	50 ±5 Hz 60 ±5 Hz
Frequency Tracking (Requires PTs):	Tracks between 40.0–65.0 Hz Below 40.0 Hz = 40.0 Hz Above 65.0 Hz = 65.0 Hz
Maximum Slew Rate:	15 Hz/s

Power Supply

24–48 Vdc

Rated Voltage:	24–48 Vdc
Operational Voltage Range:	18–60 Vdc
Vdc Input Ripple:	15% per IEC 60255-26:2013
Interruption:	20 ms at 24 Vdc, 100 ms at 48 Vdc per IEC 60255-26:2013
Burden:	<35 W

48–125 Vdc or 110–120 Vac

Rated Voltage:	48–125 Vdc, 110–120 Vac
Operational Voltage Range:	38–140 Vdc 85–140 Vac

Rated Frequency:	50/60 Hz
Operational Frequency Range:	30–120 Hz
Vdc Input Ripple:	15% per IEC 60255-26:2013
Interruption:	14 ms @ 48 Vdc, 160 ms @ 125 Vdc per IEC 60255-26:2013
Burden:	<35 W, <90 VA

125–250 Vdc or 110–240 Vac

Rated Voltage:	125–250 Vdc, 110–240 Vac
Operational Voltage Range:	85–300 Vdc 85–264 Vac
Rated Frequency:	50/60 Hz
Operational Frequency Range:	30–120 Hz
Vdc Input Ripple:	15% per IEC 60255-26:2013
Interruption:	46 ms @ 125 Vdc, 250 ms @ 250 Vdc per IEC 60255-26:2013
Burden:	<35 W, <90 VA

Control Outputs

Standard

Make:	30 A
Carry:	6 A continuous carry at 70°C 4 A continuous carry at 85°C
1 s Rating:	50 A
MOV Protection (maximum voltage):	250 Vac, 330 Vdc
Pickup/Dropout Time:	≤6 ms, resistive load
Update Rate:	1/8 cycle

Breaking Capacity (10,000 Operations) per IEC 60255-23:1994

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 = 20 ms

Cyclic Capacity (10,000 Operations) per IEC 60255-23:1994
Rate: 2.5 cycles/second for 4 seconds followed by 2 minutes idle for thermal dissipation

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 = 20 ms

Hybrid (High-Current Interrupting)

Make:	30 A
Carry:	6 A continuous carry at 70°C 4 A continuous carry at 85°C
1 s Rating:	50 A
MOV Protection (Maximum Voltage):	330 Vdc
Pickup/Dropout Time:	≤6 ms, resistive load
Update Rate:	1/8 cycle

Breaking Capacity (10,000 Operations) per IEC 60255-23:1994

24 Vdc	10.0 A	L/R = 40 ms
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 (10,000 Operations) per IEC 60255-23:1994
Rate: 2.5 cycles/second for 4 seconds followed by 2 minutes idle for thermal dissipation

24 Vdc	10.0 A	L/R = 40 ms
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

Note: Do not use hybrid control outputs to switch ac control signals.

High-Speed, High-Current Interrupting

Make:	30 A
Carry:	6 A continuous carry at 70°C 4 A continuous carry at 85°C
1 s Rating:	50 A
MOV Protection (Maximum Voltage):	250 Vac/330 Vdc
Pickup Time:	≤10 µs, resistive load
Dropout Time:	≤8 ms, resistive load
Update Rate:	1/8 cycle

Breaking Capacity (10,000 Operations) per IEC 60255-23:1994

24 Vdc	10.0 A	L/R = 40 ms
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 (10,000 Operations) per IEC 60255-23:1994
Rate: 2.5 cycles/second for 4 seconds, followed by 2 minutes idle for thermal dissipation

24 Vdc	10.0 A	L/R = 40 ms
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

Note: Make rating per IEEE C37.90-2005.
Note: Per IEC 61810-2:2005.
Note: Do not use hybrid control outputs to switch ac control signals.

Control Inputs

Optoisolated (Use With AC or DC Signals)

Main Board:	5 inputs with no shared terminals 2 inputs with shared terminals
INT2, INT7, and INT8 Interface Boards:	8 inputs with no shared terminals
INT4 Interface Board:	6 inputs with no shared terminals 18 inputs with shared terminals (2 groups of 9 inputs with each group sharing one terminal)
Voltage Options:	24, 48, 110, 125, 220, 250 V
Current Drawn:	<5 mA at nominal voltage <8 mA for 110 V option
Sampling Rate:	2 kHz

DC Thresholds (Dropout Thresholds Indicate Level-Sensitive Option)

24 Vdc:	Pickup 19.2–30.0 Vdc; Dropout <14.4 Vdc
48 Vdc:	Pickup 38.4–60.0 Vdc; Dropout <28.8 Vdc
110 Vdc:	Pickup 88.0–132.0 Vdc; Dropout <66.0 Vdc
125 Vdc:	Pickup 105–150 Vdc; Dropout <75 Vdc
220 Vdc:	Pickup 176–264 Vdc; Dropout <132 Vdc
250 Vdc:	Pickup 200–300 Vdc; Dropout <150 Vdc

AC Thresholds (Ratings Met Only When Recommended Control Input Settings Are Used—see *Table 2.1*.)

24 Vac:	Pickup 16.4–30.0 Vac rms; Dropout <10.1 Vac rms
48 Vac:	Pickup 32.8–60.0 Vac rms; Dropout <20.3 Vac rms
110 Vac:	Pickup 75.1–132.0 Vac rms; Dropout <46.6 Vac rms
125 Vac:	Pickup 89.6–150.0 Vac rms; Dropout <53.0 Vac rms

220 Vac:	Pickup 150.3–264 Vac rms; Dropout <93.2 Vac rms
250 Vac:	Pickup 170.6–300 Vac rms; Dropout <106 Vac rms

Communications Ports

EIA-232:	1 Front and 3 Rear
Serial Data Speed:	300–57600 bps

Communications Card Slot for Optional Ethernet Card

Ordering Options:	10/100BASE-T
Connector Type:	RJ45
Ordering Option:	100BASE-FX Fiber-Optic
Connector Type:	LC
Fiber Type:	Multimode
Wavelength:	1300 nm
Source:	LED
Min. TX Power:	–19 dBm
Max. TX Power:	–14 dBm
RX Sensitivity:	–32 dBm
Sys. Gain:	13 dB

Communications Ports for Optional TiDL (EtherCAT) Interface

EtherCAT Fiber-Optic Ports:	8
Data Rate:	Automatic
Connector Type:	LC fiber
Protocols:	Dedicated EtherCAT
Class 1 LASER/LED	
Wavelength:	1300 nm
Fiber Type:	Multimode
Link Budget:	11 dB
Min. TX Power:	–20 dBm
Min. RX Sensitivity:	–31 dBm
Fiber Size:	50–200 µm
Approximate Range:	2 km
Data Rate:	100 Mbps
Typical Fiber Attenuation:	–2 dB/km

Time Inputs

IRIG Time Input—Serial Port 1

Input:	Demodulated IRIG-B
Rated I/O Voltage:	5 Vdc
Operational Voltage Range:	0–8 Vdc
Logic High Threshold:	≥2.8 Vdc
Logic Low Threshold:	≤0.8 Vdc
Input Impedance:	2.5 kΩ

IRIG-B Input—BNC Connector

Input:	Demodulated IRIG-B
Rated I/O Voltage:	5 Vdc
Operational Voltage Range:	0–8 Vdc
Logic High Threshold:	≥2.2 Vdc
Logic Low Threshold:	≤0.8 Vdc
Input Impedance:	>1 kΩ
Dielectric Test Voltage:	0.5 kVac

PTP—Ethernet Port 5A, 5B

Input:	IEEE 1588 PTPv2
Profiles:	Default, C37.238-2011 (Power Profile), IEC/IEEE 61850-9-3-2016 (Power Utility Automation Profile)
Synchronization Accuracy:	±100 ns @ 1-second synchronization intervals when communicating directly with master clock

Operating Temperature

–40° to +85°C (–40° to +185°F)

Note: LCD contrast impaired for temperatures below –20° and above +70°C

Humidity

5% to 95% without condensation

Weight (Maximum)

4U Rack Unit (TiDL [EtherCAT] only):	6.4 kg (14.1 lb)
5U Rack Unit:	13.2 kg (29.2 lb)
6U Rack Unit:	15.1 kg (33.3 lb)
7U Rack Unit:	16.4 kg (36.2 lb)

Terminal Connections

Rear Screw-Terminal Tightening Torque, #8 Ring Lug

Minimum:	1.0 Nm (9 in-lb)
Maximum:	2.0 Nm (18 in-lb)

User terminals and stranded copper wire should have a minimum temperature rating of 105°C. Ring terminals are recommended.

Wire Sizes and Insulation

Wire sizes for grounding (earthing), current, voltage, and contact connections are dictated by the terminal blocks and expected load currents. You can use the following table as a guide in selecting wire sizes. The grounding conductor should be as short as possible and sized equal to or greater than any other conductor connected to the device, unless otherwise required by local or national wiring regulations.

Connection Type	Min. Wire Size	Max. Wire Size
Grounding (Earthing) Connection	14 AWG (2.5 mm^2)	N/A
Current Connection	16 AWG (1.5 mm^2)	10 AWG (5.3 mm^2)
Potential (Voltage) Connection	18 AWG (0.8 mm^2)	14 AWG (2.5 mm^2)
Contact I/O	18 AWG (0.8 mm^2)	10 AWG (5.3 mm^2)
Other Connection	18 AWG (0.8 mm^2)	10 AWG (5.3 mm^2)

Type Tests

Installation Requirements

Overvoltage Category:	2
Pollution Degree:	2

Safety

Product Standards	IEC 60255-27:2013 IEEE C37.90-2005 21 CFR 1040.10
Dielectric Strength:	IEC 60255-27:2013, Section 10.6.4.3 2.5 kVac, 50/60 Hz for 1 min: Analog Inputs, Contact Outputs, Digital Inputs 3.6 kVdc for 1 min: Power Supply, Battery Monitors 2.2 kVdc for 1 min: IRIG-B 1.1 kVdc for 1 min: Ethernet

Impulse Withstand:	IEC 60255-27:2013, Section 10.6.4.2 IEEE C37.90-2005 Common Mode: ±1.0 kV: Ethernet ±2.5 kV: IRIG-B ±5.0 kV: All other ports Differential Mode: 0 kV: Analog Inputs, Ethernet, IRIG-B, Digital Inputs ±5.0 kV: Standard Contact Outputs, Power Supply Battery Monitors +5.0 kV: Hybrid Contact Outputs
Insulation Resistance:	IEC 60255-27:2013, Section 10.6.4.4 >100 MΩ @ 500 Vdc
Protective Bonding:	IEC 60255-27:2013, Section 10.6.4.5.2 <0.1 Ω @ 12 Vdc, 30 A for 1 min
Object Penetration:	IEC 60529:2001 + CRGD:2003 Protection Class: IP30
Max Temperature of Parts and Materials:	IEC 60255-27:2013, Section 7.3
Flammability of Insulating Materials:	IEC 60255-27:2013, Section 7.6 Compliant

Electromagnetic (EMC) Immunity

Product Standards:	IEC 60255-26:2013 IEC 60255-27:2013 IEEE C37.90-2005
Surge Withstand Capability (SWC):	IEC 61000-4-18:2006 + A:2010 IEEE C37.90.1-2012 Slow Damped Oscillatory, Common and Differential Mode: ±1.0 kV ±2.5 kV Fast Transient, Common and Differential Mode: ±4.0 kV
Electrostatic Discharge (ESD):	IEC 61000-4-2:2008 IEEE C37.90.3-2001 Contact: ±8 kV Air Discharge: ±15 kV
Radiated RF Immunity:	IEEE C37.90.2-2004 IEC 61000-4-3:2006 + A1:2007 + A2:2010 20 V/m (>35 V/m, 80% AM, 1 kHz) Sweep: 80 MHz to 1 GHz Spot: 80, 160, 450, 900 MHz 10 V/m (>15 V/m, 80% AM, 1 kHz) Sweep: 80 MHz to 1 GHz Sweep: 1.4 GHz to 2.7 GHz Spot: 80, 160, 380, 450, 900, 1850, 2150 MHz
Electrical Fast Transient Burst (EFTB):	IEC 61000-4-4:2012 Zone A: ±2 kV: Communication ports ±4 kV: All other ports
Surge Immunity:	IEC 61000-4-5:2005 Zone A: ±2 kV_{L-L} ±4 kV_{L-E} ±4 kV: communication ports (Ethernet and IRIG-B) **Note:** Cables connected to EIA-232 communications ports shall be less than 10 m in length for Zone A compliance. Zone B: ±2 kV: communication ports (except Ethernet and IRIG-B) **Note:** Cables connected to EIA-232 communications ports shall be less than 10 m in length for Zone B compliance.
Conducted Immunity:	IEC 61000-4-6:2013 20 V/m; (>35 V/m, 80% AM, 1 kHz) Sweep: 150 kHz–80 MHz Spot: 27, 68 MHz
Power Frequency Immunity (DC Inputs):	IEC 61000-4-16:2015 Zone A: Differential: 150 V_{RMS} Common Mode: 300 V_{RMS}
Power Frequency Magnetic Field:	IEC 61000-4-8:2009 Level 5: 100 A/m; ≥60 Seconds; 50/60 Hz 1000 A/m 1 to 3 Seconds; 50/60 Hz **Note:** 50G1P ≥0.05 (ESS = N, 1, 2) 50G1P ≥0.1 (ESS = 3, 4)
Power Supply Immunity:	IEC 61000-4-11:2004 IEC 61000-4-17:1999/A1:2001/A2:2008 IEC 61000-4-29:2000 AC Dips & Interruptions Ripple on DC Power Input DC Dips & Interruptions Gradual Shutdown/Startup (DC only) Discharge of Capacitors Slow Ramp Down/Up Reverse Polarity (DC only)
Damped Oscillatory Magnetic Field:	IEC 61000-4-10:2016 Level 5: 100 A/m

EMC Compatibility

Product Standards:	IEC 60255-26:2013
Emissions:	IEC 60255-26:2013, Section 7.1 Class A 47 CFR Part 15B Class A Canada ICES-001 (A) / NMB-001 (A)

Environmental

Product Standards:	IEC 60255-27:2013
Cold, Operational:	IEC 60068-2-1:2007 Test Ad: 16 hours at –40°C
Cold, Storage:	IEC 60068-2-1:2007 Test Ad: 16 hours at –40°C
Dry Heat, Operational:	IEC 60068-2-2:2007 Test Bd: 16 hours at +85°C
Dry Heat, Storage:	IEC 60068-2-2:2007 Test Bd: 16 hours at +85°C
Damp Heat, Cyclic:	IEC 60068-2-30:2005 Test Db: +25 °C to +55°C, 6 cycles (12 + 12-hour cycle), 95% RH
Damp Heat, Steady State:	IEC 60068-2-78:2013 Severity: 93% RH, +40°C, 10 days
Cyclic Temperature:	IEC 60068-2-14:2009 Test Nb: –40°C to +80°C, 5 cycles
Vibration Resistance:	IEC 60255-21-1:1988 Class 2 Endurance, Class 2 Response
Shock Resistance:	IEC 60255-21-2:1988 Class 1 Shock Withstand, Class 1 Bump Withstand, Class 2 Shock Response
Seismic:	IEC 60255-21-3:1993 Class 2 Quake Response

Reporting Functions

High-Resolution Data

Rate:	8000 samples/second 4000 samples/second 2000 samples/second 1000 samples/second
Output Format:	Binary COMTRADE

Note: Per IEEE C37.111-1999 and IEEE C37.111-2013, *Common Format for Transient Data Exchange (COMTRADE) for Power Systems*.

Event Reports

Length:	0.25–24 seconds (based on LER and SRATE settings)
Volatile Memory:	3 s of back-to-back event reports sampled at 8 kHz
Nonvolatile Memory:	At least 4 event reports of a 3 s duration sampled at 8 kHz
Resolution:	4 and 8 samples/cycle

Event Summary

Storage:	100 summaries

Breaker History

Storage:	128 histories

Sequential Events Recorder

Storage:	1000 entries
Trigger Elements:	250 relay elements
Resolution:	0.5 ms for contact inputs
Resolution:	1/8 cycle for all elements

Processing Specifications

AC Voltage and Current Inputs

8000 samples per second, 3 dB low-pass analog filter cut-off frequency at 2.8 kHz, ±5%
Digital filtering
Full-cycle cosine after low-pass analog filtering

Protection and Control Processing

8 times per power system cycle

Control Points

64 remote bits
96 local control bits
32 latch bits in protection logic
64 latch bits in automation logic

Relay Element Pickup Ranges and Accuracies

Differential Elements (General)

Number of Zones:	2 (A, B, and C elements)
Number of Windings:	6
TAP Pickup:	(0.1–32.0) • I_{NOM} A secondary
TAP Range:	$TAP_{MAX}/TAP_{MIN} \leq 35$
Time-Delay Accuracy:	±0.1% plus ±0.125 cycle

Differential Elements (Restraint)

Pickup Range:	0.1–4.0 per unit
Pickup Accuracy:	1 A nominal: ±5% ±0.02 A 5 A nominal: ±5% ±0.10 A
Pickup Time (If E87UNB = N):	1.25 minimum cycle 1.38 typical cycle 1.5 maximum cycle
Pickup Time (If E87UNB = Y):	0.5 minimum cycle 0.75 typical cycle 1.5 maximum cycle
Slope 1	
Setting Range:	5%–100%
Slope 2	
Setting Range:	5%–100%

Differential Elements (Unrestraint)

Pickup Range:	(1.0–20.0) • TAP
Pickup Accuracy:	±5% of user setting, ±0.02 • I_{NOM} A
Pickup Time (Filtered Unrestraint):	0.7 minimum cycle 0.85 typical cycle 1.2 maximum cycle
Pickup Time (Raw Unrestraint):	0.25 minimum cycle 0.5 typical cycle 1.0 maximum cycle

Note: The raw unrestraint pickup is set to U87P • √2 • 2

Harmonic Elements (2nd, 4th, 5th)

Pickup Range:	OFF, 5–100% of fundamental
Pickup Accuracy:	1 A nominal ±5% ±0.02 A 5 A nominal ±5% ±0.10 A
Time-Delay Accuracy:	±0.1% plus ±0.125 cycle (differential element) ±0.1% plus ±0.25 cycle (distance element)

Negative-Sequence Differential Element

Pickup Range:	0.05–1 per unit
Slope Range:	5–100%
Pickup Accuracy:	±5% of user setting, ±0.02 • I_{NOM} A
Maximum Pickup/Dropout Time:	4 cycles
Winding Coverage:	2%

Incremental Restraint and Operating Threshold Current Supervision

Setting Range:	0.1–10.0 per unit
Accuracy:	±5% ±0.02 • I_{NOM}

Open-Phase Detection Logic

3 elements per winding (S, T, U, W, X, Y)

Pickup Range	
1 A Nominal:	0.04–1.00 A
5 A Nominal:	0.2–5.00 A
Maximum Pickup/Dropout Time:	0.625 cycle

Restricted Earth Fault (REF)

Elements

Three Independent Elements:	REF1, REF2, REF3

REF1F, REF1R (Element 1, forward and reverse)
REF2F, REF2R (Element 2, forward and reverse)
REF3F, REF3R (Element 3, forward and reverse)

Operating Quantity

Select:	IY1, IY2, IY3

Restraint Quantity

Select:	3I0S, 3I0T, 3I0U, 3I0W, and 3I0X
Pickup Range:	0.05–5 per unit 0.02–0.05 positive-sequence ratio factor (I0/I1)
Pickup Accuracy	
1 A Nominal:	0.01 A
5 A Nominal:	0.05 A
Maximum Pickup/Dropout Time:	2.75 cycles

Mho Phase Distance Elements

Zones 1–4 Impedance Reach

Setting Range	
5 A Model:	OFF, 0.05 to 64 Ω secondary, 0.01 Ω steps
1 A Model:	OFF, 0.25 to 320 Ω secondary, 0.01 Ω steps
Sensitivity	
5 A Model:	0.5 A_{P-P} secondary
1 A Model:	0.1 A_{P-P} secondary (Minimum sensitivity is controlled by the pickup of the supervising phase-to-phase overcurrent elements for each zone.)

Accuracy (Steady State): ± 3% of setting at line angle for SIR (source-to-line impedance ratio) < 30
± 5% of setting at line angle for $30 \le SIR \le 60$

Zone 1 Transient Overreach: < 5% of setting plus steady-state accuracy

Maximum Operating Time: 1.75 cycles at 90% of reach and SIR = 1

Quadrilateral Phase Distance Elements

Zones 1–4 Impedance Reach

Quadrilateral Reactance Reach

5 A Model: OFF, 0.05 to 64 Ω secondary, 0.01 Ω steps

1 A Model: OFF, 0.25 to 320 Ω secondary, 0.01 Ω steps

Quadrilateral Resistance Reach

Zones 1, 2, and 3

5 A Model: OFF, 0.05 to 50 Ω secondary, 0.01 Ω steps

1 A Model: OFF, 0.25 to 250 Ω secondary, 0.01 Ω steps

Zones 4

5 A Model: OFF, 0.05 to 150 Ω secondary, 0.01 Ω steps

1 A Model: OFF, 0.25 to 750 Ω secondary, 0.01 Ω steps

Sensitivity

5 A Model: 0.5 A secondary

1 A Model: 0.1 A secondary

Accuracy (Steady State): ±3% of setting at line angle for SIR < 30
±5% of setting at line angle for $30 \le SIR \le 60$

Transient Overreach: <5% of setting *plus* steady-state accuracy

Maximum Operating Time: 1.75 cycles at 90% of reach and SIR = 1

Mho Ground Distance Elements

Zones 1–4 Impedance Reach

Mho Element Reach

5 A Model: OFF, 0.05 to 64 Ω secondary, 0.01 Ω steps

1 A Model: OFF, 0.25 to 320 Ω secondary, 0.01 Ω steps

Sensitivity

5 A Model: 0.5 A secondary

1 A Model: 0.1 A secondary
(Minimum sensitivity is controlled by the pickup of the supervising phase and residual overcurrent elements for each zone.)

Accuracy (Steady State): ±3% of setting at line angle for SIR < 30
±5% of setting at line angle for $30 \le SIR \le 60$

Zone 1 Transient Overreach: <5% of setting *plus* steady-state accuracy

Maximum Operating Time: 1.75 cycles at 90% of reach and SIR = 1

Quadrilateral Ground Distance Elements

Zones 1–4 Impedance Reach

Quadrilateral Reactance Reach

5 A Model: OFF, 0.05 to 64 Ω secondary, 0.01 Ω steps

1 A Model: OFF, 0.25 to 320 Ω secondary, 0.01 Ω steps

Quadrilateral Resistance Reach

Zones 1, 2, and 3

5 A Model: OFF, 0.05 to 50 Ω secondary, 0.01 Ω steps

1 A Model: OFF, 0.25 to 250 Ω secondary, 0.01 Ω steps

Zones 4

5 A Model: OFF, 0.05 to 150 Ω secondary, 0.01 Ω steps

1 A Model: OFF, 0.25 to 750 Ω secondary, 0.01 Ω steps

Sensitivity

5 A Model: 0.5 A secondary

1 A Model: 0.1 A secondary
(Minimum sensitivity is controlled by the pickup of the supervising phase and residual overcurrent elements for each zone.)

Accuracy (Steady State): ±3% of setting at line angle for SIR < 30
±5% of setting at line angle for $30 \le SIR \le 60$

Transient Overreach: <5% of setting plus steady-state accuracy

Maximum Operating Time: 1.75 cycles at 90% of reach and SIR = 1

Out-of-Step Elements

Blinders (R1) Parallel to the Line Angle

5 A Model: 0.05 to 140 Ω secondary
–0.05 to –140 Ω secondary

1 A Model: 0.25 to 700 Ω secondary
–0.25 to –700 Ω secondary

Blinders (X1) Perpendicular to Line Angle

5 A Model: 0.05 to 140 Ω secondary
–0.05 to –140 Ω secondary

1 A Model: 0.25 to 700 Ω secondary
–0.25 to –700 Ω secondary

Accuracy (Steady State)

5 A Model: ±5% of setting plus ±0.01 A for SIR (source to line impedance ratio) < 30
±10% of setting plus ±0.01 A for $30 \le SIR \le 60$

1 A Model: ±5% of setting plus ±0.05 A for SIR (source to line impedance ratio) < 30
±10% of setting plus ±0.05 A for $30 \le SIR \le 60$

Negative-Sequence Supervision

Setting Range

5 A Model: 0.5–100.0 A, 0.01 A steps

1 A Model: 0.1–20.0 A, 0.01 A steps

Accuracy (Steady State)

5 A Model: ±3% of setting plus ±0.05 A

1 A Model: ±3% of setting plus ±0.01 A

Transient Overreach: <5% of setting

Instantaneous/Definite-Time Overcurrent Elements (50)

Phase- and Negative-Sequence, Ground-Residual Elements

Pickup Range

5 A Nominal: 0.25–100.00 A secondary, 0.01-A steps

1 A Nominal: 0.05–20.00 A secondary, 0.01-A steps

Accuracy (Steady State)

5 A Nominal: ±0.05 A plus ±3% of setting

1 A Nominal: ±0.01 A plus ±3% of setting

Transient Overreach (Phase and Ground Residual)

5 A Nominal: ±5% of setting, ±0.10 A

1 A Nominal: ±5% of setting, ±0.02 A

Transient Overreach (Negative Sequence)

5 A Nominal: ±6% of setting, ±0.10 A

1 A Nominal: ±6% of setting, ±0.02 A

Time-Delay Range: 0.00–16000.00 cycles, 0.125 cycle steps

Timer Accuracy: ±0.25 cycle plus ±0.1% of setting

Maximum Pickup/Dropout Time: 1.5 cycles

Adaptive Time-Overcurrent Elements (51)

Pickup Range (Adaptive Within the Range)

5 A Nominal:	0.25–16.00 A secondary, 0.01 A steps
1 A Nominal:	0.05–3.20 A secondary, 0.01 A steps

Accuracy (Steady State)

5 A Nominal:	±0.05 A plus ±3% of setting
1 A Nominal:	±0.01 A plus ±3% of setting

Transient Overreach

5 A Nominal:	±5% of setting, ±0.10 A
1 A Nominal:	±5% of setting, ±0.10 A

Time Dial Range (Adaptive Within the Range)

U.S.:	0.50–15.00, 0.01 steps
IEC:	0.05–1.00, 0.01 steps
Curve Timing Accuracy:	±1.50 cycles plus ±4% of curve time (for current between 2 and 30 multiples of pickup)

Curves operate on definite time for current greater than 30 multiples of pickup.

Reset:	1 power cycle or Electromechanical Reset Emulation time

Combined Time-Overcurrent Elements (51)

Pickup Range

5 A Nominal:	0.25–16.00 A secondary, 0.01 A steps
1 A Nominal:	0.05–3.20 A secondary, 0.01 A steps

Accuracy (Steady State)

5 A Nominal:	±0.05 A plus ±3% of setting
1 A Nominal:	±0.01 A plus ±3% of setting

Transient Overreach

5 A Nominal:	±5% of setting, ±0.10 A
1 A Nominal:	±5% of setting, ±0.20 A

Time Dial Range

U.S.:	0.50–15.00, 0.01 steps
IEC:	0.05–1.00, 0.01 steps
Curve Timing Accuracy:	±1.50 cycles plus ±4% of curve time (for current between 2 and 30 multiples of pickup)

Curves operate on definite time for current greater than 30 multiples of pickup.

Reset:	1 power cycle or electromechanical reset emulation time

Phase Directional Elements (67)

Number:	6 (1 each for S, T, U, W, X, Y)
Polarization:	Positive-sequence memory voltage Negative-sequence voltage
Time-Delay Range:	0.000–16,000 cycles, 0.125 cycle increment
Time-Delay Accuracy:	±0.1% of setting ±0.25 cycle

Phase-to-Phase Directional Elements

Number:	6 (1 each for S, T, U, W, X, Y)
Polarization Quantity:	Negative-sequence voltage
Operate Quantity:	Negative-sequence current ($3I_2$)
Sensitivity:	0.05 • I_{NOM} A of secondary $3I_2$
Accuracy:	±0.05 Ω secondary
Transient Overreach:	+5% of set reach
Max. Delay:	1.75 cycles
Time-Delay Range:	0.000–16,000 cycles, 0.125-cycle increment
Time-Delay Accuracy:	±0.1% of setting ±0.25 cycle

Ground Directional Elements

Number:	6 (1 each for S, T, U, W, X, Y)
Outputs:	Forward and Reverse
Polarization Quantity:	Zero-sequence voltage
Operate Quantity:	Zero-sequence current 3I0, where 3I0 = IA + IB + IC
Sensitivity:	0.05 • I_{NOM} of secondary 3I0
Accuracy:	±0.05 Ω secondary
Transient Overreach:	+5% of set reach
Max. Delay:	1.75 cycles

Undervoltage and Overvoltage Elements

Pickup Ranges

300 V Maximum Inputs

Phase Elements:	2–300 V_{LN} in 0.01-V steps
Phase-to-Phase Elements:	4–520 V_{LL} in 0.01-V steps
Sequence Elements:	2–300 V_{LN} in 0.01-V steps

8 V LEA Maximum Inputs (see *Potential Transformer (PT) Ratio Settings With LEA Inputs on page 2* for information on setting voltage elements when using LEA inputs.)

Phase Elements:	0.05–8.00 V
Phase-to-Phase Elements:	0.10–13.87 V
Sequence Elements:	0.05–8.00 V

Pickup Accuracy (Steady State)

Phase Elements:	±3% of setting, ±0.5 V
Phase-to-Phase Elements (Wye):	±3% of setting, ±0.5 V
Phase-to-Phase Elements (Delta):	±3% of setting, ±1 V
Sequence Elements:	±5% of setting, ±1 V

Pickup Accuracy (Transient Overreach)

Phase Elements:	±5%
Phase-to-Phase Elements (Wye):	±5%
Phase-to-Phase Elements (Delta):	±5%
Sequence Elements:	±5%

Maximum Pickup/Dropout Time

Phase Elements:	1.5 cycles
Phase-to-Phase Elements (Wye):	1.5 cycles
Sequence Elements:	1.5 cycles

Under- and Overfrequency Elements

Pickup Range:	40.01–69.99 Hz, 0.01-Hz steps
Accuracy, Steady State Plus Transient:	±0.005 Hz for frequencies between 40.00 and 70.00 Hz
Maximum Pickup/Dropout Time:	3.0 cycles
Time-Delay Range:	0.04–300.00 s, 0.001-s increment
Time-Delay Accuracy:	±0.1% ±0.0042 s
Pickup Range, Undervoltage Blocking:	20.00–200.00 V_{LN} (Wye) or V_{LL} (Open-Delta)
Pickup Accuracy, Undervoltage Blocking:	±2% ±0.5 V

Volts/Hertz Elements (24)

Definite-Time Element

Pickup Range:	100–200% steady state
Pickup Accuracy, Steady-State:	±1% of set point
Maximum Pickup/Dropout Time:	1.5 cycles
Time-Delay Range:	0.0–400.00 s
Time-Delay Accuracy:	±0.1% ±4.2 ms @ 60 Hz
Reset Time-Delay Range:	0.00–400.00 s

User-Definable Curve Element

Pickup Range:	100–200%
Pickup Accuracy:	±1% of set point
Reset Time-Delay Range:	0.00–400.00 s

Breaker-Failure Instantaneous Overcurrent

Setting Range	
5 A Nominal:	0.50–50 A, 0.01-A steps
1 A Nominal:	0.10–10.0 A, 0.01-A steps
Accuracy	
5 A Nominal:	±0.05 A, ±3% of setting
1 A Nominal:	±0.01 A, ±3% of setting
Transient Overreach	
5 A Nominal:	±5%, ±0.10 A
1 A Nominal:	±5%, ±0.02 A
Maximum Pickup Time:	1.5 cycles
Maximum Dropout Time:	less than 1 cycle
Maximum Reset Time:	less than 1 cycle
Timers	
Setting Range:	0–6000 cycles, 0.125-cycle steps
Time-Delay Accuracy:	±0.1% of setting ±0.125 cycle

Directional Overpower/Underpower Element

Operating Quantities:	OFF, 3P*m*F, 3Q*m*F,3P*qp*F, 3Q*qp*F (*m* = S, T, U, W, X, Y *qp* = ST, TU, UW, WX)
Pickup Range:	–20000.00 VA (secondary) to 20000.00 VA (secondary, 0.01 steps) Pickup range cannot fall within $\pm I_{NOM}$
Pickup Accuracy:	±3% of setting and ±5 VA, power factor >±0.5 at nominal frequency
Time-Delay Range:	0.000–16,000 cycles, 0.25-cycle increment
Time-Delay Accuracy:	±0.1% of setting ±0.25 cycle

Bay Control

Breakers:	6 maximum
Disconnects (Isolators):	20 maximum
Timers	
Setting Range:	1–99999 cycles, 1-cycle steps
Time-Delay Accuracy:	±0.1% of setting ±0.25 cycle

Station DC Battery System Monitor Specifications

Rated Voltage:	24–250 Vdc
Operational Voltage Range:	0–350 Vdc
Input Sampling Rate:	2 kHz
Processing Rate:	1/8 cycle
Operating Time:	≤1.5 seconds (element dc ripple) 1.5 cycles (all elements but dc ripple)
Setting Range	
DC Settings:	1 Vdc Steps (OFF, 15–300 Vdc)
AC Ripple Setting:	1 Vac Steps (1–300 Vac)
Pickup Accuracy:	±10% ±2 Vdc (dc ripple) ±3% ±2 Vdc (all elements but dc ripple)

Metering Accuracy

All metering accuracies are based on an ambient temperature of 20°C and nominal frequency.

Absolute Phase-Angle Accuracy

IA, IB, and IC per Terminal:	±0.5° (both 1 and 5 A)
VA, VB, and VC Per Terminal:	±0.125°

Currents

Phase Current Magnitude

5 A Model:	±0.2% plus ±4 mA (2.5–15 A sec)
1 A Model:	±0.2% plus ±0.8 mA (0.5–3.0 A sec)

Phase Current Angle

All Models:	±0.2° in the current range (0.5–3.0) • I_{NOM}

Sequence Current Magnitude

5 A Model:	±0.3% plus ±4 mA (0.5–100 A s)
1 A Model:	±0.3% plus ±0.8 mA (0.1–20 A s)

Sequence Current Angle

All Models:	±0.3°

Voltages

300 V Maximum Inputs

Phase and Phase-to-Phase Voltage Magnitude:	±2.5% ±1 V (5–33.5 V) ±0.1% (33.5–300 V)
Phase and Phase-to-Phase Angle:	±1.0° (5–33.5 V) ±0.5° (33.5–300 V)
Sequence Voltage Magnitude (V1, V2, 3V0):	±2.5%, ±1 V (5–33.5 V) ±0.1% (33.5–300 V)
Sequence Voltage Angle (V1, V2, 3V0):	±1.0° (5–33.5 V) ±0.5° (33.5–300 V)

8 V LEA Maximum Inputs

Phase and Phase-to-Phase Voltage Magnitude:	±0.3% (0.2–0.6 V) ±0.1% (0.6–8.0 V)
Phase and Phase-to-Phase Angle:	±0.5° (0.2–8.00 V)
Sequence Voltage Magnitude (V1, V2, 3V0):	±0.3%, (0.2–0.6 V) ±0.1% (0.6–8.0 V)
Sequence Voltage Angle (V1, V2, 3V0):	±0.5° (0.2–8.00 V)

Power

MW (P), Per Phase (Wye), 3ϕ (Wye or Delta) Per Terminal

±1% (0.1–1.2) • I_{NOM}, 33.5–300 Vac, PF = 1, 0.5 lead, lag (1ϕ)
±0.7% (0.1–1.2) • I_{NOM}, 33.5–300 Vac, PF = 1, 0.5 lead, lag (3ϕ)

MVAr (Q), Per Phase (Wye), 3ϕ (Wye or Delta) Per Terminal

±1% (0.1–1.2) • I_{NOM}, 33.5–300 Vac, PF = 0, 0.5 lead, lag (1ϕ)
±0.7% (0.1–1.2) • I_{NOM}, 33.5–300 Vac, PF = 0, 0.5 lead, lag (3ϕ)

MVA (S), Per Phase (Wye), 3ϕ (Wye or Delta) Per Terminal

±1% (0.1–1.2) • I_{NOM}, 33.5–300 Vac, PF = 1, 0.5 lead, lag (1ϕ)
±0.7% (0.1–1.2) • I_{NOM}, 33.5–300 Vac, PF = 1, 0.5 lead, lag (3ϕ)

PF, Per Phase (Wye), 3ϕ (Wye or Delta) Per Terminal

±1% (0.1–1.2) • I_{NOM}, 33.5–300 Vac, PF = 1, 0.5 lead, lag (1ϕ)
±0.7% (0.1–1.2) • I_{NOM}, 33.5–300 Vac, PF = 1, 0.5 lead, lag (3ϕ)

Energy

MWh (P), Per Phase (Wye), 3ϕ (Wye or Delta)

±1% (0.1–1.2) • I_{NOM}, 33.5–300 Vac, PF = 1, 0.5 lead, lag (1ϕ)
±0.7% (0.1–1.2) • I_{NOM}, 33.5–300 Vac, PF = 1, 0.5 lead, lag (3ϕ)

MVARh (Q), Per Phase (Wye), 3ϕ (Wye or Delta)

±1% (0.1–1.2) • I_{NOM}, 33.5–300 Vac, PF = 0, 0.5 lead, lag (1ϕ)
±0.7% (0.1–1.2) • I_{NOM}, 33.5–300 Vac, PF = 0, 0.5 lead, lag (3ϕ)

Demand/Peak Demand Metering

Time Constants:	5, 10, 15, 30, and 60 minutes
IA, IB, and IC per Terminal:	±0.2% ±0.0008 • I_{NOM}, (0.1–1.2) • I_{NOM}
3I2 per Terminal 3I0 (IG) per Terminal (Wye-Connected Only):	±0.3% ±0.0008 • I_{NOM}, (0.1–20) • I_{NOM}

Optional RTD Elements (Models Compatible With SEL-2600 Series RTD Module)

12 RTD inputs via SEL-2600 Series RTD Module and SEL-2800 Fiber-Optic Transceiver

Monitor Ambient or Other Temperatures

PT 100, NI 100, NI 120, and CU 10 RTD-Types Supported, Field Selectable

As long as 500 m Fiber-Optic Cable to SEL-2600 Series RTD Module

Synchrophasor

Number of Synchrophasor Data Streams:	5

Number of Synchrophasors for Each Stream:
24 Phase Synchrophasors (6 Voltage and 18 Currents)
8 Positive-Sequence Synchrophasors (2 Voltage and 6 currents)

Number of User Analogs for Each Stream:	16
Number of User Digitals for Each Stream:	64
Synchrophasor Protocol:	IEEE C37.118-2005, SEL Fast Message (Legacy)
Synchrophasor Data Rate:	As many as 60 messages per second
Synchrophasor Accuracy	
Voltage Accuracy:	±1% Total Vector Error (TVE) Range 30–150 V, f_{NOM} ±5 Hz
Current Accuracy:	±1% Total Vector Error (TVE) Range (0.1–2.0) • I_{NOM} A, f_{NOM} ±5 Hz
Synchrophasor Data Recording:	Records as much as 120 s IEEE C37.232-2011, File Naming Convention

Breaker Monitoring

Running Total of Interrupted Current (kA) per Pole:	±5% ±0.02 • I_{NOM}
Percent kA Interrupted for Trip Operations:	±5%
Percent Breaker Wear per Pole:	±5%
Compressor/Motor Start and Run Time:	±1 s
Time Since Last Operation:	±1 day

Technical Support

We appreciate your interest in SEL products and services. If you have questions or comments, please contact us at:

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Notes

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