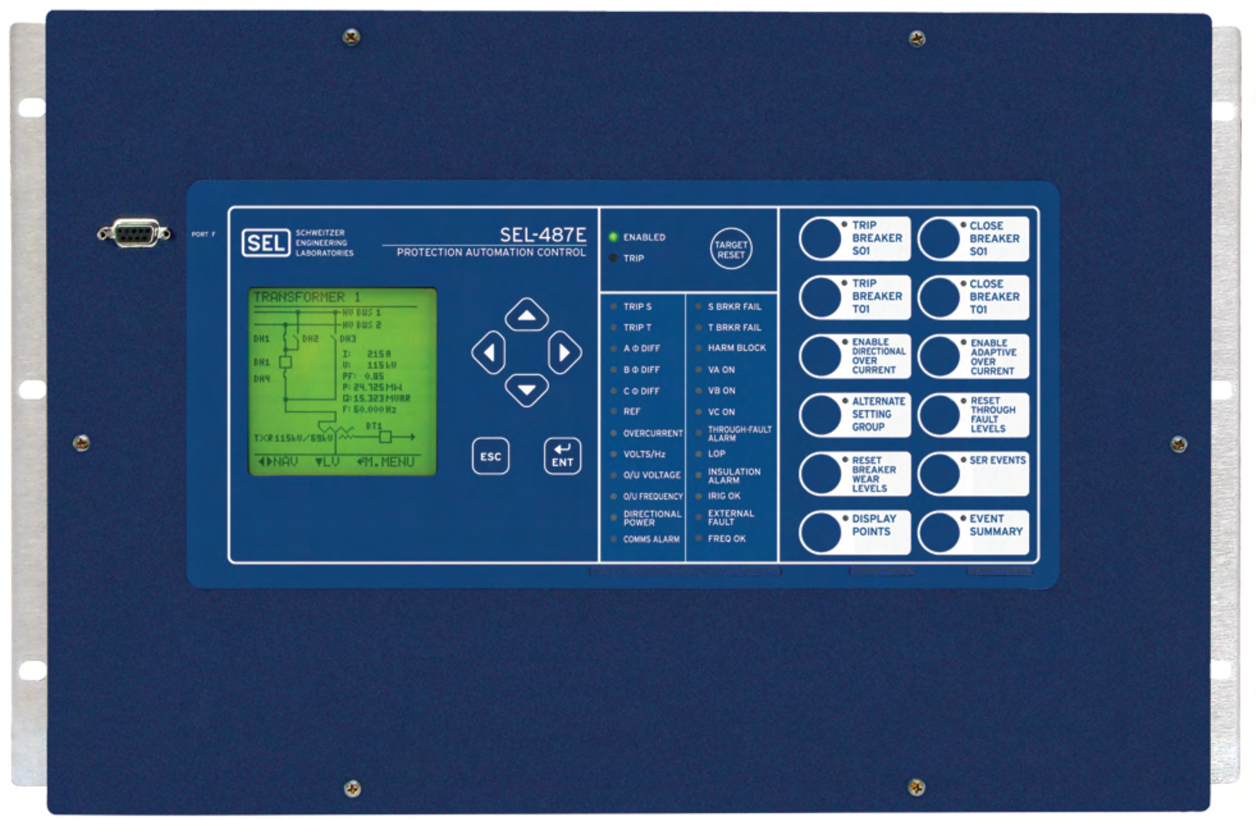
SEL-487E-3, -4 Transformer Differential Relay

Three-Phase Transformer Protection, Automation, and Control System



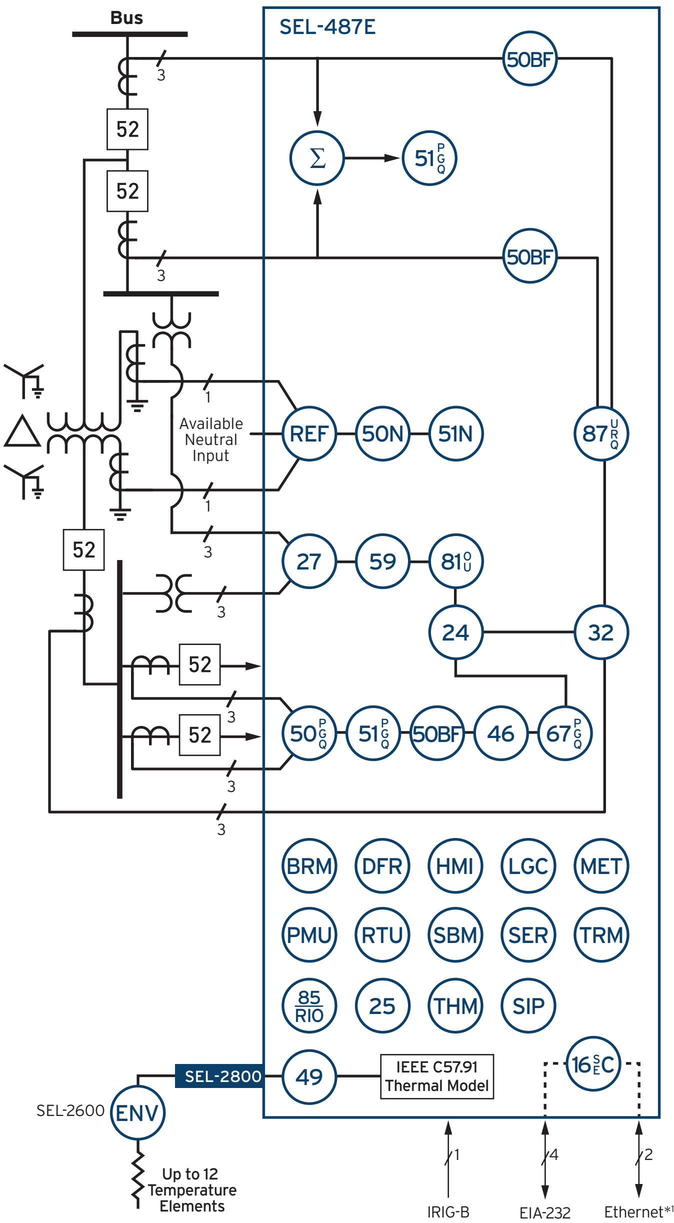
Major Features and Benefits

The SEL-487E Transformer Differential Relay provides three-phase differential protection for transformer applications with as many as five three-phase restraint current inputs. Use the three independent restricted earth fault (REF) elements for sensitive ground-fault detection in grounded wye-transformer applications. Detect turn-to-turn winding faults for as little as two percent of the total transformer winding with the negative-sequence differential element. Apply the two three-phase voltage inputs for over- and undervoltage, frequency, and volts/hertz protection. Make any overcurrent element directional using voltage polarized directional elements as torque control inputs to the overcurrent elements. Monitor and protect critical substation assets with comprehensive breaker wear and transformer thermal and through-fault monitoring. Perform bay control functions for as many as five breakers and 20 disconnect switches using the built-in system mimic diagrams.

- **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.
- **Multiple Synchrophasor Data Channels.** System-wide monitoring is available through as many as 24 synchrophasor data channels. Record and store up to 120 seconds of IEEE C37.118 binary synchrophasor data.
- **Restricted Earth Fault Protection.** Three independent REF elements provide sensitive protection for faults close to the winding neutral in grounded wye-connected transformers.
- **Inrush and Overexcitation Detection.** Combined harmonic blocking and restraint features provide maximum security during transformer magnetizing inrush conditions. Wave-shape-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.
- **Combined Overcurrent.** SEL-487E 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.
- **Directional Element Performance Optimization.** Application of phase and ground directional overcurrent elements with Best Choice Ground Directional Element® voltage polarization optimizes directional element performance and eliminates the need for many directional settings.
- **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.
- **Reverse Power Flow and Overload Condition Protection.** 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.
- **Front-Panel Display of Operational, Breaker, and Disconnect Device Status.** Integral mimic displays on the relay front panel provide easy-to-read operational, control, breaker, and disconnect device information.
- **Transformer Configuration and Compensation Setting Verification.** The Commissioning Assistance Report verifies proper transformer configuration and compensation settings automatically and identifies wiring errors quickly.
- **IEC 60255-Compliant Thermal Model.** Use the relay to provide a configurable thermal model for the protection of a wide variety of devices.
- **Reduced System Coordination Delays.** SEL-487E breaker failure protection with subsidence detection minimizes system coordination delays.
- **Simplified System Integration.** Ethernet communication using DNP3 LAN/WAN and IEC 61850 protocols simplify system integration.
- **Serial Data Communication.** The SEL-487E 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.
- **Input/Output Scaling.** The SEL-2600 RTD Module provides as many as 12 temperature inputs, and SEL-2505/SEL-2506 Remote I/O Modules provide a scalable number of discrete I/O points.
- **Setting and Commissioning Standardization.** ACSELERATOR QuickSet® SEL-5030 Software standardizes and simplifies settings and commissioning.
- **Two CT Input Levels.** Selectable 1 A or 5 A nominal secondary input levels are available for any three-phase winding input.
- **Software-Invertible Polarities.** Invert individual or grouped CT and PT polarities 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.

- **No Need for Auxiliary CTs.** The SEL-487E can accommodate a CT ratio mismatch as great as 35:1.
- **Parallel Redundancy Protocol (PRP).** PRP provides 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.
- **IEEE 1588, Precision Time Protocol.** The relay shall support Precision Time Protocol version 2 (PTPv2). PTP provides high-accuracy timing over an Ethernet network.
- **Time-Domain Link (TiDL) Technology.** The relay supports remote data acquisition through use of the SEL-2240 Axion®. The Axion provides remote analog and digital data over an IEC 61158 EtherCAT® TiDL network. This technology provides very low and deterministic latency over a fiber point-to-point architecture. The SEL-487E-3, -4 relay can receive fiber links from as many as eight Axion remote data acquisition nodes.

Functional Overview



ANSI NUMBERS/ACRONYMS AND FUNCTIONS	
16 SEC	Access Security (Serial, Ethernet)
24	Volts/Hertz
25	Synchronism Check
27	Undervoltage
32	Directional Power
46	Current Unbalance
49	Thermal
50BF	Breaker Failure Overcurrent
50N	Neutral Overcurrent
50 (P, G, Q)	Overcurrent (Phase, Ground, Neg. Seq.)
51N	Neutral Time-Overcurrent
51 (P, G, Q)	Time-Overcurrent (Phase, Ground, Neg. Seq.)
59	Overvoltage
67 (P, G, Q)	Directional Overcurrent (Phase, Ground, Neg. Seq.)
81 (O, U)	Over- and Underfrequency
85 RIO	SEL Mirrored Bits® Communications
87 (U, R, Q)	Transformer Differential (Unrestrained, Restrained, Neg. Seq.)
DFR	Event Reports
ENV	SEL-2600
HMI	Operator Interface
LGC	Expanded SELogic® Control Equations
MET	High-Accuracy Metering
PMU	Synchrophasors
REF	Restricted Earth Fault
RTU	Remote Terminal Unit
SER	Sequential Events Recorder

ADDITIONAL FUNCTIONS	
BRM	Breaker Wear Monitor
LDP	Load Data Profiling
SBM	Station Battery Monitor
SIP	Software-Invertible Polarities
THM	IEC 60255-Compliant Thermal Model
TiDL	Time-Domain Link Remote Data Acquisition
TRM	Transformer Monitor

[1] Copper or Fiber Optic * Optional Feature

Figure 1 Functional Diagram

SEL-487E Relay Functions

- SEL-487E three-phase differential protection sensing:
  - 15 restraint input current channels
  - Three REF input current channels
  - Six voltage channels with over- and undervoltage and frequency protection. Voltage inputs accept delta- or wye-connected potential transformers.
- Negative-sequence differential element for sensitive internal fault (turn-to-turn) detection detects as little as two percent short-circuit of total winding
- Five unique IEEE C37.118 compliant synchrophasor data streams via serial or Ethernet communications ports
- Transformer through-fault monitoring
- Volts/hertz protection with independent loaded versus unloaded V/Hz curves
- Phase, negative-sequence, ground, and combined current time-overcurrent elements
- Phase and ground-directional overcurrent elements with Best Choice Ground Directional Element logic polarization
- Adaptive time-overcurrent elements allow programming of input current source, time dial, and pickup levels
- Synchronism-check elements that incorporate slip frequency, maximum angle difference, breaker close time, and allow different sources of synchronizing voltage.
- Breaker failure protection with subsidence detection and retrip
- As many as 12 temperature-measuring elements when used with the SEL-2600 RTD Module. Use IEC 61850 GOOSE Message Remote Analog quantities to stream data from other remote devices.
- Add contact I/O with the SEL-2505/SEL-2506 Remote I/O Module
- Enhanced SELOGIC® with advanced math for analog quantities
- Integrated mimic displays for direct control of transformer breaker and disconnect switches with metering for analog quantities
- Station battery monitor detects over- and undervoltage, grounds, and excess ripple
- Ethernet support with DNP3 LAN/WAN or IEC 61850 protocol option
- Four EIA-232 ports
- COMTRADE oscillography at 8 kHz
- Standard main board provides five independent inputs, three common outputs, and seven standard outputs
- Optional expansion I/O boards provide a wide range of contact input and output configurations
- IEEE C57.91 compliant transformer thermal model with hot-spot temperature and insulation aging factors
- As many as two additional expansion I/O boards in a 7U chassis, one additional expansion I/O board in a 6U chassis, or no I/O board in a 5U chassis
- Breaker wear monitoring for as many as five three-phase breakers
- Directional power (32) elements for watts and VARs
- Commissioning assistance with automatic CT phase, transformer compensation, and polarity checking
- 256 remote analog inputs (integer, long and floating point) provide analog values from other devices using unsolicited SEL Fast Message write protocol that supports the remote analog values. Use remote analog values like any other analog quantity in the relay, such as for display points, and SELOGIC equations. Remote analog inputs can also be used for inputs to the Thermal model.
- The SEL-487E provides comprehensive protection, automation, and control for transformers. The SEL-487E-4 variant is identical to the SEL-487E-3 in all aspects but has been relabeled for use in phasor measurement applications that prohibit personnel from accessing protective relays.

Transformer 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 using second and fourth harmonic quantities provide secure operation during transformer energization, while maintaining sensitivity for internal faults. Wave-shape-based inrush detection addresses inrush conditions that contain low second and fourth harmonic content. For applications without voltage inputs (therefore no volts/hertz element), use the fifth harmonic monitoring to detect and alarm on over-excitation conditions.

Use the 1 A and 5 A CT ordering options that allow selection of 1 A and 5 A CT inputs for each transformer winding to configure the SEL-487E for a variety of CT configurations, including:

- 1 A high-voltage, 5 A low-voltage CTs
- 5 A high-voltage, 5 A low-voltage, 1 A tertiary CTs

Configure the SEL-487E for transformer differential protection for transformer applications using as many as five three-phase restraint current inputs. This includes single transformers with tertiary windings. *Figure 2* shows the SEL-487E in a typical two-winding transformer application. Use the remaining three-phase current inputs for feeder backup protection.

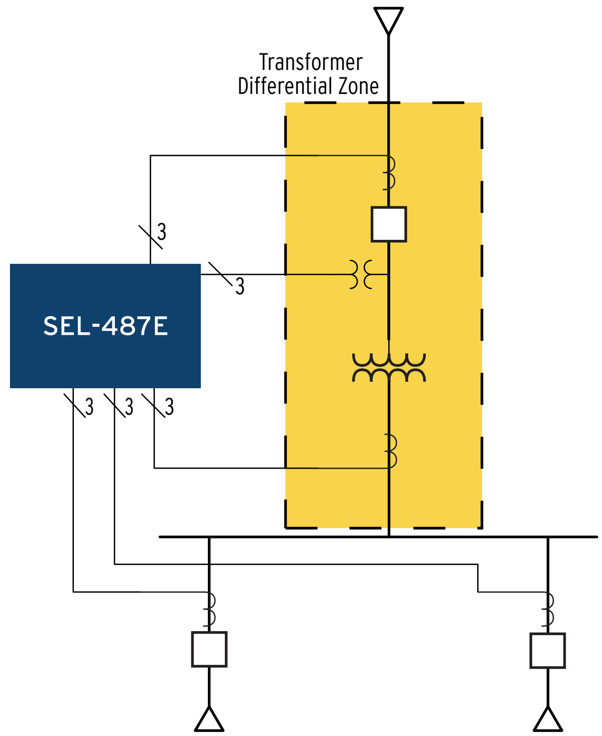


Figure 2 Two-Winding Transformer Application

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 volts/hertz elements provide the SEL-487E with accurate transformer protection for off-frequency events and overexcitation conditions.

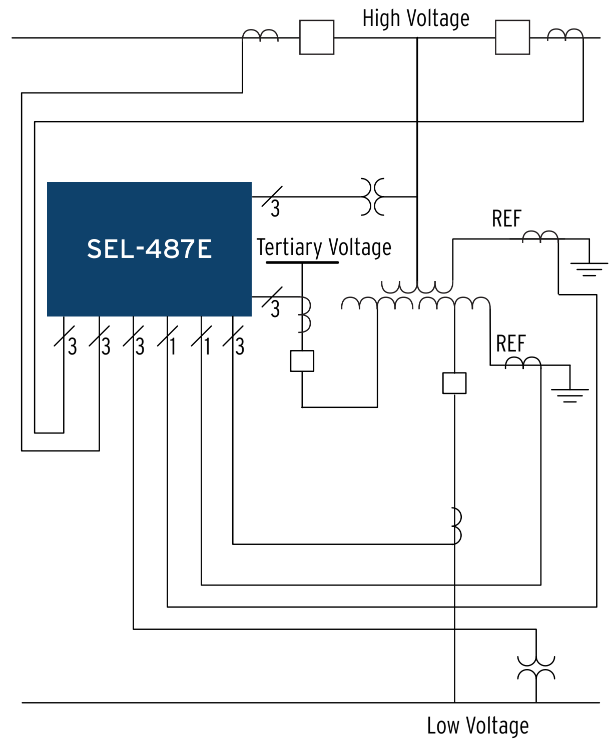


Figure 3 Single Transformer Restricted Earth Fault (REF) Application

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 volts/hertz 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 generator step-up (GSU) transformer in prime power, standby, base load, and peak shaving applications. *Figure 4* shows the SEL-487E in a typical GSU application.

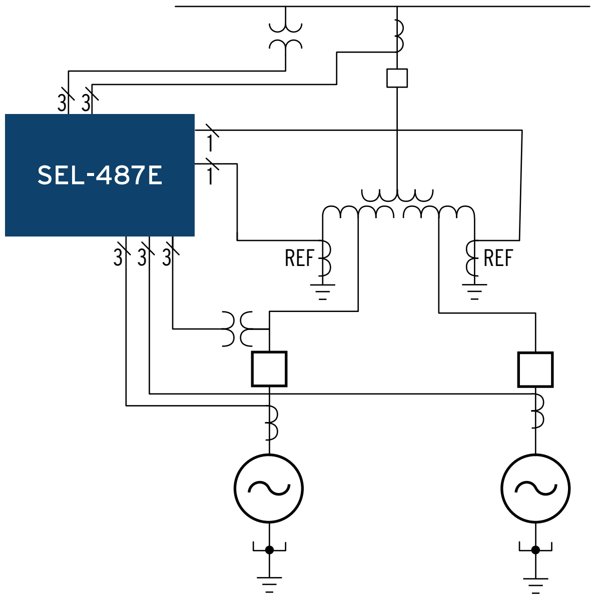


Figure 4 Generator Step-Up Application

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 up to 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.

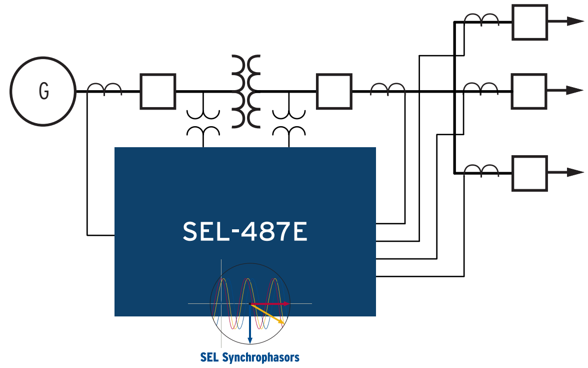


Figure 5 Station-Wide Synchrophasor Application

Protection Features

Transformer protection includes the following protection elements:

- Unrestrained, restrained, and negative-sequence differential
- Breaker-failure with subsidence detection for three-pole breakers
- Restricted Earth Fault (REF) for grounded wye windings
- Instantaneous overcurrent (phase, negative-, and zero-sequence)
- Adaptive (selectable) time overcurrent (phase, negative-, and zero-sequence)
- Voltage polarized directional overcurrent (Best Choice Ground Directional Element selection logic)
- Current unbalance
- Directional power
- Over- and undervoltage elements (phase, negative-, and zero-sequence)
- Over- and underfrequency
- Volts/hertz elements
- Thermal elements

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 6* shows the characteristic of the filtered differential element as a straight line through the origin of the form:

IOPA (IRTA) = SLP*c* • IRTA

For operating quantities (IOPA) exceeding the threshold level O87P and falling in the operate region of *Figure 6*, 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.

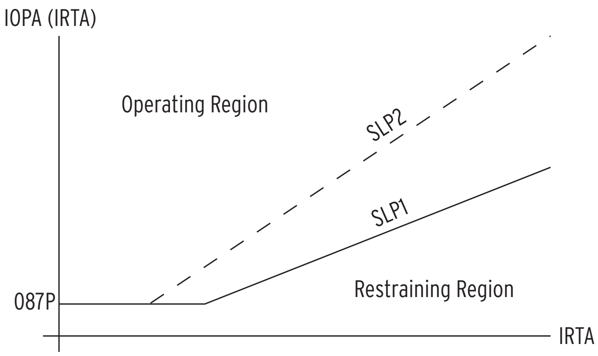


Figure 6 Adaptive Slope Differential Characteristics

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. Wave-shape-based inrush detection addresses inrush conditions that contain low second and fourth harmonic content. Fast sub-cycle external fault detection supervision adds security during external faults with CT saturation. The harmonic blocking element includes common or independent 2nd and 4th harmonic blocking and independent 5th harmonic blocking.

Volts/Hertz Elements

The SEL-487E provides comprehensive volts/hertz (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.

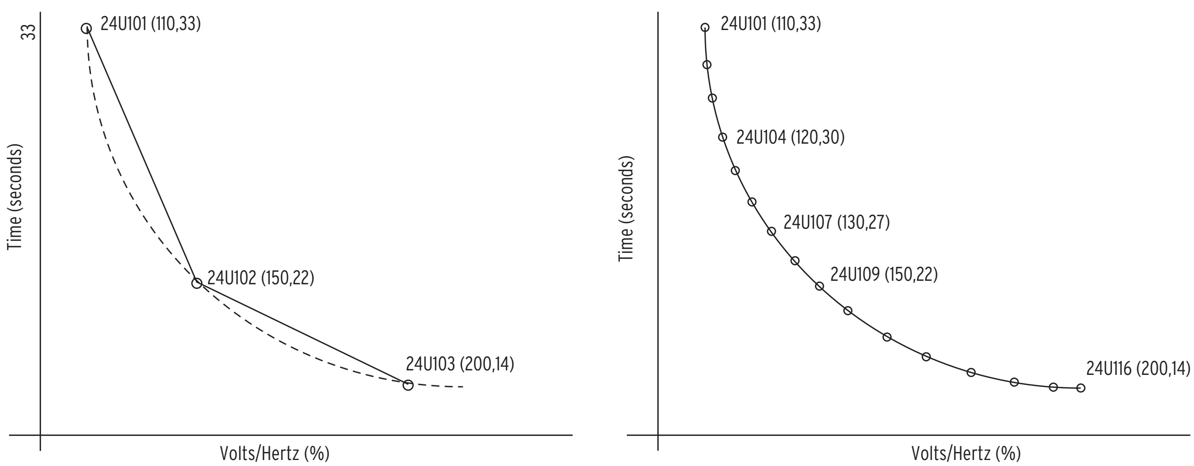


Figure 7 Volts/Hertz Curve Diagrams

Voltage and Frequency Elements

Voltage elements consist of five undervoltage (27) and five overvoltage (59) elements, with two pickup levels per element and definite-time delay. These elements can be assigned any of the following available voltage inputs shown in *Table 1*.

Table 1 Voltage Element Inputs

Input	Description
Fundamental Voltages (V, Z): $V_{A,B,C}$, $V\phi-\phi$, V_{MAX}, V_{MIN}, V_1, $3V_2$[a], $3V_0$[a]	Voltages measured at the fundamental frequency of the power system. V_{MAX}, V_{MIN} are maximum/minimum of three-phase voltages.
RMS Voltages: $V_{A,B,C}$, $V\phi-\phi$, V_{MAX}, V_{MIN}	RMS voltages include fundamental plus all measurable harmonics. V_{MAX}, V_{MIN} are maximum/minimum of three-phase voltages.

[a] Not available for undervoltage elements.

Additionally, six frequency elements (81) with time-delay are provided for use on any of the relay voltage inputs. Each frequency element has undervoltage supervision to allow blocking of the frequency element if the input voltage drops below a specified level. All frequency elements maintain their pickup accuracy from 40.0 to 70.0 Hz.

Instantaneous Overcurrent Elements

The SEL-487E calculates instantaneous overcurrent elements for phase, negative-sequence, and zero-sequence currents. The relay offers three levels of phase, negative-, and zero-sequence overcurrent protection per differential terminal (S, T, U, W, X, ST, TU, UW, WX). The directionality of each element can be controlled individually by means of a 67*xxx*TC setting. The same setting is used to torque-control each element individually.

Adaptive Time-Overcurrent Elements (51S)

The relay supports ten 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 2* (5 IEC and 5 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 2 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

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 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.

Combined Overcurrent Elements

Combined overcurrent elements operate on the vector sum of two winding currents (ST, TU, UW, WX). The individual currents are scaled by the appropriate ratio so that the combined current accurately reflects the primary system current. These combined elements offer added flexibility when the relay is applied with multiple breakers, such as breaker-and-a-half applications.

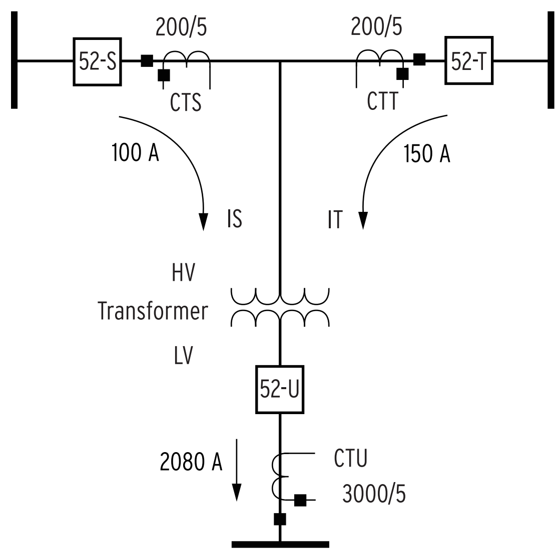


Figure 8 Adaptive Overcurrent Elements

Restricted Earth-Fault 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 phase CTs and the neutral CTs can be mismatched by a ratio of 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 five breakers with a common 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.

Breaker-Failure Protection

The SEL-487E provides complete breaker-failure protection, including retrip, for as many as five breakers. For applications requiring external breaker-failure protection, set the SEL-487E to external breaker fail and connect the input from any external breaker failure relay to the SEL-487E; any terminal can be set to either internal or external breaker-failure protection.

High-speed open-phase sensing logic uses subsidence current recognition algorithms to detect open-phase conditions in less than 0.75 cycle as shown in *Figure 9*. This reduces breaker-failure coordination times and minimizes overall system coordination delays.

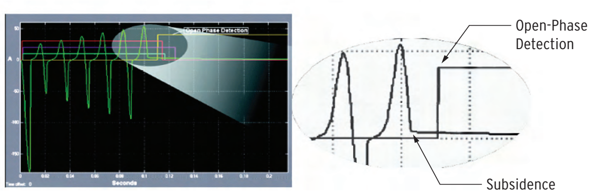


Figure 9 Open-Phase Detection Using Subsidence Logic

Negative-Sequence Differential Element

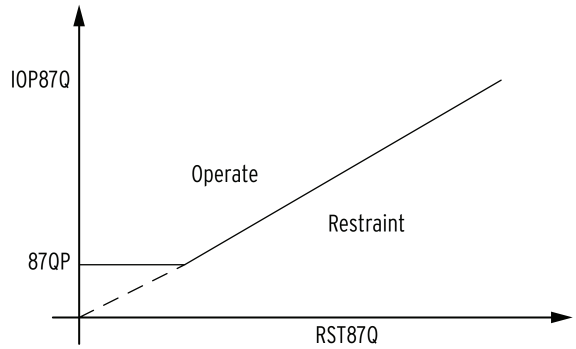


Figure 10 Negative-Sequence Differential Characteristic

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 unchecked 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 using a single-slope characteristic. Using negative-sequence restraint, the differential element is impervious to 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.

Directional Overcurrent Control Elements

When voltage inputs are provided to the SEL-487E, directional elements can be used to supervise phase and ground overcurrent elements on a per-winding basis. CT polarity reversal settings are provided for CTs that are connected with reverse polarity from the required polarity input to the element.

Use the phase and ground directionally controlled overcurrent elements (67) for backup protection of transformer differential or feeder overcurrent relays. Customize a SELOGIC equation to determine when to block the phase and ground directional element on a per terminal basis. Voltage-polarized directional elements supervise currents that are on the same side of the transformer as the selected polarizing voltages.

An ORDER setting is provided to prioritize the selection of zero- or negative-sequence polarization for directional control of ground overcurrent elements using patented Best Choice Ground Directional Element switching logic.

Positive- and negative-sequence voltages are used for directional control of phase-overcurrent elements. Positive-sequence voltage memory is used to provide security during three-phase faults. Loss-of-potential elements supervise the voltage-polarized directional elements.

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.

Thermal Overload Protection

The SEL-487E supports three independent thermal elements that conform to the IEC 60255-149 standard. Use these elements to activate a control action or issue an alarm or trip when your equipment overheats as a result of adverse operating conditions.

The SEL-2600 RTD Module provides ambient temperature measurements for the thermal model.

Power Elements

The SEL-487E provides ten over- or underpower elements. Each enabled power element can be set to detect real power or reactive power, and has a definite-time-delay setting. Use the power elements to detect transformer MW or MVAR overload conditions. Used as inputs to SELOGIC control equations, the power elements can provide a wide variety of protection and control applications, including capacitor and reactor bank control, generator, and load-sequencing control.

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).

Six Independent Settings Groups Increase Operation Flexibility

The relay stores six settings groups. Select the active settings group by control input, **SCADA** command, or other programmable conditions. Use these settings groups to cover a wide range of protection and control contingencies. Selectable settings groups make the SEL-487E ideal for applications requiring frequent settings changes and for adapting the protection to changing system conditions. Selecting a group changes both protection and SELOGIC settings. Program group logic to adjust settings for different operating conditions, such as station maintenance, time-of-day or seasonal operations, and emergency contingencies.

Automation and Communication

Automation

Time-Domain Link (TiDL) Technology

The SEL-487E supports remote data acquisition through use of an SEL Axion with a technology known as TiDL. The Axion provides remote analog and digital data over an IEC 61158 EtherCAT TiDL network. This technology provides very low and deterministic 1.5 ms latency over a point-to-point architecture. The SEL-487E Relay can receive as many as eight fiber links from as many as eight Axion remote data acquisition nodes.

The relay supports a number of fixed topologies. The relay maps the voltage and current inputs from the Axion to existing analog quantities in the SEL-487E Relay based on the connected topology. This limits the number of settings and simplifies conversion of an existing system to TiDL. *Figure 11* shows a sample TiDL topology. The SEL-487E Instruction Manual shows all supported topologies.

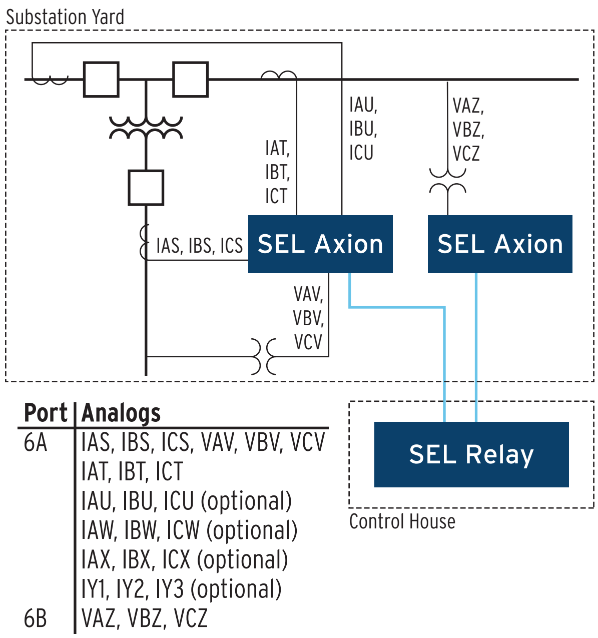


Figure 11 Sample SEL-487E Topology

Flexible Control Logic and Integration Features

Use the SEL-487E control logic to replace the following:

- ➤ Traditional panel control switches
- ➤ RTU-to-relay wiring
- ➤ Traditional latching relays
- ➤ Traditional indicating panel lights

Eliminate traditional panel-control switches with 32 local control points (local bits). 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 same local control points for functions such as taking a terminal out of service for testing. You can also use the licensed version of QuickSet to design application-specific settings templates and then store the templates in memory within the relay for trouble-free retrieval.

Program SELOGIC using structured text, or create graphical logic diagrams using the graphical logic editor (GLE) within QuickSet.

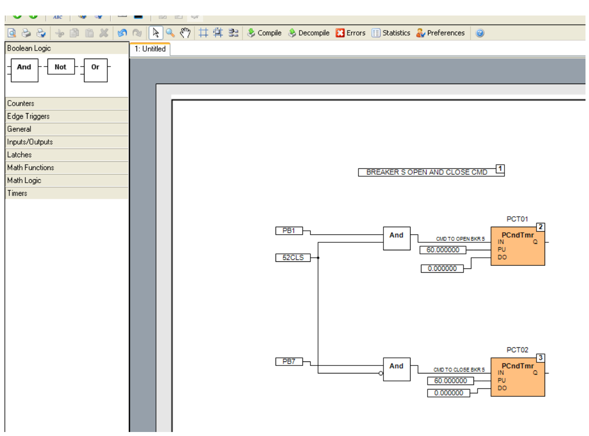


Figure 12 SELOGIC Graphical Logic Editor (GLE)

Eliminate RTU-to-relay wiring with 32 remote control points. 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, settings group selection).

Replace traditional-latching relays for such functions as remote control enable with 32 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 powering up following a power interruption. Replace traditional indicating panel lights and switches with 24 tri-color latching target LEDs and 12 programmable pushbuttons with LEDs. Define custom messages to report power system or relay conditions on the large format LCD. Control displayed messages via SELOGIC control equations by driving the LCD display via any logic point in the relay.

High-Accuracy Timekeeping

Using high-accuracy IRIG-B from a global positioning satellite clock, the SEL-487E can time-tag oscillography to within 1 µs accuracy. This high accuracy can be combined with the high sampling rate of the relay to synchronize data from across the system with an accuracy of better than 1/4 electrical degree. This allows examination of the power system state at given times, including load angles, system swings, and other system-wide events. Triggering can be via external signal (contact or communications port), set time, or system event. Optimal calibration of this feature requires a knowledge of primary-input component (VT and CT) phase delay, and error. A high-accuracy C37.118 IRIG-B time-code input synchronizes the SEL-487E time to be within ±1 µs of the time-source input when the time-source input jitter is less than 500 ns and the time error is less than 1 µs.

Precision Time Protocol (PTP) Time Synchronization

In addition to using IRIG-B for high-accuracy timekeeping, the relay can use IEEE 1588 Precision Time Protocol, version 2 (PTPv2) to obtain time synchronization through the Ethernet network. 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. The relay is capable of receiving as many as 32 sync messages per second.

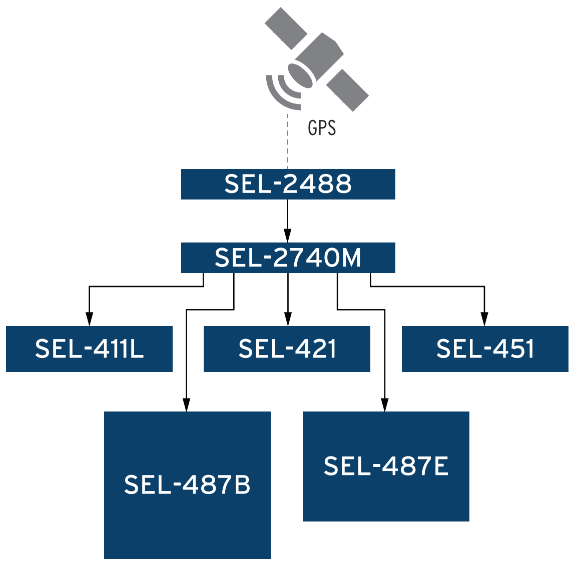


Figure 13 Example PTP Network

SNTP Time Synchronization

Use simple network time protocol (SNTP) to cost-effectively synchronize SEL-487E-3, -4 relays equipped with Ethernet communication to as little as ±1 ms over standard Ethernet networks. Use SNTP as a primary time source, or as a backup to a higher accuracy IRIG-B time input to the relay.

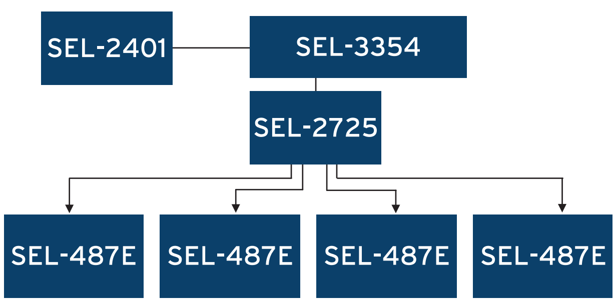


Figure 14 Simple Network Time Protocol

SELOGIC Control Equations With Expanded Capabilities and Aliases

Expanded SELOGIC control equations (*Table 3*) put relay logic in the hands of the protection engineer. Use 250 lines of freeform protection logic, operating at protection processing speed, and 1000 lines of freeform automation logic operating once per second to design a wide variety of custom applications. Assign the relay inputs to suit your application, logically combine selected relay 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. Any of the relay internal variables (Relay Word bits) can be used in these equations. For complex or unique applications, these expanded SELOGIC control equation functions allow superior flexibility. Add programmable control functions to your protection and automation systems. New functions and capabilities enable you to use analog values in conditional logic statements.

Use the alias capability to assign more meaningful relay variable names. 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 using 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)
```

Table 3 Expanded SELOGIC Control Operators

Operator Type	Operators	Comments
Edge Trigger	R_TRIG, F_TRIG	Operates at the change-of-state of an internal function.
Math Functions	SQRT, LN, EXP, COS, SIN, ABS, ACOS, ASIN, CEIL, FLOOR, LOG	Combine these to calculate other trigonometric functions (i.e., TAN := SIN(THETA)/COS(THETA)).
Arithmetic	*, /, +, -	Uses traditional math functions for analog quantities in an easily programmable equation.
Comparison	<, >, <=, >=, =, <>	Compares the values of analog quantities against predefined thresholds or against each other.
Boolean	AND, OR, NOT	Combines variables, and inverts the status of variables.
Precedence Control	( )	Allows as many as 14 sets of parentheses.
Comment	#	Provides for easy documentation of control and protection logic.

Transformer Control

Operate disconnects and breakers with ASCII commands, local or remote bits, SELOGIC control equations, Fast Operate messages, or from the one-line diagram at the relay front-panel. The one-line diagram includes user-configurable apparatus labels and user-definable analog quantities.

One-Line Diagrams

The SEL-487E provides dynamic one-line diagrams on the front-panel screen with disconnect and breaker control capabilities for predefined bus and transformer configurations. Transformer configurations are represented using standard IEC or ANSI one-line transformer diagrams.

The SEL-487E offers a variety of preconfigured one-line diagrams for common bus and transformer configurations. Once a one-line diagram is selected, the user can customize the names for all of the breakers, disconnect switches, and buses. All one-line diagrams contain analog display points. These display points can be set to any of the available analog quantities with labels, units, and scaling. These values are updated in real-time along with the breaker status and disconnect switch position to give instant status and complete control of a bay. *Figure 15* demonstrates one of the preconfigured bay arrangements available in the SEL-487E. The operator can see key information on a bay before making a critical control decision. Programmable interlocks help prevent operators from incorrectly opening or closing switches or breakers.

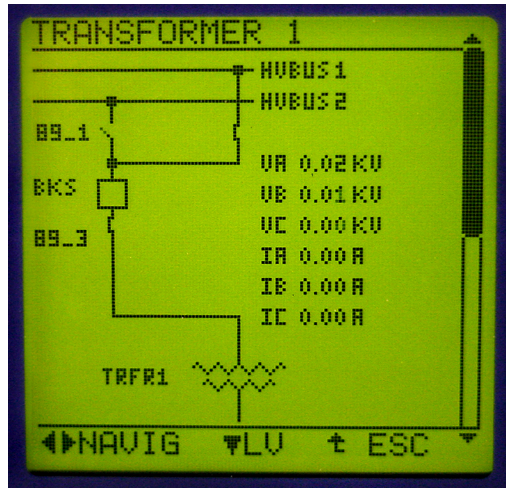


Figure 15 Front-Panel One-Line Transformer Diagram

The SEL-487E will provide control of as many as five breakers and 20 disconnect switches using the one-line diagram displays.

MIRRORED BITS Communications

The SEL patented MIRRORED BITS technology provides bidirectional relay-to-relay digital communication. *Figure 16* shows an SEL-487E with MIRRORED BITS communications to communicate with an SEL-2505 Remote I/O Module in a transfer trip application.

In the SEL-487E, 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. This MIRRORED BITS protocol can be used to transfer information between stations to enhance coordination and achieve faster tripping.

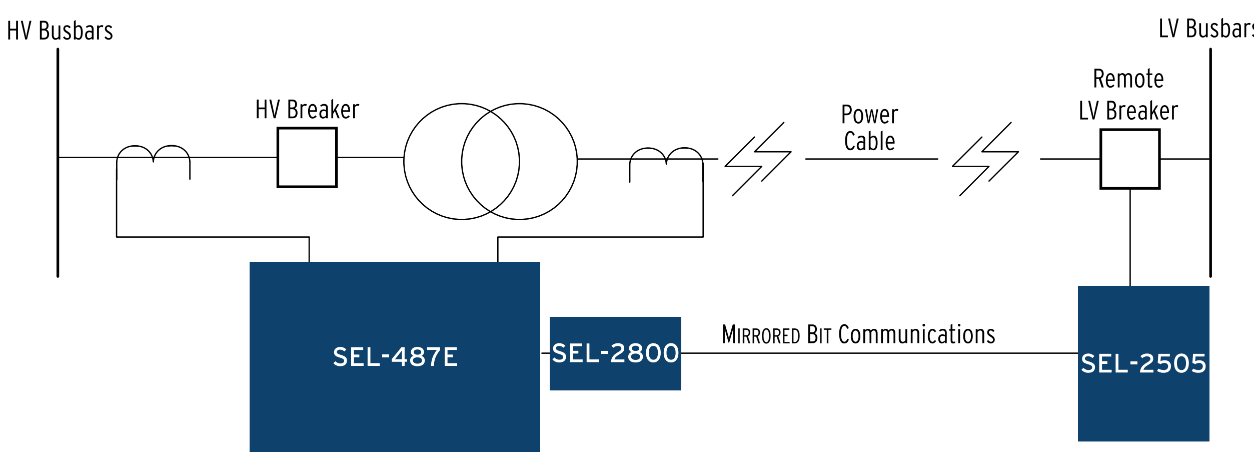


Figure 16 SEL-487E Using MIRRORED BITS in a Transfer Trip Application

Serial Communications Features

The SEL-487E offers the following serial communications features:

- Four independent EIA-232 serial ports
- Full access to event history, relay status, and meter information from the communications ports
- Settings and group switching password control
- SEL unsolicited block transfer for communication with the SEL-2600 RTD Module
- 60 message-per-second synchrophasor data via SEL Synchrophasor Fast Message or C37.118 data format
- SEL ASCII, SEL Compressed ASCII, SEL Fast Operate, SEL Fast Meter, SEL Fast SER and Enhanced SEL MIRRORED BITS serial protocols are standard with each relay
- SEL Unsolicited Fast Message Write for transfer of analog quantities between other devices communicating these protocols

Open Communications Protocols

The SEL-487E 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.

SEL Unsolicited Block Transfer Communication

The SEL-487E has the capability to operate as a client for unsolicited SEL Fast Message communication between the relay and the SEL-2600 RTD Module. Any of the four EIA-232 serial ports on the SEL-487E can be set for direct communication with the SEL-2600. Use the SEL-2600 to provide the SEL-487E with as many as 12 channels of temperature information, updated every 600 ms.

SEL Unsolicited Fast Message Write (Remote Analogs)

From the perspective of the SEL-487E, remote analogs (RA01–RA256) are specific, pre-allocated memory addresses. These memory addresses are available to accept and store values from remote devices such as an SEL-3530 Real-Time Automation Controller (RTAC). Once these values from the remote devices are written into the memory addresses in the SEL-487E, you can use these values similar to any other analog quantity in the relay, including display points and SELOGIC programming.

Ethernet Communication

The SEL-487E provides Ethernet communications capabilities with an optional Ethernet card. This card mounts directly in the relay. Use Telnet applications for easy terminal communication with SEL relays and other devices. Transfer data at high speeds (10 Mbps or 100 Mbps) for fast file uploads. The Ethernet card can communicate using File Transfer Protocol (FTP) applications for easy and fast file transfers. The Ethernet card option provides two Ethernet ports for failover redundancy in case one network connection fails.

Choose Ethernet connection media options for primary and stand-by connections:

- 10/100BASE-T Twisted Pair Network
- 100BASE-FX Fiber-Optic Network

Telnet and FTP

Order the SEL-487E with Ethernet communication and use built-in Telnet and FTP (File Transfer Protocol) that come standard with Ethernet to enhance real communications sessions. Use Telnet to access relay settings and metering and event reports remotely using the ASCII interface. Transfer settings files to and from the relay via the high-speed Ethernet port using FTP.

IEEE C37.118 Synchrophasor Data Over Ethernet

The SEL-487E can provide synchrophasor data compliant with the IEEE C37.118 synchrophasor protocol when equipped with Ethernet communication. This protocol provides standardized packet content of synchrophasor data for use with other IEEE C37.118 compliant networks and devices. The integrated Ethernet card in the SEL-487E provides two independent connections using either TCP/IP, UDP/IP, or a combination thereof. Each data stream can support as many as 60 frames per second.

DNP LAN/WAN

The DNP3 LAN/WAN option provides the SEL-487E with DNP3 Level 2 Outstation functionality over Ethernet. Custom DNP3 data maps can be configured for use with specific DNP3 masters.

Precision Time Protocol (PTP)

An Ethernet card option with Ports 5A and 5B populated provides the ability for the SEL-487E to accept IEEE 1588 Precision Time Protocol, version 2 (PTPv2) for data time synchronization. Optional PTP support includes both the Default and Power System (C37.238-2011) PTP Profiles.

Parallel Redundancy Protocol (PRP)

This protocol is used 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.

IEC 61850 Ethernet Communication

IEC 61850 Ethernet-based communication provides interoperability between intelligent devices within the substation. Logical nodes using IEC 61850 allow standardized interconnection of intelligent devices from different manufacturers for monitoring and control of the substation. Reduce wiring between various manufacturers' devices and simplify operating logic with IEC 61850. Eliminate system RTUs by streaming monitoring and control information from the intelligent devices directly to remote SCADA client devices.

The SEL-487E can be ordered with embedded IEC 61850 protocol operating on 100 Mbps Ethernet. Use the IEC 61850 Ethernet protocol for relay monitoring and control functions, including:

- ➤ As many as 128 incoming GOOSE messages. The incoming GOOSE messages can be used to control as many as 256 control bits in the relay with <3 ms latency from device to device. These messages provide binary control inputs to the relay for high-speed control functions and monitoring.
- ➤ As many as eight outgoing GOOSE messages. Outgoing GOOSE messages can be configured for Boolean or analog data. Boolean data are provided with <3 ms latency from device to device. Use outgoing GOOSE messages for high-speed control and monitoring of external breakers, switches, and other devices.
- ➤ IEC 61850 Data Server. The SEL-487E equipped with embedded IEC 61850 Ethernet protocol provides data according to predefined logical node objects. As many as seven simultaneous client associations are supported by each relay. Relevant Relay Word bits are available within the logical node data, so status of relay elements, inputs, outputs or SELOGIC equations can be monitored using the IEC 61850 data server provided in the relay.
- ➤ Configuration of as many as 256 virtual bits within GOOSE messaging to represent a variety of Boolean values available within the relay. The virtual bits the relay receives are available for use in SELOGIC control equations.
- ➤ As many as 64 remote analog outputs that you can assign 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 using IEC 61850 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.

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 CID file, the relay will require authentication from any client requesting to initiate an MMS session. The client request must be accompanied by the Access Level 2 password.

ACSELERATOR Architect® SEL-5032 Software

Use Architect to manage the logical node data for all IEC 68150 devices on the network. This Microsoft® Windows®-based software provides easy-to-use displays for identifying and binding IEC 61850 network data between logical nodes using IEC 61850 compliant CID (Configured IED Description) files. CID files are used by Architect to describe the data that will be provided by the IEC 61850 logical node within each relay.

Table 4 Open Communications Protocol (Sheet 1 of 2)

Type	Description
ASCII	Plain-language commands for human and simple machine communication. Use for metering, setting, self-test status, event reporting, and other functions.
Compressed ASCII	Comma-delimited ASCII data reports allow external devices to obtain relay data in an appropriate format for direct import into spreadsheets and database programs. Data are checksum protected.
Extended SEL Fast Meter, SEL Fast Operate, and SEL Fast SER	Binary protocol for machine-to-machine communication. Quickly updates SEL communications processors, RTUs, and other substation devices with metering information, relay element, I/O status, time-tags, open and close commands, and summary event reports. Data are checksum protected.
Ymodem	Support for reading event, settings, and oscillography files.
Optional DNP3 Level 2 Outstation	Distributed Network Protocol with point remapping. Includes access to metering data, protection elements, contact I/O, targets, SER, relay summary event reports, and settings groups.
MIRRORED BITS	SEL protocol for exchanging digital and analog information among SEL relays and for use as low-speed terminal connection.

Table 4 Open Communications Protocol (Sheet 2 of 2)

Type	Description
Optional FTP and Telnet	Available with the optional Ethernet card. Use Telnet to establish a terminal-to-relay connection over Ethernet. Use FTP to move files in and out of the relay over Ethernet.
IEC 61850	Ethernet-based international standard for interoperability among intelligent devices in a substation.
SNTP	Ethernet-based simple network time protocol for time synchronization among relays.
Precision Time Protocol	Ethernet-based network time protocol for high-accuracy time synchronization among relays.

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. Differential metering shows the operating and restraint currents for each three-phase differential element as well as the reference current.

Fundamental phase and real and reactive power, per-phase voltage magnitude, angle, and frequency are displayed in the metering report for applications utilizing the relay voltage inputs.

Table 5 SEL-487E Metering Quantities

Capabilities	Description
Instantaneous Quantities	
Fundamental voltages: $V_{A,B,C}$ (V, Z), $V_{\phi\phi}$, 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), $V_{\phi\phi}$	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) $I_{A,B,C}$ (ST, TU, UW, WX)	RMS currents include fundamental plus all measurable harmonics.
Power/Energy Metering Quantities	
Fundamental power quantities: $S_{A,B,C}$, $P_{A,B,C}$, $Q_{A,B,C}$ (S, T, U, W, X) $S_{A,B,C}$, $P_{A,B,C}$, $Q_{A,B,C}$ (ST, TU, UW, WX) $S_{3\phi}$, $P_{3\phi}$, $Q_{3\phi}$ (S, T, U, W, X) $S_{3\phi}$, $P_{3\phi}$, $Q_{3\phi}$ (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	IOP, operate current magnitude (per unit). IRT, restraint current magnitude (per unit).
Harmonics: 2nd: IOPAF2, IOPBF2, IOPCF2 4th: IOPAF4, IOPBF4, IOPCF4 5th: IOPAF5, IOPBF5, IOPCF5	Differential harmonic quantities represents 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) $I_{A,B,C}$, 3I2, 3I0 (ST, TU, UW, WX) IMAX (S, T, U, W, X,) IMAX (ST, TU, UW, WX)	Thermal or rolling interval demand.

Transformer Thermal Monitoring

Transformer thermal modeling per IEEE C57.91-1995 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.

Use the thermal event report to capture current hourly and daily data about your transformer. Operating temperature calculations are based on load currents, type of cooling system, and actual temperature inputs (ambient and top-oil). Use as many as 12 thermal sensor inputs: a single ambient temperature transducer and one transducer for top-oil temperature from each of three single-phase transformers. Temperature data can come from an SEL-2600 RTD Module connected via SEL-2800 on any of the rear serial ports (as shown in *Figure 17*), or from Ethernet-based IEC 61850 GOOSE Message Remote Analogs (RA001–RA256). While the SEL-487E can receive temperature data at any rate, the thermal element uses the temperature data once per minute.

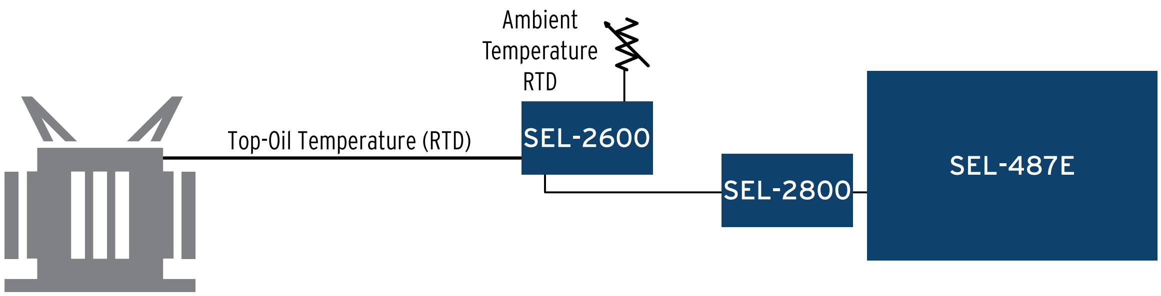


Figure 17 Typical One-Line Diagram for Collecting Transformer Temperature Data

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 aging acceleration factor (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.

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, 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.

Breaker Contact Wear Monitor

Circuit breakers experience mechanical and electrical wear every time they operate. Effective scheduling of breaker maintenance compares published manufacturer breaker wear data, interruption levels, and operation count with actual field data.

The SEL-487E breaker monitoring function captures the total interrupted current and number of operations for as many as five three-pole breakers. Each time a monitored breaker trips, the relay integrates the interrupted current with previously stored current values. When the results exceed the threshold set with reference to the breaker-wear curve, the relay can alarm via an output contact or the front-panel display.

The typical settings are:

- Set Point 1 approximates the continuous load current rating of the breaker.
- Set Point 2 is an intermediate current value providing the closest visual fit to the manufacturer's curve.
- Set Point 3 is the maximum rated interrupting current for the particular breaker.

The breaker wear monitor accumulates current by phase and so calculates wear for each pole separately. When first applying the relay, preload any previous estimated breaker wear. The incremental wear for the next interruption, and all subsequent interruptions, adds to the pre-stored value for a total wear value. Reset the breaker monitor operation counters, cumulative interrupted currents by pole, and percent wear by pole after breaker maintenance or installing a new breaker. The breaker wear monitor report lists all breakers, number of internal and external trips for each breaker, total accumulated rms current by phase, and the percent wear by pole.

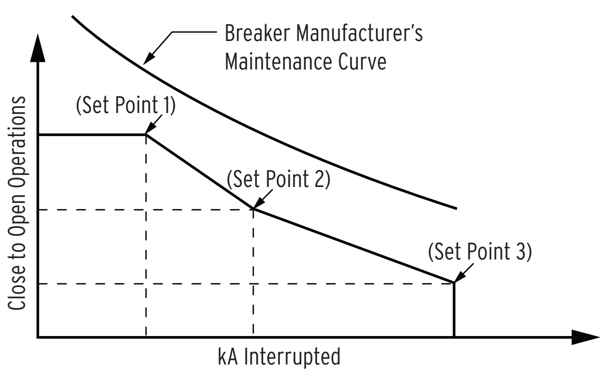


Figure 18 Breaker Contact Wear Curve and Settings

Substation Battery Monitor for DC Quality Assurance

The SEL-487E measures and reports the substation battery voltage for substation battery systems. The relay provides alarm, control, ripple voltage measurement, and ground detection for battery banks and their associated chargers. The battery monitors include warning and alarm thresholds that can be monitored and used to trigger messages, telephone calls, or other actions. The measured dc voltage is reported in the METER display via serial or Ethernet port communication, on the LCD, and in the event report. Use the event report data to see an oscillographic display of the battery voltage during trip, close, and other dc-powered control operations.

Event Reporting and Sequential Events Recorder (SER)

Event reports and Sequential Events Recorder 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 protection 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 SEL-487E 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 SEL-487E provides event reports for analysis with software such as SYNCHROWAVE® Event SEL-5601 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 SEL-487E with an IRIG-B clock input or Precision Time Protocol (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
- Terminals tripped for this fault

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

Sequential Events Recorder (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 input/output change-of-state, element pickup/dropout. The relay SER stores the latest 1000 events.

Additional Features

ACSELERATOR QuickSet SEL-5030 Software

Use QuickSet to develop settings offline. The system automatically checks interrelated settings and highlights out-of-range settings. Settings created off-line can be transferred by using a PC communication link with the SEL-487E. The relay converts event reports to oscillograms with time-coordinated element assertion and phasor diagrams. The QuickSet interface supports Microsoft® Windows® 7 32-bit and 64-bit and Microsoft® Windows® Server 2008 operating systems.

QuickSet Templates

Use the fully licensed version of QuickSet to create custom views of settings, called Application Designs, to reduce complexity, decrease the chance of errors, and increase productivity.

- Lock and hide unused settings
- Lock settings to match your standard for protection, I/O assignment, communication, and SELOGIC control equations
- Enforce settings limits narrower than the device settings
- Define input variables based on the equipment nameplate or manufacturer's terminology or scaling and calculate settings from these "friendlier" inputs
- Use settings comments to guide users and explain design reasoning

Front-Panel Display

The front panel includes a 128 x 128 pixel (82 mm x 82 mm or 3.25 in x 3.25 in) LCD screen, 24 tri-color LED target indicators, and 12 control pushbuttons with indicating LEDs for local control functions. Target and pushbutton identification can be custom configured with easily changed slide-in labels.

The LCD is controlled by the navigation pushbuttons, automatic messages the relay generates, and user-programmable display points.

The rotating display scrolls through any active, nonblank display points. If none are active, the relay scrolls through displays of the differential operating and restraint quantities and the primary current and voltage values. Metering screens can be enabled and displayed in an order defined by the user. Each display remains for user-settable period of time before the display continues scrolling. Any message generated by the relay because of an alarm condition takes precedence over the rotating display.

Configurable Front-Panel Labels

Customize the SEL-487E front panel to fit your needs. Use SELOGIC control equations and slide-in configurable front-panel labels to change the function and identification of target LEDs, operator control pushbuttons, and pushbutton LEDs. The blank slide-in label set is included with the SEL-487E. Label sets can be printed from a laser printer using a template or handwritten on blank labels supplied with the relay.

HTTP Web Server

When equipped with Ethernet communication, the relay can serve read-only web pages displaying certain settings, metering, and status reports. As many as four users can access the embedded HTTP server simultaneously.

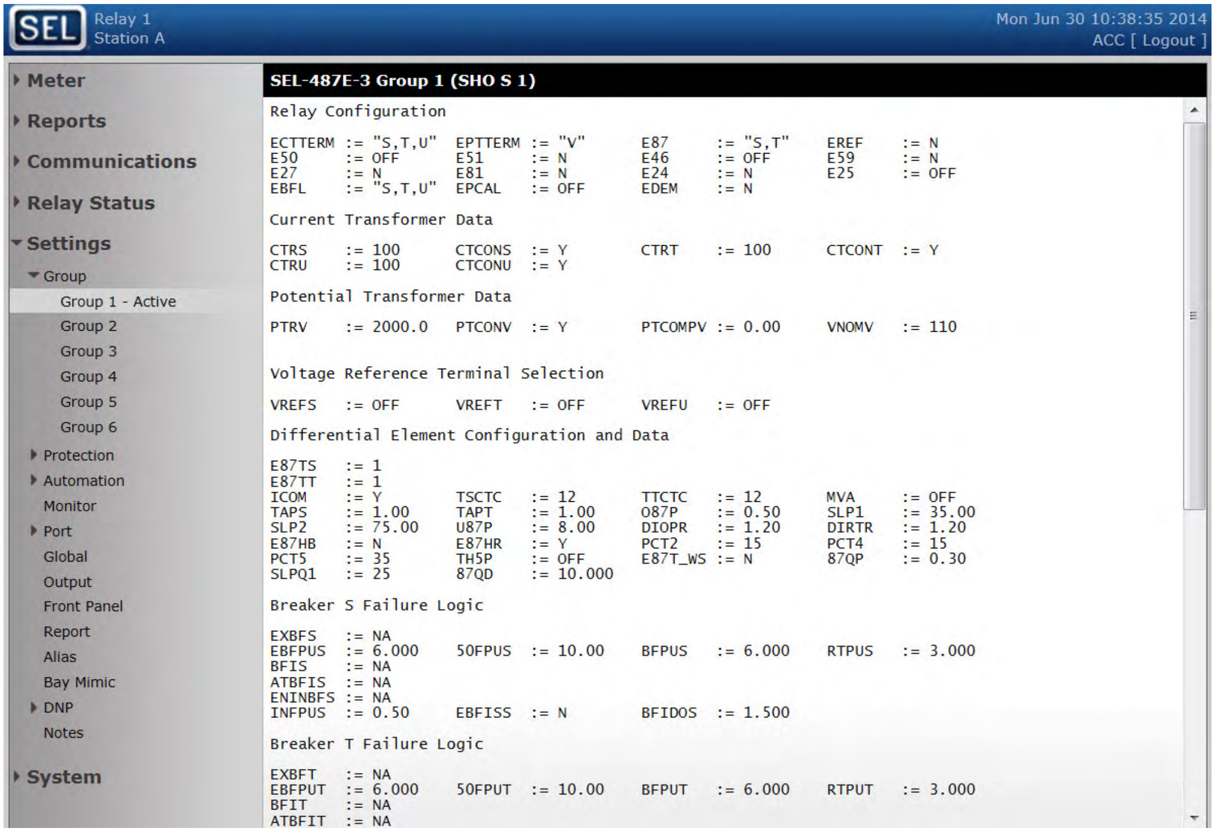


Figure 19 SEL-487E HTTP Web Server Settings Screen

Control Inputs and Outputs

The basic SEL-487E (main board only) includes:

- 3 high-current interrupting Form A outputs
- 2 standard Form A outputs
- 3 standard Form C outputs
- 7 optoisolated level-sensitive inputs

Add as many as two interface boards with a variety of contact input and output configurations, including:

- Optoisolated, level-sensitive contact inputs
- High-current interrupting contact outputs
- High-speed, high-current interrupting contact outputs

The relay is available in 5U, 6U, or 7U chassis heights. The 7U chassis supports as many as two expansion I/O boards. The 6U chassis supports one expansion I/O board, and the 5U chassis supports no I/O boards. Assign the control inputs for disconnect auxiliary contact status and breaker auxiliary contact status. Set the input debounce time independently for each input or as a group. Each control output is programmable using SELOGIC control equations.

Commissioning Assistance

The SEL-487E works with commissioning assistance software to automatically check and recognize improper CT configurations. By referencing all CT inputs to a common point, the software can compare measured phase angles and magnitudes to those expected by the CT configuration and compensation settings within the relay. Mismatches between the measured and calculated CT vector quantities generates specific alarm conditions that indicate polarity, compensation setting, or ratio errors that often occur during the commissioning of low-impedance differential relays. A commissioning assistance report provides magnitude, phase angle, and compensation information, along with improper condition notification in a simple, easy-to-read format.

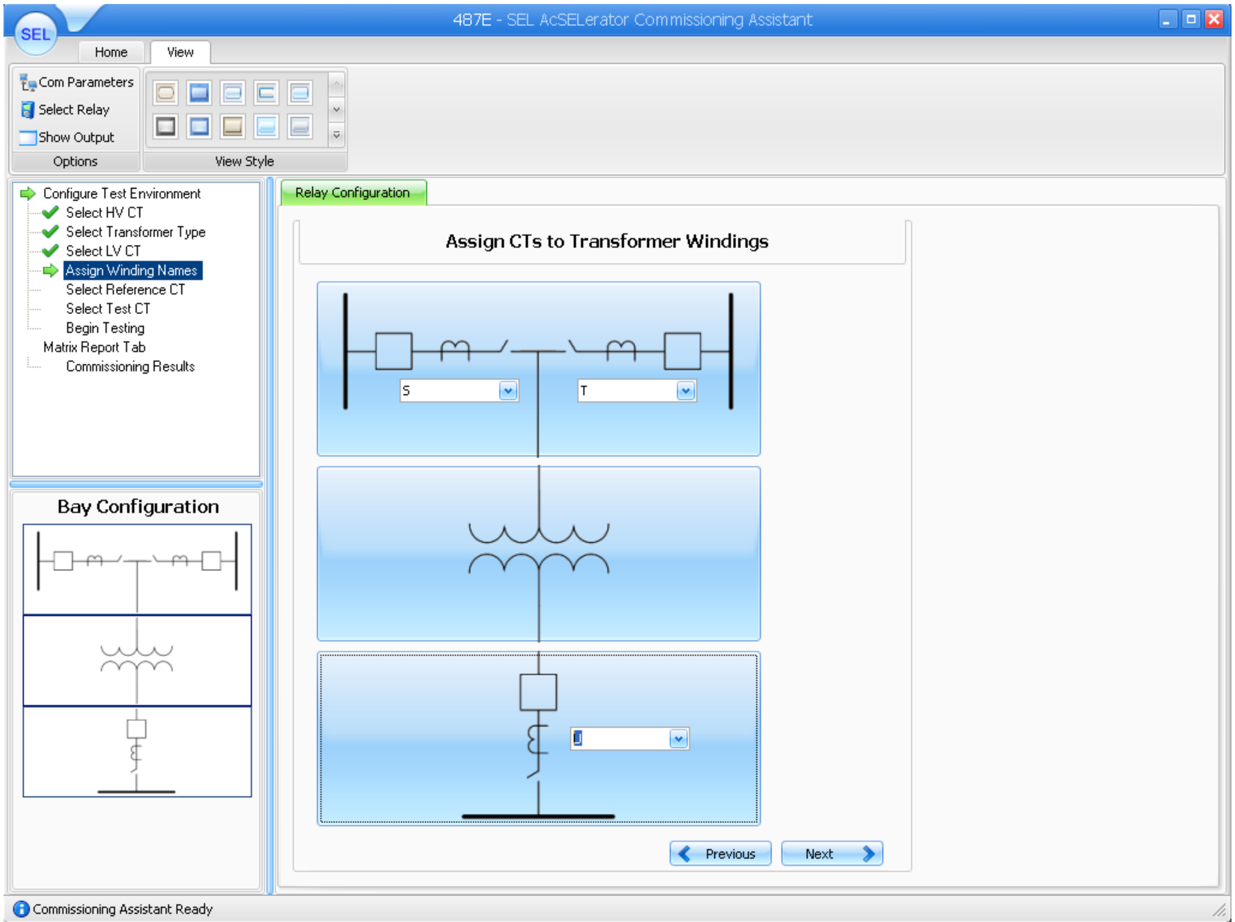


Figure 20 Commissioning Assistant Screen

Front- and Rear-Panel Diagrams

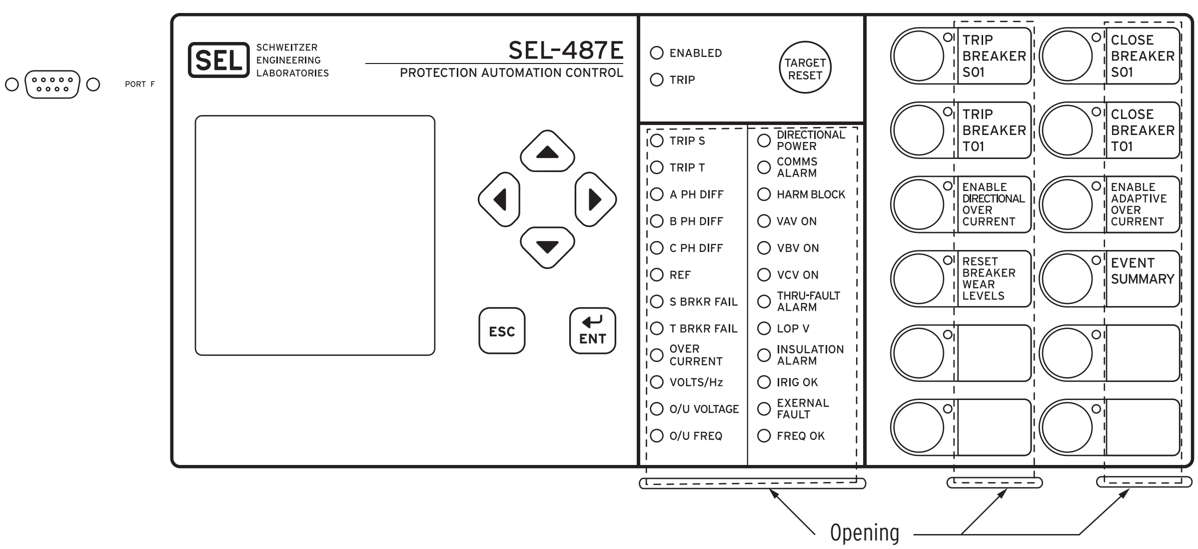


Figure 21 SEL-487E Front Panel

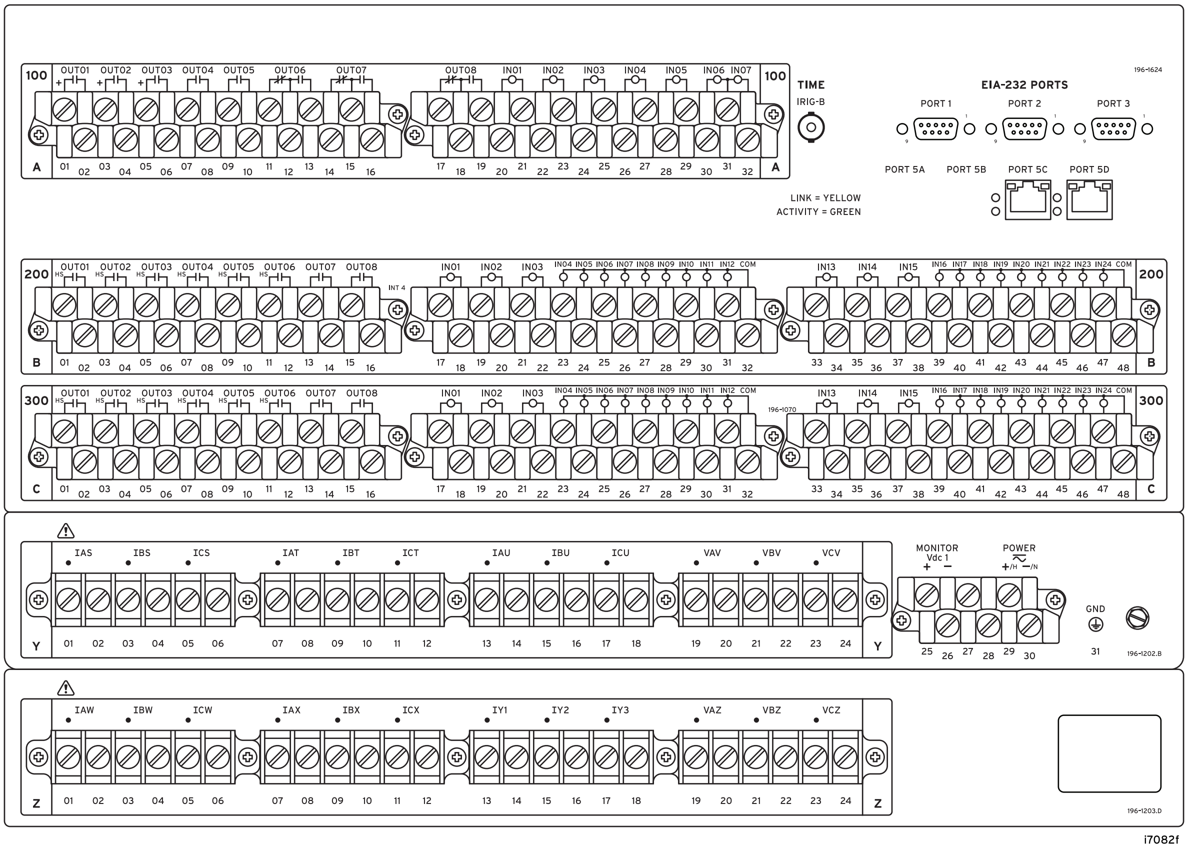


Figure 22 SEL-487E Rear Panel (7U With 2 Expansion I/O Boards)

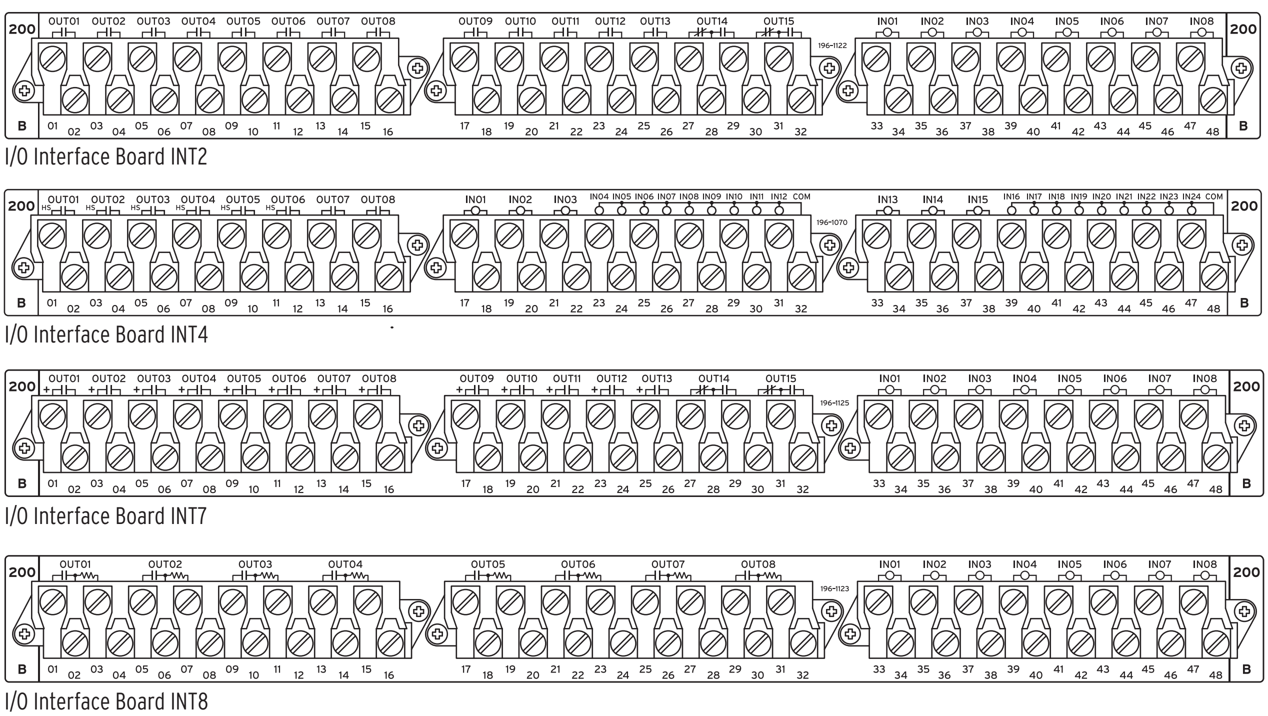
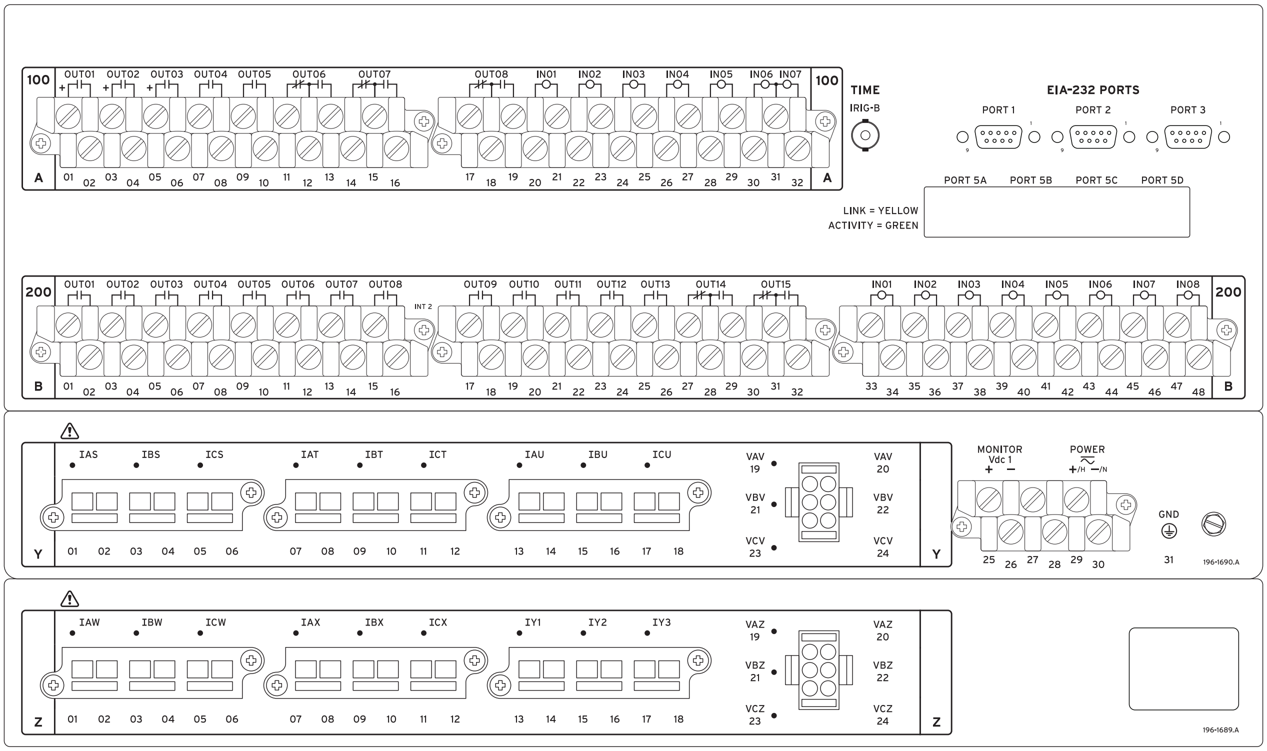
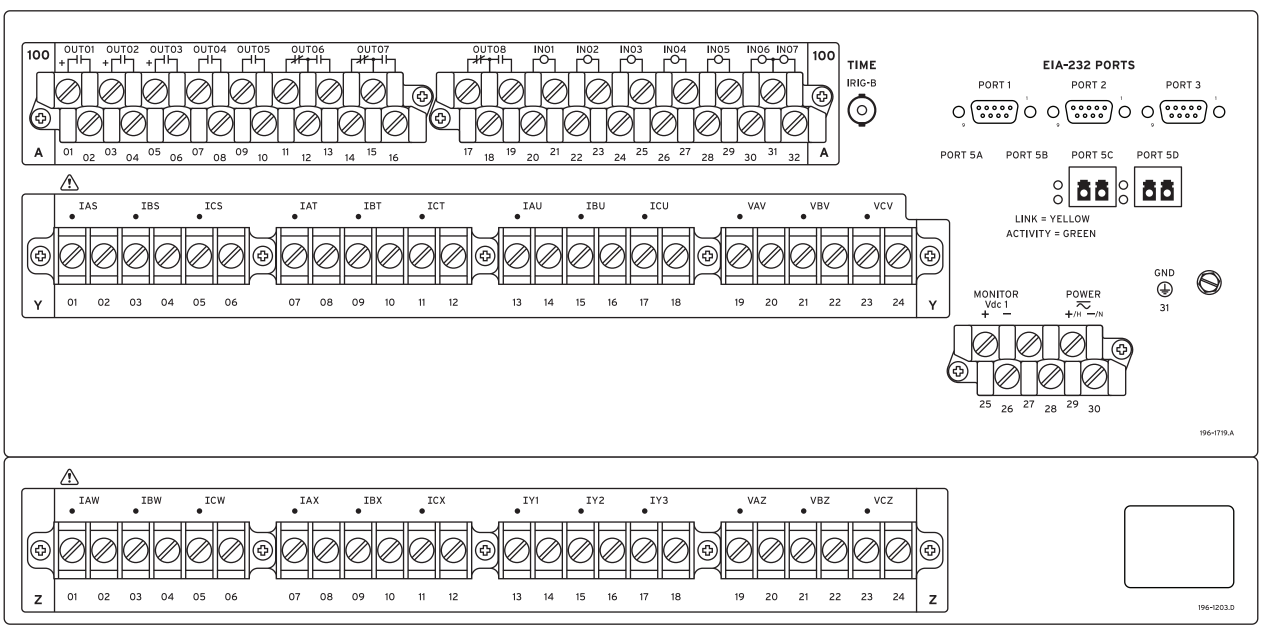


Figure 23 SEL-487E Expansion I/O Board Options



i7081f

Figure 24 Rear Panel Connectorized® (6U)



i7116d

Figure 25 Rear Panel With Fixed Terminal Blocks (5U)

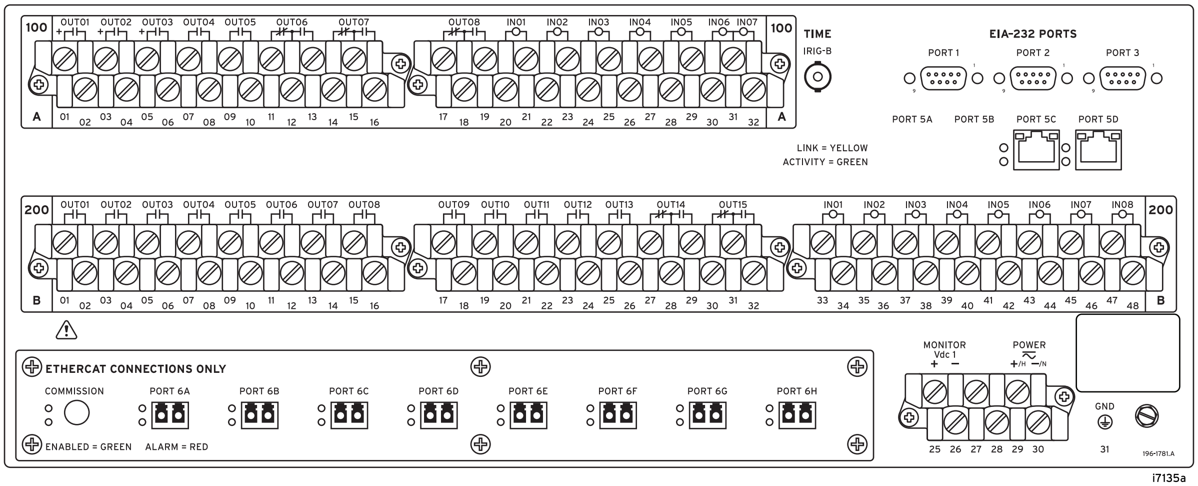
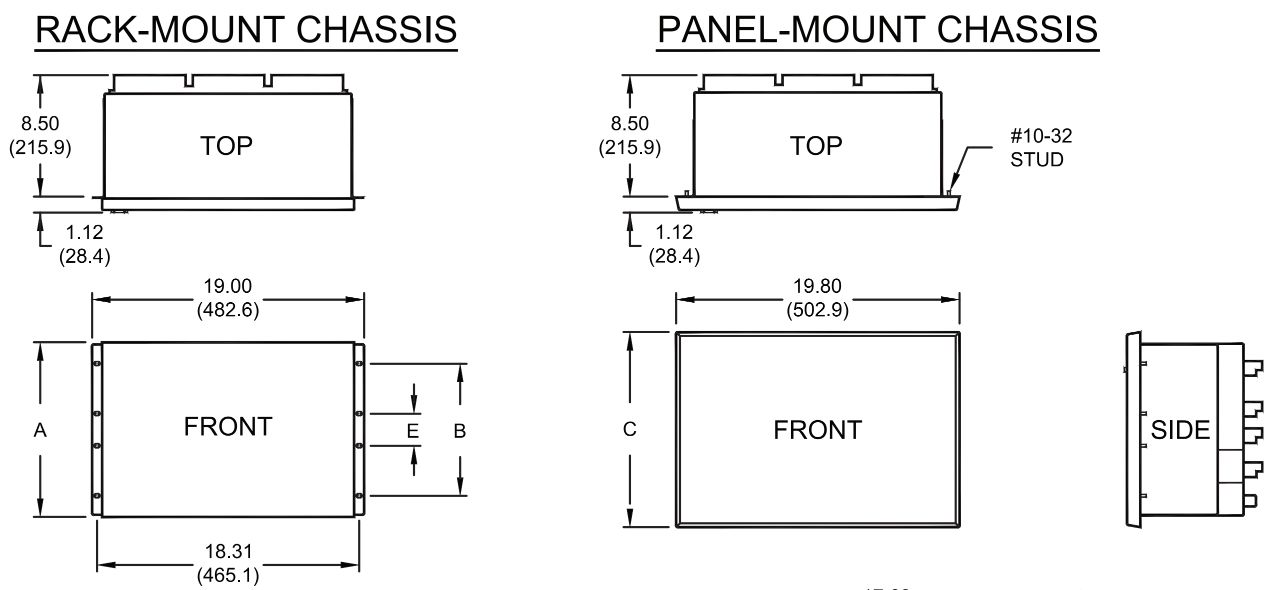


Figure 26 Rear Panel With TiDL Option (4U)

Dimensions



DIMENSION	TiDL (4U)	NO I/O BOARD (5U)	ONE I/O BOARD (6U)	TWO I/O BOARD (7U)
A	6.97 (177.0)	8.72 (221.5)	10.47 (265.9)	12.22 (310.4)
B	4.00 (101.6)	5.75 (146.1)	7.50 (190.5)	9.25 (235.0)
C	8.40 (213.4)	10.15 (257.8)	12.10 (307.3)	13.65 (346.7)
D	6.85 (174.0)	8.6 (218.4)	10.55 (268.0)	12.10 (307.3)
E	N/A	N/A	3.00 (76.2)	2.25 (57.2)

*ADD 0.30 (7.6) FOR CONNECTORIZED RELAYS

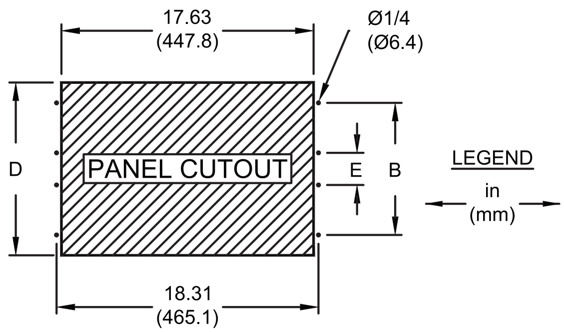


Figure 27 SEL-487E Dimensions for Rack- and Panel-Mount Models

Specifications

Note: If the relay is using a remote data acquisition 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

47 CFR 15B Class A

This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference 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

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

LEA Voltage Inputs

Rated Voltage Range:	0–8 V_{LN}
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. These outputs are polarity-dependent.

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.

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

DC Thresholds (Dropout Thresholds Indicate Level-Sensitive Option)

24 Vdc: Pickup 19.2–30.0 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

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

Current Drawn: <5 mA at nominal voltage
<8 mA for 110 V option

Sampling Rate: 2 kHz

Communications Ports

EIA-232: 1 Front and 3 Rear

Serial Data Speed: 300–57600 bps

Communications Card Slot for Optional Ethernet Card

Ordering Options: 100BASE-FX fiber-optic Ethernet

Mode: Multi

Wavelength (nm): 1300

Source: LED

Connector Type: LC

Min. TX Pwr. (dBm): –19

Max. TX Pwr. (dBm): –14

RX Sens. (dBm): –32

Sys. Gain (dB): 13

Communications Ports for Optional TiDL 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:	50 Ω or >1 kΩ
Dielectric Test Voltage:	0.5 kVac

PTP—Ethernet Port 5A, 5B

Input:	IEEE 1588 PTPv2
Profiles:	Default, C37.238-2011 (Power 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 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

These tests do not apply to optoisolated control inputs rated for 24 V.

Electromagnetic Compatibility (EMC)

Electromagnetic Emissions:	IEC 60255-25:2000

Electromagnetic Compatibility Immunity

Conducted RF Immunity:	IEC 60255-22-6:2001 IEC 61000-4-6:2008 10 Vrms
Electrostatic Discharge:	IEC 60255-22-2:2008 IEC 61000-4-2:2008 Levels 2, 4, 6, 8 kV contact Levels 2, 4, 8, 15 kV air IEEE C37.90.3-2001 Levels 2, 4, 8 kV contact Levels 4, 8, 15 kV air
Fast Transient/Burst Immunity:	IEC 60255-22-4:2008 IEC 61000-4-4:2011 4 kV at 5 kHz
Magnetic Field Immunity:	IEC 61000-4-8:2009 1000 A/m for 3 s 100 A/m for 1 min IEC 61000-4-9:2001 1000 A/m
Power Supply Immunity:	IEC 60255-11:2008 IEC 61000-4-11:2004 IEC 61000-4-29:2000
Digital Radio Telephone RF:	ENV 50204:1995, 10 V/m at 900 MHz and 1.89 GHz
Radiated Radio Frequency:	IEC 60255-22-3:2007 IEC 61000-4-3:2010, 10 V/m IEEE C37.90.2-2004, 35 V/m
Surge Immunity:	IEC 60255-22-5:2008 IEC 61000-4-5:2005 1 kV line-to-line 2 kV line-to-earth
Damped Oscillatory Magnetic Field:	IEC 61000-4-10:2001 Severity Level: 100 A/m
Surge Withstand:	IEC 60255-22-1:2007 2.5 kV peak common mode 1 kV peak differential mode IEEE C37.90.1-2002 2.5 kV oscillatory 4 kV fast transient

Environmental

Cold:	IEC 60068-2-1:2007 16 hours at –40°C
Damp Heat, Cyclic:	IEC 60068-2-30:2005 25°C to 55°C, 6 cycles, 95% humidity
Dry Heat:	IEC 60068-2-2:2007 16 hours at +85°C

Vibration:	IEC 60255-21-1:1988 Class 2, Endurance Class 2, Response IEC 60255-21-2:1988 Class 1, Shock withstand, Bump Class 2, Shock Response IEC 60255-21-3:1993, Class 2
Object Penetration	IEC 60529:2001 + CRGD:2003 Protection Class: IP30

Safety

Dielectric Strength:	IEC 60255-5:2000 IEEE C37.90-2005 2500 Vac on contact inputs, contact outputs, and analog inputs 3100 Vdc on power supply
Impulse:	IEC 60255-5:2000 IEEE C37.90:2005 0.5 J, 5 kV

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

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

Relay Element Pickup Ranges and Accuracies

Differential Elements (General)

Number of Zones:	1 (A, B, and C elements)
Number of Windings:	5
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%
Accuracy:	±5% ±0.02 • I_{NOM}
Slope 2	
Setting Range:	5–100%
Accuracy:	±5% ±0.02 • I_{NOM}

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 • $\sqrt{2}$ • 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

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)

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:	1.75 cycles

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:	5 (1 each for S, T, U, W, X)
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:	5 (1 each for S, T, U, W, X)
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:	5 (1 each for S, T, U, W, X)
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 5.2* 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 *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:	5 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:	15–300 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, 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, 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

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