SEL-487E Transformer Differential Relay

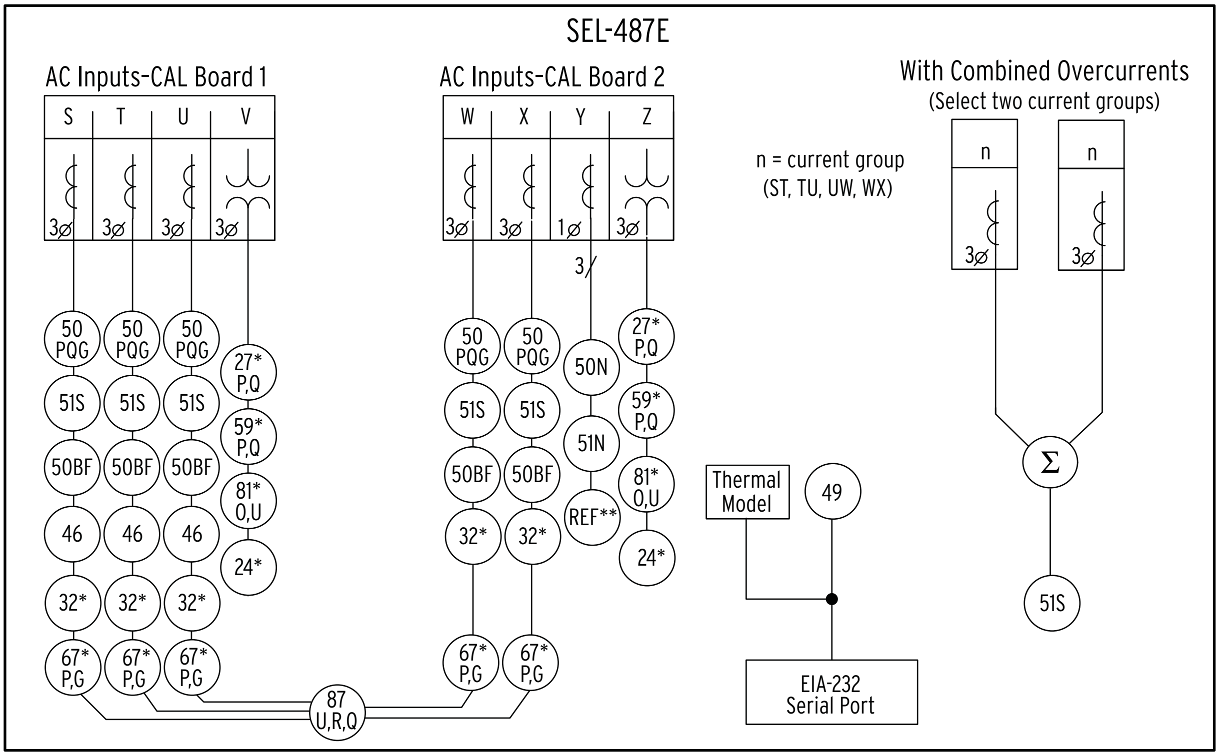
Three-Phase Transformer Protection, Automation, and Control System

Major Features and Benefits

The SEL-487E Transformer Differential Relay provides three-phase differential protection for transformer applications with up to 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 2% 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 eight disconnect switches using the built-in system mimic diagrams that include up to six programmable analog quantities for readouts.

- **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 60 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.
- **Harmonic Blocking and Restraint.** Combined harmonic blocking and restraint features provide maximum security during transformer magnetizing inrush conditions.
- **Turn-to-Turn Winding Fault Protection.** Innovative negative-sequence differential elements provide transformer windings protection from as little as 2% 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.
- **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.
- **Reduced System Coordination Delays.** SEL-487E breaker failure protection with subsidence detection minimizes system coordination delays.
- **Simplified System Integration.** Ethernet communications 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 is provided in either SEL Fast Message or IEEE C37.118 format.
- **Input/Output Scaling.** The SEL-2600A RTD and SEL-2505/SEL-2506 Remote I/O Modules provide scaling of the number of discrete and analog I/O points.
- **Setting and Commissioning Standardization.** ACSELERATOR QuickSet Designer® SEL-5031 and ACSELERATOR QuickSet® SEL-5030 Software standardize and simplify settings and commissioning.
- **Two CT Input Levels.** Selectable 1 Amp or 5 Amp nominal secondary input levels are available for any three-phase winding input.
- **No Need for Auxiliary CTs.** The SEL-487E can accommodate a CT ratio mismatch as great as 25:1.

Functional Overview



* These elements require voltage inputs
** Maximum of 3 independent REF elements (1 A/5 A per phase on Y currents)

Figure 1 Functional Diagram

Table 1 SEL-487E Protection Functions

ANSI Device Number	Description
87U	Unrestrained Differential Element
87R	Restrained Differential Element
87Q	Negative-Sequence Differential Element
50	Instantaneous Overcurrent Element (P = Phase, Q = Negative Sequence, N = Neutral)
51S	Adaptive Time-Overcurrent Element (selectable phase, negative-sequence, or ground operate quantity with programmable pickup and time-delay)
50BF	Breaker Failure Element
46	Current Unbalance
32	Directional Power Element
67	Directional Overcurrent Element
81	Frequency Element (o = over, u = under)
27	Undervoltage Element
59	Overvoltage Element
24	Volt/Hertz Element
49	Thermal Element
G, N, P, Q, R, S, U	(G) Ground (Residual), (N) Neutral, (P) Phase, (Q) Negative Sequence, (R) Restrained, (S) Adaptive (Selectable), (U) Unrestrained

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 2% short-circuit of total winding
- IEEE C37.118 compliant synchrophasor data via serial or Ethernet communication 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
- Breaker failure protection with subsidence detection and retrip
- Up to 12 temperature-measuring elements when used with the SEL-2600 RTD Module
- 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 up to six 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
- Up to two additional expansion I/O boards in a 7U chassis, one additional expansion I/O board in a 6U chassis
- Through-fault accumulation monitoring and alarms uses IEEE through-fault duration curves
- Breaker wear monitoring for up to 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.
- The SEL-487E relay provides comprehensive protection, automation, and control for transformers. The SEL-487E-2 variant is identical to the SEL-487E relay 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 2nd and 4th harmonic quantities provide secure operation during transformer energization, while maintaining sensitivity for internal faults. 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 up to 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.

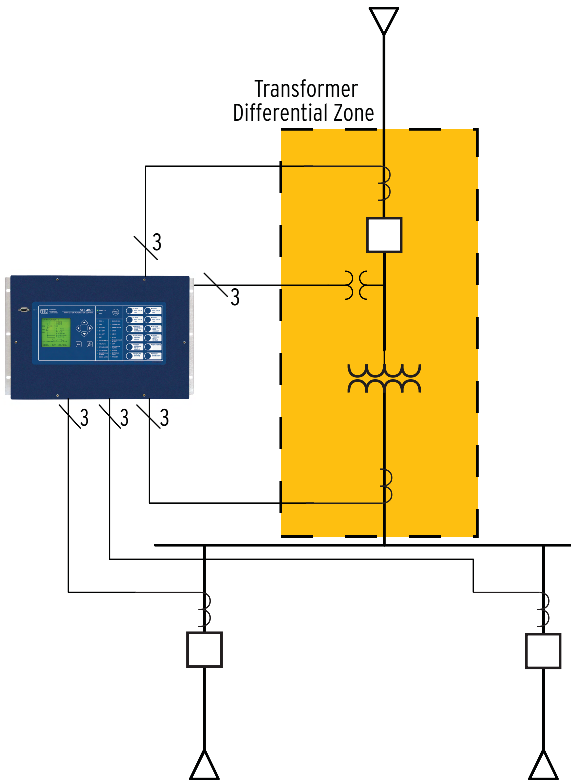


Figure 2 Two-Winding Transformer Application

Figure 3 shows the SEL-487E in a single transformer application that provides protection of three transformer windings (HV, Tertiary, LV) as well as restricted earth fault (REF) protection. REF protection derives zero-sequence current (3I0) from the three-phase current for each winding assigned to the REF protection element and compares this calculated quantity to the measured zero-sequence current on the transformer neutral (3I0).

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 40.1 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.

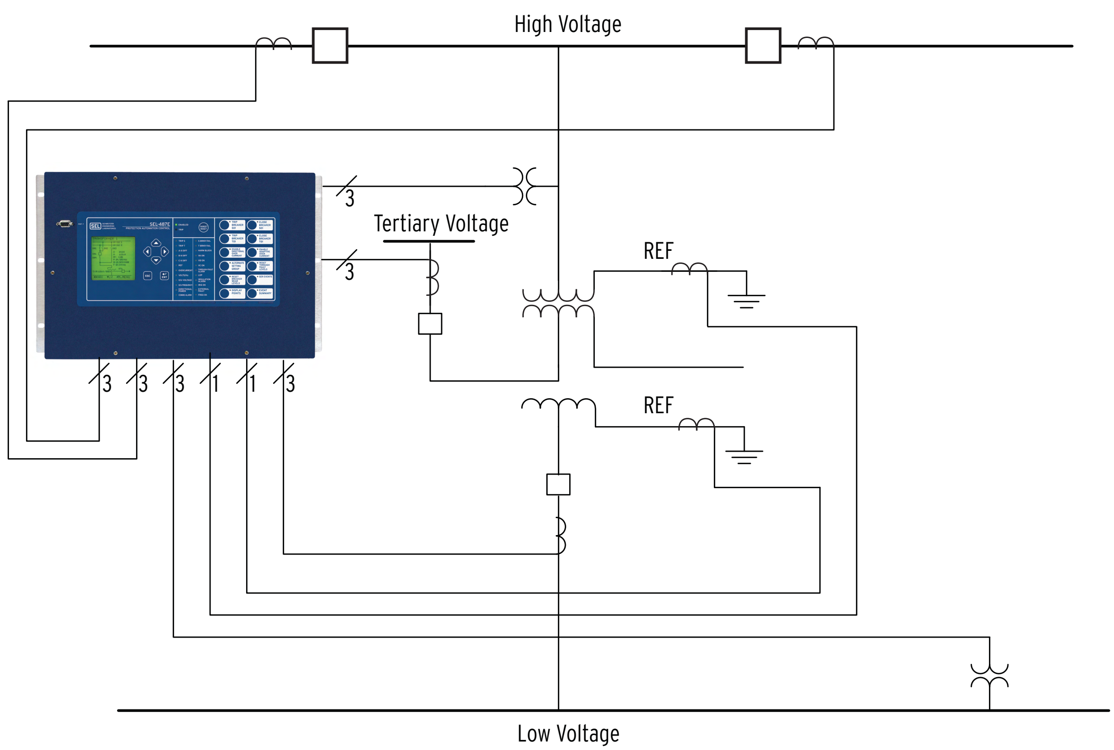


Figure 3 Single Transformer Restricted Earth Fault (REF) Application

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.

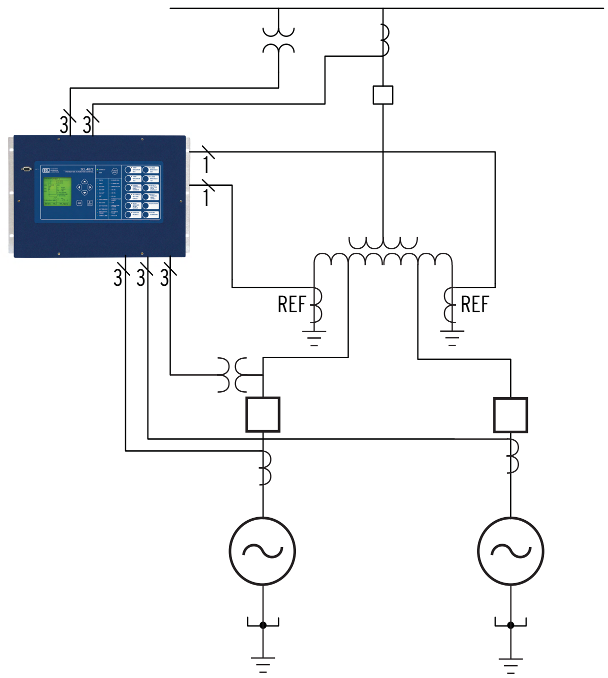


Figure 4 Generator Step-Up Application

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. 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 60 seconds of IEEE C37.118 binary synchrophasor data for all 24 analog channels. A SELOGIC control equation triggers storage of data. Capture data as necessary, and then store this information in SEL-487E non-volatile memory.

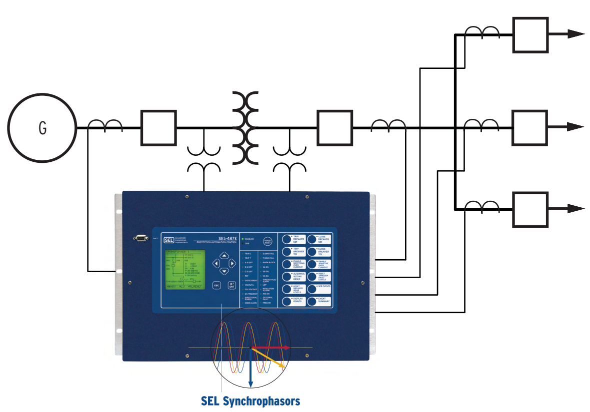


Figure 5 Station-Wide Synchrophasor Application

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 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 (IOPF*n*, where *n* = A, B, C) and restraint (IRTF*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:

IOPFA (IRTFA) = SLP*c* • IRTFA

For operating quantities (IOPFA) 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.

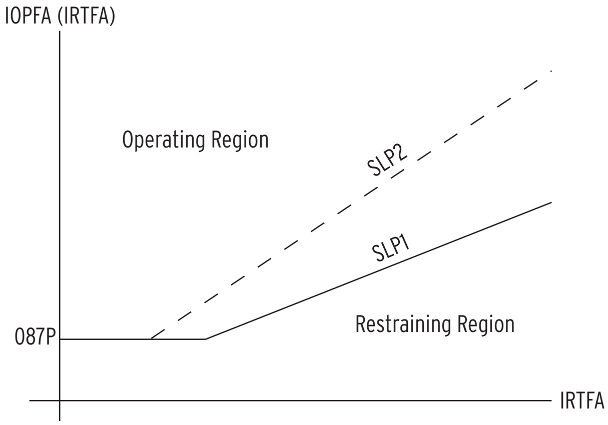


Figure 6 Adaptive Slope Differential Characteristics

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. 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 40.1 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 volts/hertz element in the relay can be assigned to either set of three-phase voltage inputs.

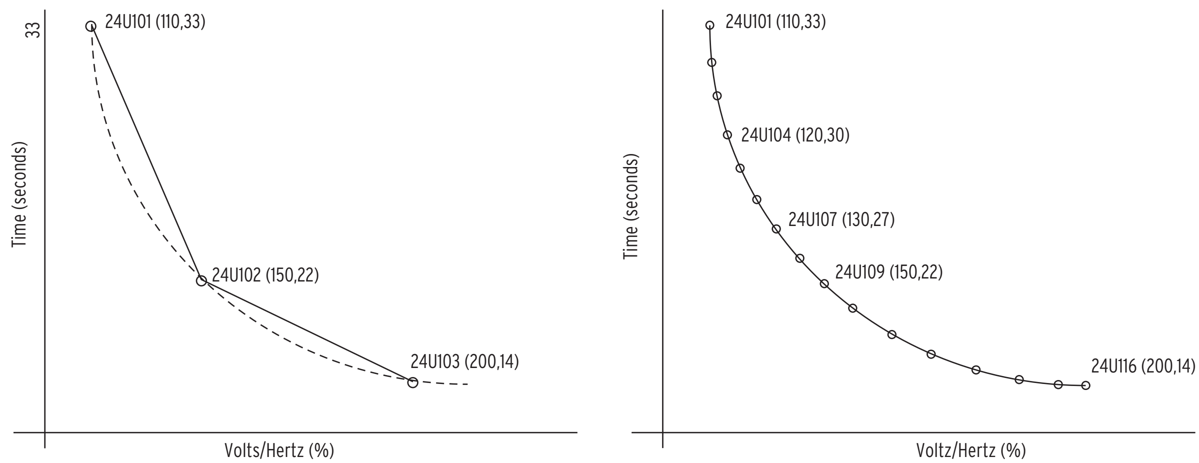


Figure 7 Volts/Hertz Curve Diagrams

Voltage and Frequency Elements

Voltage elements consist of five under- (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 2*.

Table 2 Voltage Element Inputs

Input	Description
Fundamental Voltages (V, Z): $V_{A,B,C}$, $V\phi-\phi$, V_{MAX}, V_{MIN}, $3V_2$, $3V_0$	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.

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 40.1 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). 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 10 adaptive time-overcurrent elements with selectable operate quantity and programmable time-delay and pickup levels. Choose from the 10 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 3 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*n*FM, IB*n*FM, IC*n*FM
- Maximum filtered phase current: IMAX*m*F
- Combined filtered phase currents (any 2 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*n*FM, 3I2*m*FM, 3I0*m*FM
- 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*RMS

where:

m = Relay current terminals S, T, U, W, X
mm = Relay current terminals ST, TU, UW, WX
n = Relay current terminals S, T, U, W, X, Y
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.

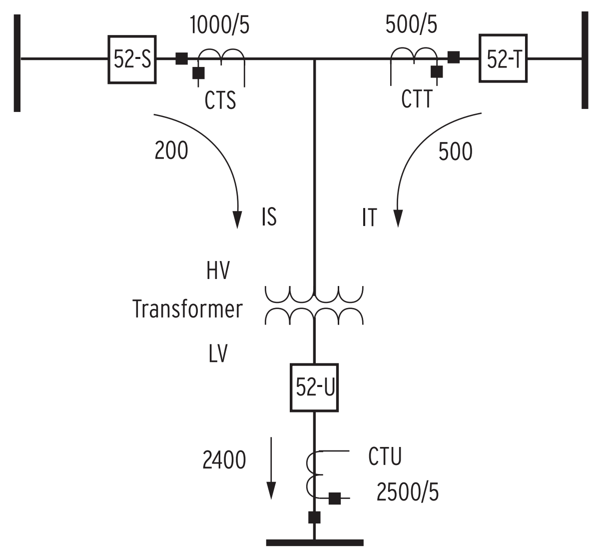


Figure 8 Adaptive Overcurrent Element (51S)

Combined Time-Overcurrent Elements

Four sets of 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. Inverse-time fundamental and rms elements are available for each of the combined currents. These combined elements offer added flexibility when the relay is applied with multiple breakers, such as breaker-and-a-half applications. Different CT ratios are permitted on the two windings that are summed to create the combined current.

Restricted Earth-Fault Protection

Apply the REF protection feature to provide sensitive detection of internal ground faults on grounded wye-connected transformer windings and autotransformers. Use single-phase neutral current inputs for providing neutral CT operating current for up to 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 25:1.

Breaker-Failure Protection

The SEL-487E provides complete breaker-failure protection, including retrip, for up to 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-pole conditions in less than 0.75 cycle as shown in *Figure 9*. This reduces breaker-failure coordination times and minimizes overall system coordination delays.

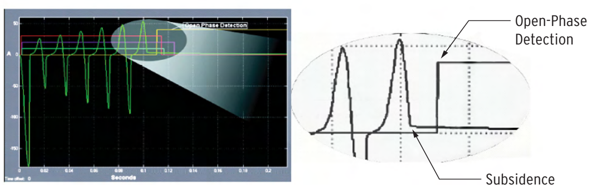


Figure 9 Open-Phase Detection Using Subsidence Logic

Negative-Sequence Differential Element

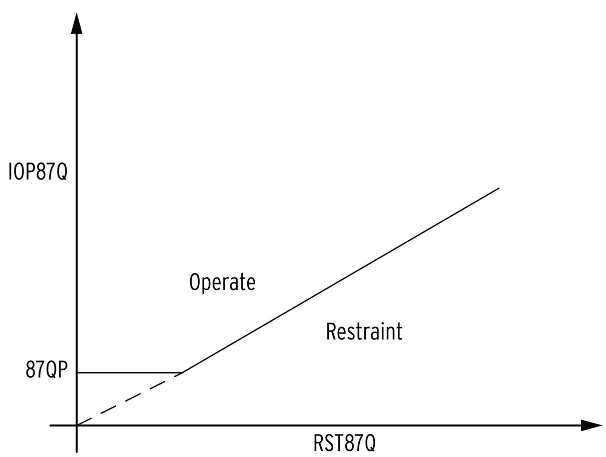


Figure 10 Negative-Sequence Differential Characteristic

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 2% 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. 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.

Power Elements

The SEL-487E provides 10 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.

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

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.

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 Time Keeping

Using high accuracy IRIG-B from a global positioning satellite clock, the SEL-487E can time-tag oscillography to within 10 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 standard accuracy IRIG-B time-code input synchronizes the SEL-487E time to within ±500 µs of the time-source input. A convenient source for this time code is an SEL-2032, SEL-2030, or SEL-2020 Communications Processor.

SELOGIC Control Equations With Expanded Capabilities and Aliases

Expanded SELOGIC control equations (*Table 4*) put relay logic in the hands of the protection engineer. Use 250 lines of free-form protection logic, operating at protection processing speed, and 1000 lines of free-form 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 4 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 up to 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 as many as six 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 20 predefined bus and seven 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 has the ability to 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 real-time along with the breaker status and disconnect switch position to give instant status and complete control of a bay. The diagrams below demonstrate some of the preconfigured bay arrangements available in the SEL-487E. The operator can see all valuable information on a bay before making a critical control decision. Programmable interlocks help prevent operators from incorrectly opening or closing switches or breakers.

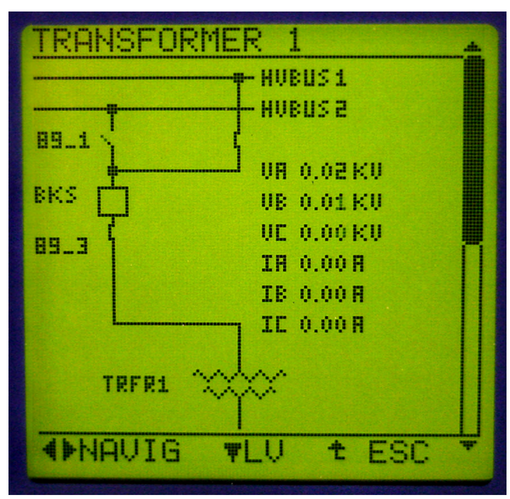


Figure 11 Front-Panel One-Line Transformer Diagram

The SEL-487E will provide control of up to five breakers and eight 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 12* 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.

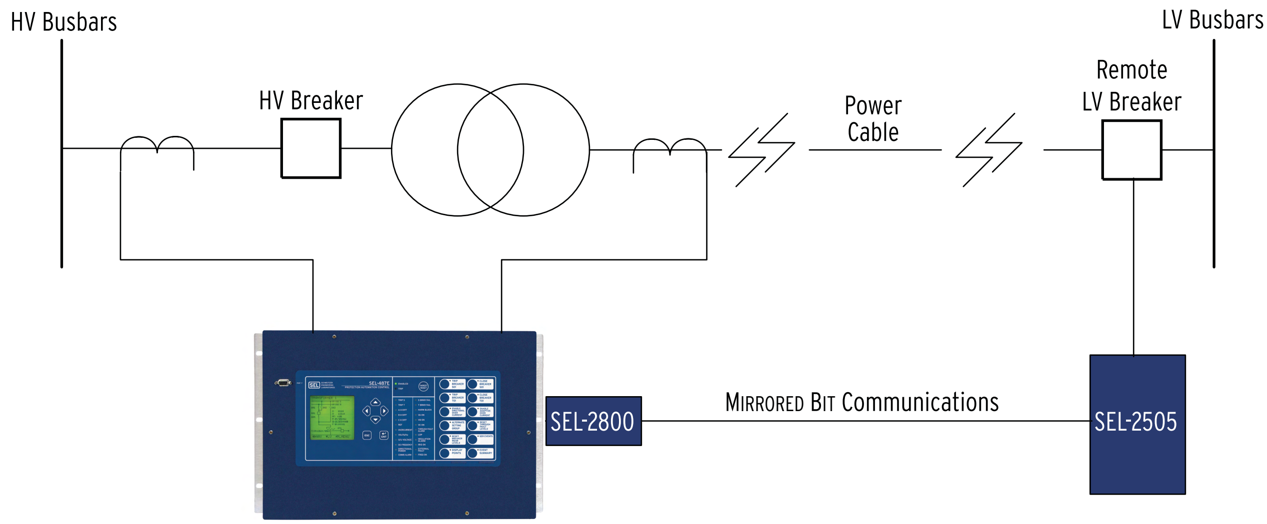


Figure 12 SEL-487E Using MIRRORED BITS in a Transfer Trip Application

Serial Communications Features

The SEL-487E offers the following serial communication 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 communications with the SEL-2600A 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 Communications

The SEL-487E has the capability to operate as a client for unsolicited SEL Fast Message communications between the relay and the SEL-2600A RTD Module. Any of the four EIA-232 serial ports on the SEL-487E can be set for direct communications with the SEL-2600A. Use the SEL-2600A to provide the SEL-487E with up to 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 through RA256) are specific, pre-allocated memory addresses. These memory addresses are available to accept and store values from remote devices such as an SEL-2032, SEL-2030, or SEL-2020 Communications Processor. 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 Communications

The SEL-487E provides Ethernet communication 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

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 communications. 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 connection supports unicast for serving data to a single client. Each data stream can support up to 60 frames per second.

IEC 61850 Ethernet Communications

IEC 61850 Ethernet-based communications provide 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 24 incoming GOOSE messages. The incoming GOOSE messages can be used to control up to 128 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 is 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 pre-defined logical node objects. As many as six 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.

Use ACSELERATOR Architect® SEL-5032 Software 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 ACSELERATOR Architect to describe the data that will be provided by the IEC 61850 logical node within each relay.

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), Vϕϕ, 3V0, V1, 3V2	Voltages measured at the fundamental frequency of the power system.
Compensated fundamental voltages: $V_{A,B,C}$ (V, Z), Vϕϕ, 3V0, V1, 3V2	Fundamental voltages compensated by VCOMP setting to account for delta/wye-transformer and PT configurations.
RMS voltages: $V_{A,B,C}$ (V, Z), Vϕϕ	RMS voltages include fundamental plus all measurable harmonics.
Compensated fundamental currents: IA, B, C (S, T, U, W, X, Y), Iϕ-ϕ, 3I0, I1, 3I2 IA, B, C (ST, TU, UW, WX), Iϕ-ϕ, 3I0, I1, 3I2	Currents measured at the fundamental frequency of the power system, with transformer phase-compensation applied.
RMS currents: $I_{A,B,C}$ (S, T, U, W, X, Y), IMAX (S, T, U, W, X) $I_{A,B,C}$ (ST, TU, UW, WX), IMAX (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 four thermal sensor inputs: a single ambient temperature transducer and one transducer for top-oil temperature from each of three single-phase transformers. Temperature data are obtained via a relay serial port. These data could come from an SEL-2600A RTD Module (as shown in *Figure 13*) or from an SEL-2032 Communications Processor, which receives the temperature data from either an SEL-2600A or PLC. While the SEL-487E can receive temperature data at any rate, the thermal element uses the temperature data once per minute.

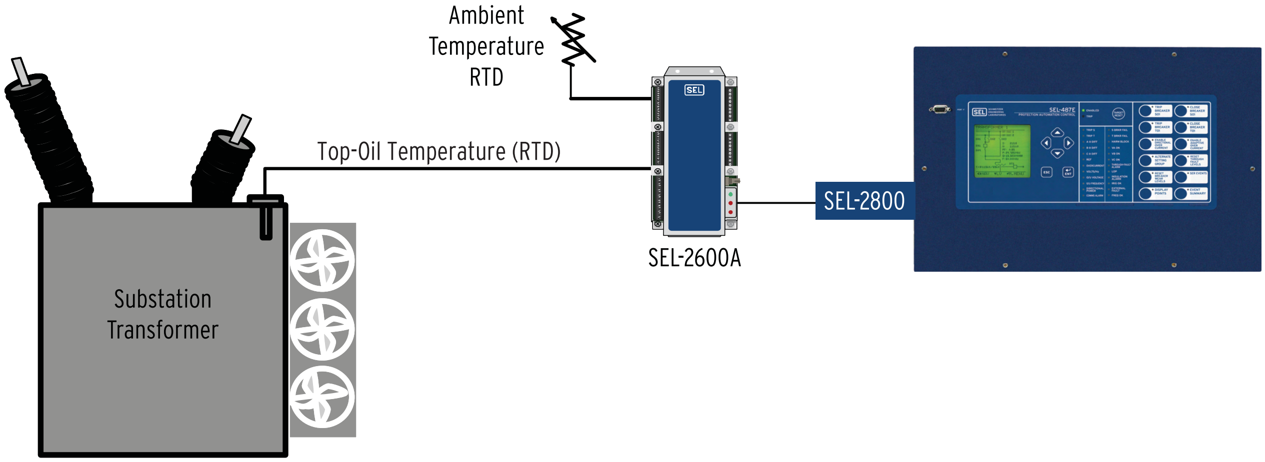


Figure 13 Typical One-Line Diagram for Collecting Transformer Temperature Data

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 due to 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 up to 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.

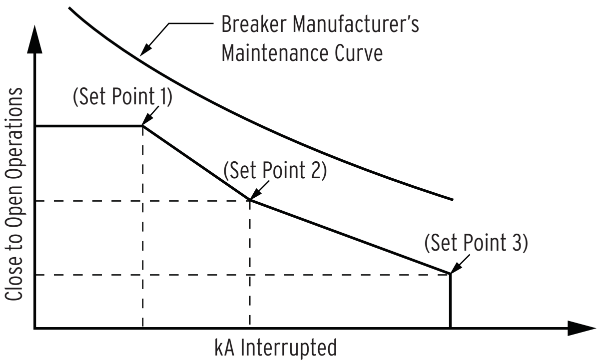


Figure 14 Breaker Contact Wear Curve and Settings

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 with the SEL-2030 Communications Processor and used to trigger messages, telephone calls, or other actions. The measured dc voltage is reported in the METER display via serial port communications, on the LCD, and in the event report. Use the event report data to see an oscillographic display of the battery voltage 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 up to 8 kHz sampling rates 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 up to 5 seconds of 8 kHz event data. 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 the ACSELERATOR® Analytic Assistant SEL-5601 Software. With the ACSELERATOR Analytic Assistant you can display events within the same time stamp range from as many as three different relays in one window 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 to utilize 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.

Synchrophasor Data Recording

Trigger 60 second synchrophasor data recording using a SELOGIC equation. The SEL-487E stores one 60 second synchrophasor data recording in non-volatile memory. 24 channels of synchrophasor data are available and stored in IEEE C37.118 binary format in the relay at a recording rate of 60 messages per second. Use this capability to record system transients for comparison to state machine estimations.

Additional Features

ACSELERATOR QuickSet SEL-5030 Software

Use ACSELERATOR QuickSet to develop settings offline. The system automatically checks interrelated settings and highlights out-of-range settings. Settings created offline can be transferred by using a PC communications link with the SEL-487E. The relay converts event reports to oscillograms with time-coordinated element assertion and phasor diagrams. The ACSELERATOR QuickSet interface supports Windows® 95, 98, 2000, XP, ME, and Windows NT® operating systems.

ACSELERATOR QuickSet Designer SEL-5031 Software

Use ACSELERATOR QuickSet Designer 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, communications, 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. Each display remains for five seconds 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.

Control Inputs and Outputs

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

- 3 high-current interrupting 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 6U or 7U chassis heights. The 7U chassis supports up to two expansion I/O boards. The 6U chassis supports one expansion I/O board. 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.

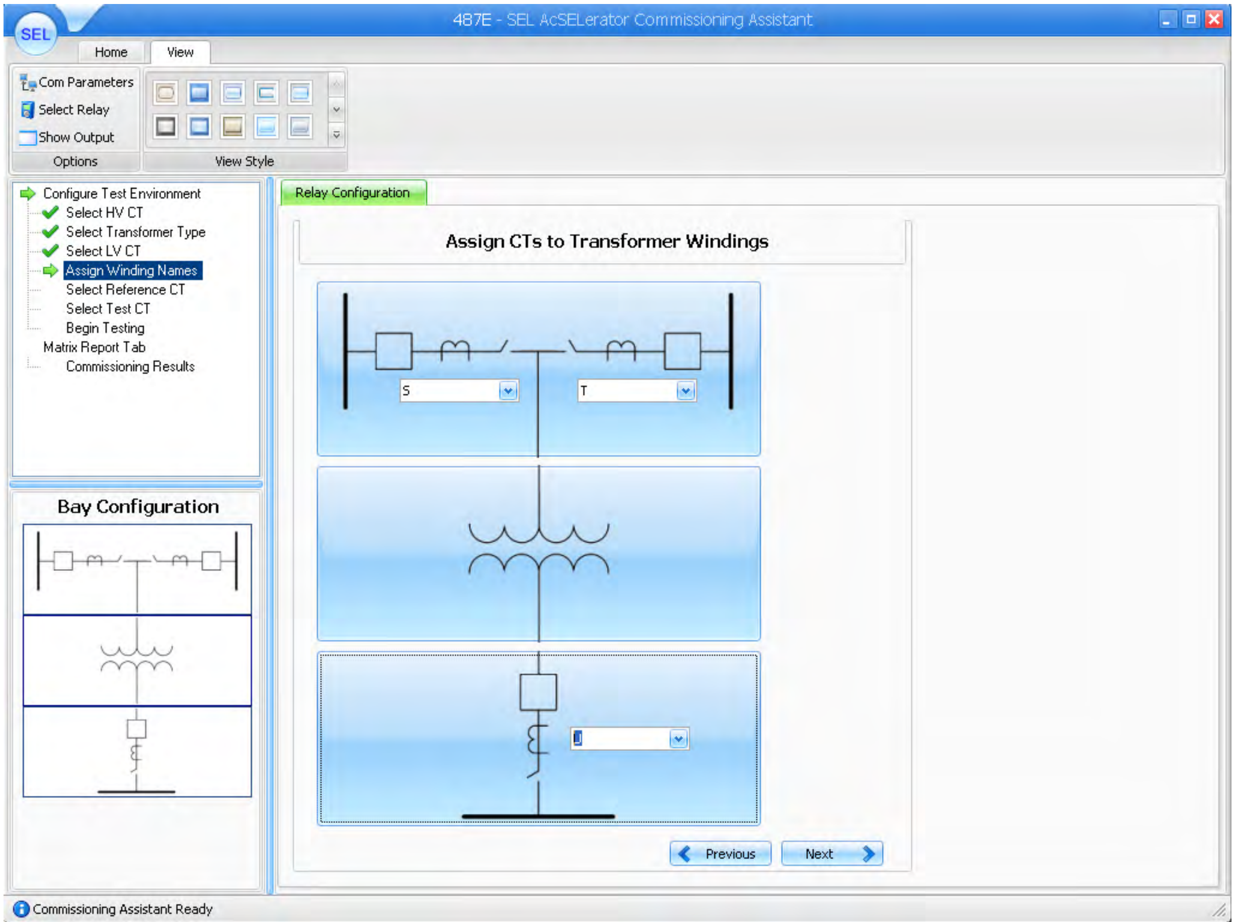


Figure 15 Commissioning Assistant Screen

Guideform Specification

The microprocessor-based relay shall provide protection, monitoring, control, and automation. Relay self-checking functions shall be included. Specific requirements are as follows:

- **Transformer Differential Protection.** The relay shall include a single, three phase low-impedance current differential element with adaptive restraint/operate slope characteristics.
- **Negative-Sequence Differential Protection.** The relay shall include negative-sequence differential protection for turn-to-turn fault detection within the transformer. The negative-sequence differential element shall be capable of detecting turn-to-turn faults as low as 2% of the total winding.
- **Synchrophasors.** The relay shall provide high accuracy, synchrophasor data that is compliant with the IEEE C37.118 synchrophasor data standard. The IEEE C37.118 synchrophasor data shall be supported on serial and Ethernet ports of the relay.
- **Synchrophasor Data Recording.** The relay shall provide 60 second synchrophasor data recording stored in non-volatile memory using IEEE C37.118 binary data format.
- **Harmonic Elements.** The relay shall incorporate 2nd, 4th, and 5th harmonic blocking. In addition, 2nd and 4th harmonic restraint shall be provided. These restraint and blocking elements may be used independently, or in combination to prevent restrained differential element operation during inrush or overexcitation conditions. An independent fifth-harmonic element shall be included to warn of transformer overexcitation conditions.
- **Unrestrained Differential Protection.** The relay shall include unrestrained differential protection to provide rapid tripping for internal faults.
- **External Faults.** The relay shall detect an external fault and enter into a high-security mode.
- **Directional Element.** The relay shall include Best Choice Ground Directional Element logic voltage polarized directional elements for phase and ground currents.
- **CT Phase Angle Compensation.** The relay shall incorporate full “round-the-clock” current compensation, in 30-degree increments, to accommodate virtually any type of transformer and CT winding connection.
- **Combined Currents.** The relay shall incorporate elements to provide overcurrent protection based on summation of currents from combinations of the ST, TU, UW, and WX transformer winding inputs to the relay.
- **Restricted Earth Fault Protection.** The relay shall provide three separate restricted earth fault (REF) protection elements for the detection of ground faults in wye-connected windings.
- **Analog Inputs.** The relay shall accept 24 ac inputs configured as follows:
  - 15 transformer winding current inputs
  - 3 REF current inputs
  - 6 voltage inputs
- **Current Transformer Inputs.** The relay shall accept CTs from different classes and a ratio mismatch of 25:1. Measuring quantities shall be on a phase-segregated basis and not from summation CTs.
- **Minimum CT Requirement.** The relay requires primary CTs that shall reproduce the primary current without saturation for at least 2 ms after external fault inception.
- **Breaker Failure Protection.** The relay shall include internal breaker failure protection with retrip functions for each of the terminals, and be selectable to also accept external breaker failure protection.
- **Overcurrent Protection.** The relay shall include phase, negative, and zero-sequence overcurrent for both instantaneous and time-overcurrent elements. Torque control capability shall be provided for the inverse time overcurrent elements. Adaptive time-overcurrent elements shall be provided that allow operate quantity selection and programmable time-delay and pickup settings.
- **Current Unbalance.** The relay shall provide current unbalance elements for detecting phase current unbalance as compared to the average phase current.
- **Voltage Elements.** The relay shall include three-phase over- and undervoltage elements as well as negative- and zero-sequence overvoltage elements.
- **Volts/Hertz Elements.** The relay shall provide a single V/Hz element with two separate characteristic curves for protection during loaded and unloaded transformer operation.
- **Frequency Elements.** The relay shall include two levels of over- and underfrequency settings for each set of three-phase voltage inputs (six elements total). The frequency elements shall maintain pickup accuracy from 40.1 to 70.0 Hz.
- **Frequency Tracking.** The relay shall provide frequency tracking from 40.1 Hz to 65.0 Hz when voltage inputs are provided to the relay.
- **Auxiliary Relays.** The relay shall not need auxiliary relays. All configuration and logic shall be realized in the relay software.

- **Event Reporting.** The relay shall store at 5 seconds of event data recorded at 8000 samples per cycle in nonvolatile memory. Event reports at 8 kHz (COMTRADE only), 8 samples per cycle, and 4 samples per cycle shall be provided by the relay.
- **Sequential Events Recorder.** The relay shall include an SER (Sequential Events Recorder) report that stores the latest 1000 entries of at least 250 monitored points.
- **Substation Battery Monitor.** The relay shall measure and record the substation battery voltage and provide ground and excess ripple detection. High- and low-voltage level settings shall be provided for alarm and control purposes.
- **Transformer Thermal Monitor.** The relay shall incorporate a transformer thermal monitor based on IEEE C57.91-1995. The model shall include capability for entering known transformer thermal constants as well as default constants. Three loss-of-insulation-life alarms shall be provided, including loss-of-life per day, total loss-of-life, and insulation aging factor. Up to four temperature inputs shall be accommodated by the relay.
- **Through-Fault Event Monitor.** The relay shall provide for the capability of reporting fault current level, duration, and date/time for overcurrent events through the differential protection zone. Through-fault monitoring shall provide accumulated through-fault levels, number of through-faults and the total consumed through-fault capacity of the transformer (based on the *IEEE Guide for Liquid-Immersed Transformer Through-Fault-Current Duration, C57.109-1993*).
- **Expandable Remote I/O.** The relay shall send and receive RTD or analog and binary data directly from the SEL-2600A RTD Module or the SEL-2505/SEL-2506 Remote I/O Module. Any EIA-232 port may be configured for direct communications with either device.
- **Automation.** The relay shall include 32 local control switches, 32 remote control switches, 32 latching switches, and programmable display messages in conjunction with a local display panel in the relay. The relay shall be capable of displaying custom messages.
- **Relay Logic.** The relay shall include programmable logic functions for a wide range of user-configurable protection, monitoring, and control schemes. Logic shall have the ability to use relay elements, math functions, comparison functions, and Boolean logic functions.
- **Terminal Communication.** The relay shall allow communication from any ASCII terminal without proprietary software.
- **IRIG-B.** The relay shall include an interface port for a demodulated IRIG-B time-synchronization input signal.
- **IEC 61850 Communications.** The relay shall be capable of providing communications compliant to the IEC 61850 protocol standard.
- **Environment**. The relay shall be suitable for continuous operation over a temperature range of –40° to +85°C.
- **Reliability**. The vendor shall supply the actual measured Mean-Time Between Failures (MTBF) for the device upon request.
- **Service**. The device shall include no-charge technical support for the life of the product.
- **Manufacturer**. The device shall be manufactured in the United States.
- **Conformal Coating**. The device shall have optional conformal coating to protect the circuit boards from harsh environments.
- **Warranty Return**. The vendor shall support a 72-hour turn-around on all warranty repairs.
- **Warranty**. The device shall include a ten-year, no-questions-asked warranty for all material and workmanship defects. In addition, the warranty shall cover accidental customer-induced damage.

Front- and Rear-Panel Diagrams

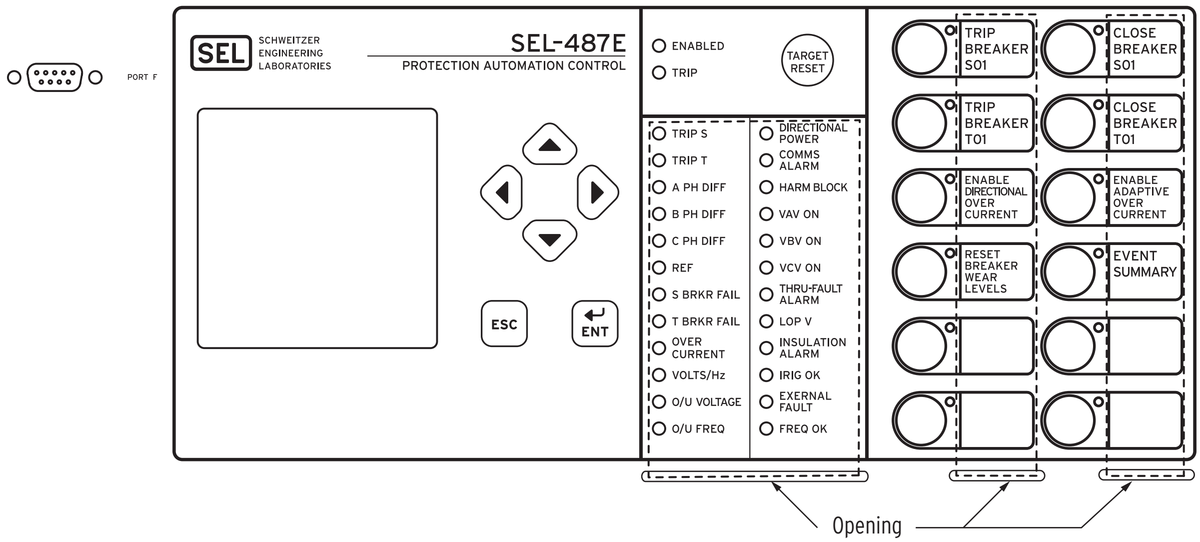


Figure 16 SEL-487E Front Panel

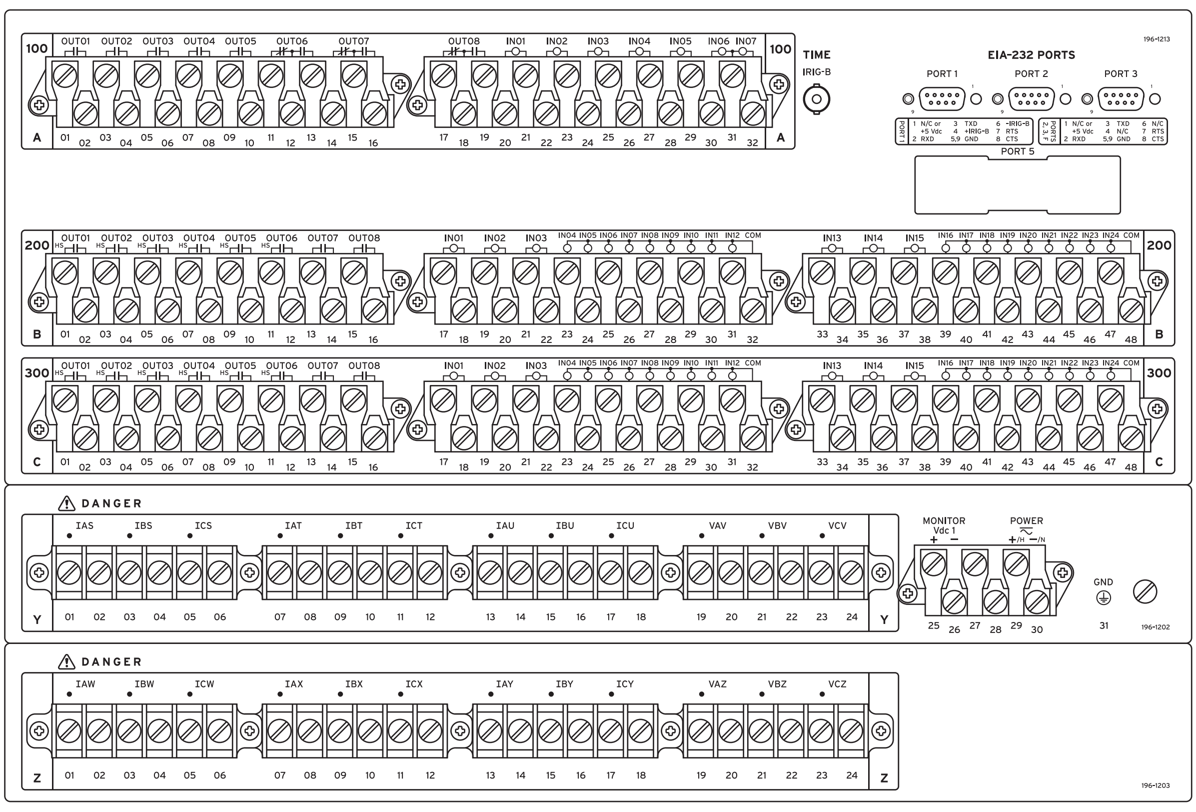
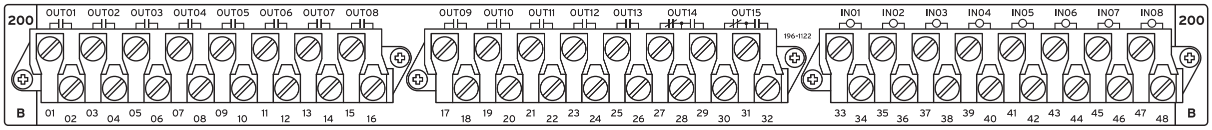
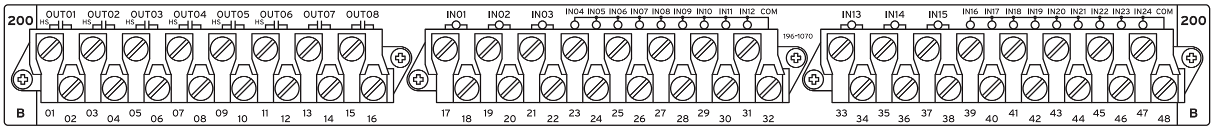


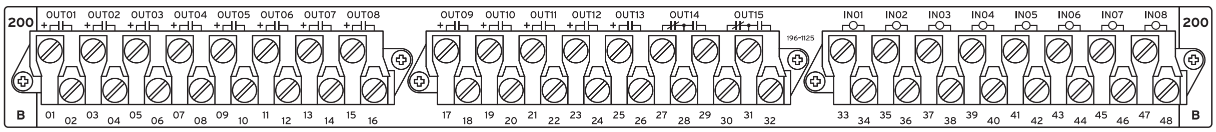
Figure 17 SEL-487E Rear Panel (7U With 2 Expansion I/O Boards)



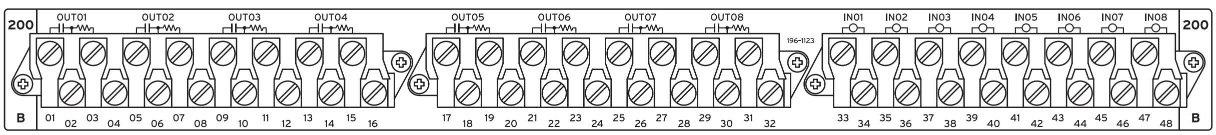
I/O Interface Board INT2



I/O Interface Board INT4



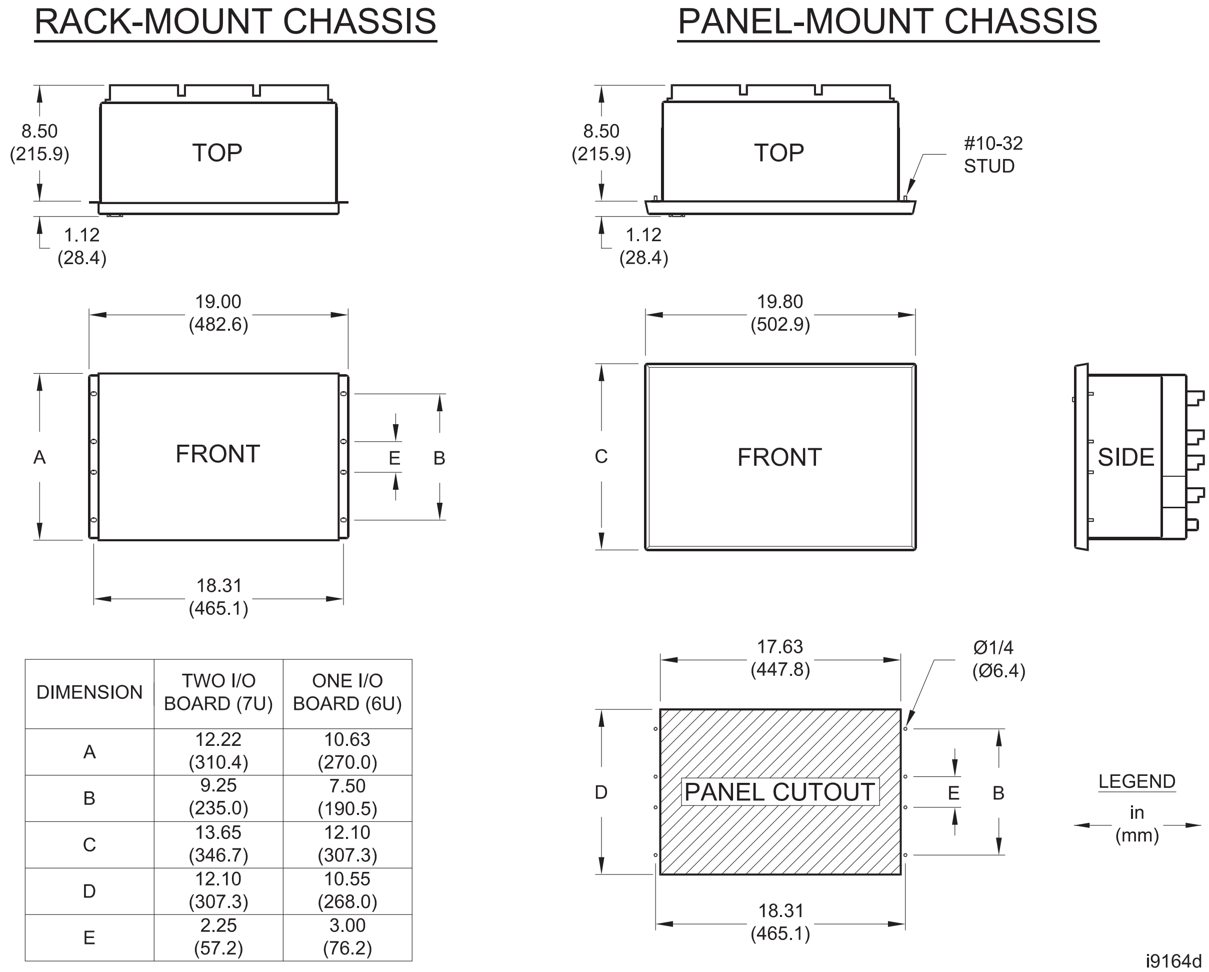
I/O Interface Board INT7



I/O Interface Board INT8

Figure 18 SEL-487E Expansion I/O Board Options

Dimensions



DIMENSION	TWO I/O BOARD (7U)	ONE I/O BOARD (6U)
A	12.22 (310.4)	10.63 (270.0)
B	9.25 (235.0)	7.50 (190.5)
C	13.65 (346.7)	12.10 (307.3)
D	12.10 (307.3)	10.55 (268.0)
E	2.25 (57.2)	3.00 (76.2)

Figure 19 SEL-487E Dimensions for Rack- and Panel-Mount Models

Specifications

Important: Do not use the following specification information to order an SEL-487E. Refer to the actual ordering information sheets.

General

AC Current Inputs (Secondary Circuits)

Note: Current transformers are Measurement Category II.

Continuous Thermal Rating

5 A nominal:	15 A
1 A nominal:	3 A

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 2.51 VA at 15 A
1 A nominal:	≤0.1 VA at 1 A 1.31 VA at 3 A

Minimum A/D Current Limit (peak)

5 A nominal:	247.5 A
1 A nominal:	49.5 A
Sampling Rate:	Analog input signals shall be sampled at a rate of 8 kHz.
Rated Voltage (U_e):	240 Vac
Rated Insulation Voltage (U_i):	300 Vac
Sampling Rate Analog inputs:	8 kHz
Rotation:	ABC, ACB

AC Voltage Inputs

300 V_{L-N} continuous (connect any voltage up to 300 Vac)

600 Vac for 10 seconds

Burden:	<0.5 VA at 67 V
Sampling Rate Analog inputs:	8 kHz
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 Hz = 40 Hz Above 65.0 Hz = 65 Hz
Maximum Slew Rate:	15 Hz/s

Power Supply

125/250 Vdc or 120/240 Vac

Rated Supply Voltage:	120/240 Vac 125/250 Vdc
Absolute Voltage Range:	85–300 Vdc 85–264 Vac
Rated Frequency:	50/60 Hz ± 5 Hz
Range:	30–120 Hz
Vdc Input Ripple:	15% per IEC 60255-11:2008
Interruption:	250 ms @ 250 Vdc per IEC 60255-11:2008
Burden:	<35 W

48/125 Vdc or 120 Vac

Rated Supply Voltage:	120 Vac 48/125 Vdc
Absolute Voltage Range:	38–140 Vdc 85–140 Vac
Rated Frequency:	50/60 Hz ± 5 Hz
Range:	30–120 Hz
Vdc Input Ripple:	15% per IEC 60255-11:2008
Interruption:	160 ms @ 125 Vdc per IEC 60255-11:2008
Burden:	<35 W

24/48 Vdc

Rated Supply Voltage:	24/48 Vdc
Absolute Voltage Range:	18–60 Vdc
Vdc Input Ripple:	15% per IEC60255-11: 2008
Interruption:	100 ms at 48 Vdc per IEC 60255-11: 2008
Burden:	<25 W

Operating Temperature

–40° to +85°C (–40° to +185°F)

Note: LCD contrast impaired for temperatures below –20° and above +70°C. Stated temperature ranges not applicable to UL applications.

Control Outputs

Standard

Rated Insulation Voltage (U_i):	300 Vac 470 Vdc
Dielectric Test Voltage:	2500 Vac
Rated Impulse Voltage (U_{imp}):	5000 V
Continuous Carry:	6 A at 70°C 4 A at 85°C
Make:	30 A at 250 Vdc per IEEE C37.90
Thermal:	50 A for 1 s
Contact Protection:	360 Vdc, 40 J MOV protection across open contacts

Operating Time
(coil energization to contact closure, resistive load)

Pickup time (resistive load): ≤6 ms maximum

Dropout time (resistive load): ≤6 ms maximum

Break Capacity (10000 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 = 40 ms

Cyclic Capacity (2.5 cycles/second) 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 = 40 ms

Mechanical Durability: 10,000 no-load operations

Minimum Current Rating: 10 mA

Update Rate: 1/8 cycle

High-Current Contact Output Ratings

Rated Insulation Voltage (U_i): 300 Vac
470 Vdc

Rated Carry: 6 Amps continuous carry at 70°C
4 Amps continuous carry at 85°C

Note: dc control signals only.

Rated Make: 30 A at 250 Vdc per IEEE C37.90

One Second Thermal Rating: 50 A

Contact Protection: 330 Vdc, 40J, MOV protection across open contacts

Operating Time
(coil energization to contact closure, resistive load)

Pickup time (resistive load): ≤6 ms maximum

Dropout time (resistive load): ≤8 ms maximum

Inductive Breaking Capacity (10,000 operations):

24 Vdc	10 A	L/R = 40 ms
48 Vdc	10 A	L/R = 40 ms
125 Vdc	10 A	L/R = 40 ms
250 Vdc	10 A	L/R = 20 ms

Cyclic Capacity (4 cycles in 1 second, followed by 2 minutes idle for thermal dissipation):

24 Vdc	10 A	L/R = 40 ms
48 Vdc	10 A	L/R = 40 ms
125 Vdc	10 A	L/R = 40 ms
250 Vdc	10 A	L/R = 20 ms

Mechanical Durability: 10,000 no-load operations

High-Speed, High-Current Interrupting Contact Output Ratings

Rated Insulation Voltage (U_i): 300 Vac
470 Vdc

Rated Carry: 6 Amps continuous carry at 70°C
4 Amps continuous carry at 85°C

Rated Make: 30 A at 250 Vdc per IEEE C37.90

One Second Thermal Rating: 50 A

Operating Time
(coil energization to contact closure, resistive load)

Pickup time (resistive load): ≤10 µs maximum

Dropout time (resistive load): ≤8 ms maximum

Inductive Breaking Capacity (10,000 operations):

24 Vdc	10 A	L/R = 40 ms
48 Vdc	10 A	L/R = 40 ms
125 Vdc	10 A	L/R = 40 ms
250 Vdc	10 A	L/R = 20 ms

Cyclic Capacity (4 cycles in 1 second, followed by 2 minutes idle for thermal dissipation):

24 Vdc	10 A	L/R = 40 ms
48 Vdc	10 A	L/R = 40 ms
125 Vdc	10 A	L/R = 40 ms
250 Vdc	10 A	L/R = 20 ms

Update Rate: 1/8 cycle

Optoisolated Digital Inputs

General

Sampling Rate: 2 kHz

Rated Insulation Voltage (U_i): 300 Vac

Dielectric Test Voltage: 2500 Vac or 3100 Vdc

Rated Impulse Voltage (U_{imp}): 5000 V

Main Board: 5 independent, 2 common, level-sensitive optoisolated

INT2: 8 independent, level-sensitive optoisolated

INT4: 18 common, 6 independent, level-sensitive optoisolated

INT7: 8 independent, level-sensitive optoisolated

INT8: 8 independent, level-sensitive optoisolated

DC Digital Input Ratings

Voltage Options: 48, 110, 125, 220, 250 V standard

DC Thresholds

48 Vdc: Pickup 38.4–60.0 Vdc;
Dropout below 28.8 Vdc

110 Vdc: Pickup 88.0–132.0 Vdc;
Dropout below 66.0 Vdc

125 Vdc: Pickup 105–150 Vdc;
Dropout below 75 Vdc

220 Vdc: Pickup 176–264 Vdc;
Dropout below132 Vdc

250 Vdc: Pickup 200–300 Vdc;
Dropout below 150 Vdc

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

AC Digital Input Ratings

Rated Frequency: 50±5 Hz, 60±5 Hz

48 Vac: Pickup 32.8–60.0 Vac;
Dropout below 20.3 Vac

110 Vac: Pickup 75.1–132.0 Vac;
Dropout below 46.6 Vac

125 Vac: Pickup 89.6–150.0 Vac;
Dropout below 53.0 Vac

220 Vac: Pickup 150.3–264.0 Vac;
Dropout below 93.2 Vac

250 Vac: Pickup 170.6–300.0 Vac; Dropout below 106.0 Vac

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

Frequency and Rotation

System Frequency: 50/60 Hz

Phase Rotation: ABC or ACB

Communications Ports

EIA-232: 1 Front and 3 Rear

Serial Data Speed: 300–57600 bps

Communications Card Slot for Optional Ethernet Card

Fiber Optic (Optional)

Ordering Options: 100BASE-FX

Mode: Multi

Wavelength (nm): 1300

Source: LED

Connector Type: ST

Min. TX Pwr. (dBm): –19

Max. TX Pwr. (dBm): –14

RX Sens. (dBm): –32

Sys. Gain (dB): 13

IRIG Time Input

Demodulated IRIG-B time code

Nominal Voltage: 5 Vdc ± 10%

Maximum Voltage: 8 Vdc

Input Impedance: 50 Ω or > 1 kΩ

Isolation: 1.5 kV_{RMS} for 1 minute

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.

Connection Type	Minimum Wire Size	Maximum Wire Size
Grounding (Earthing) Connection	18 AWG (0.8 mm^2)	14 AWG (2.5 mm^2)
Current Connection	16 AWG (1.5 mm^2)	12 AWG (4 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)	14 AWG (2.5 mm^2)
Other Connection	18 AWG (0.8 mm^2)	14 AWG (2.5 mm^2)

Type Tests

Electromagnetic Compatibility Emissions

Emissions: IEC 60255-25:2000

Electromagnetic Compatibility Immunity

Conducted RF Immunity: IEC 60255-22-6:2001
Severity Level: 10 Vrms
IEC 61000-4-6:2008
Severity Level: 10 Vrms

Electrostatic Discharge Immunity: IEC 60255-22-2:2008
Severity Level: 2, 4, 6, 8 kV contact; 2, 4, 8, 15 kV air
IEC 61000-4-2:2008
Severity Level: 2, 4, 6, 8 kV contact; 2, 4, 8, 15 kV air
IEEE C37.90.3-2001
Severity Level: 2, 4, 8 kV contact; 4, 8, 15 kV air

Fast Transient/Burst Immunity: IEC 60255-22-4:2008
Severity Level: Class A: 4 kV, 5 kHz; 2 kV, 5 kHz on communication ports
IEC 61000-4-4:2011
Severity Level: 4 kV, 5 kHz

Magnetic Field Immunity: IEC 61000-4-8:2009
Severity Level: 900 A/m for 3 seconds (50G set to 0.1), 410 A/m for 3 seconds (50G set to 0.05), 100 A/m for 1 minute
IEC 61000-4-9:2001
Severity Level: 1000 A/m (50G set to 0.1), 410 A/m (50G set to 0.05)

Power Supply Immunity: IEC 60255-11:2008
IEC 61000-4-11:2004
IEC 61000-4-29:2000

Radiated Digital Radio Telephone RF Immunity: ENV 50204:1995
Severity Level: 10 V/m at 900 MHz and 1.89 GHz

Radiated Radio Frequency Immunity: IEC 60255-22-3:2007
Severity Level: 10 V/m
IEC 61000-4-3:2010
Severity Level: 10 V/m
IEEE C37.90.2-2004
Severity Level: 35 V/m

Surge Immunity: IEC 60255-22-5:2008
Severity Level: 1 kV Line to Line, 2 kV Line to Earth
IEC 61000-4-5:2005
Severity Level: 1 kV Line to Line, 2 kV Line to Earth

Surge Withstand Capability Immunity: IEC 60255-22-1:2007
Severity Level: 2.5 kV peak common mode, 1.0 kV peak differential mode
IEEE C37.90.1-2002
Severity Level: 2.5 kV oscillatory, 4 kV fast transient waveform

Environmental

Cold: IEC 60068-2-1:2007,
Severity Level: 16 hours at –40°C

Damp Heat, Cyclic: IEC 60068-2-30:2005
Severity Level: 25°C to 55°C, 6 cycles, Relative Humidity 95%

Dry Heat: IEC 60068-2-2:2007
Severity Level: 16 hours at +85°C

Vibration:	IEC 60255-21-1:1988 Severity Level: Class 1 Endurance, Class 2 Resonse IEC 60255-21-2:1988 Severity Level: Class 1 – Shock Withstand, Bump, and Class 2 – Shock Response IEC 60255-21-3:1993 Severity Level: Class 2 (Quake Response)

Safety

Dielectric Strength:	IEC 60255-5:2000 Severity Level: 2500 Vac on control inputs, control outputs, and analog inputs. 3100 Vdc on power supply. Type Tested for 1 minute. IEEE C37.90-2005 Severity Level: 2500 Vac on control inputs, control outputs, and analog inputs. 3100 Vdc on power supply. Type Tested for 1 minute.
Impulse:	IEC 60255-5:2000 Severity Level: 0.5 Joule, 5 kV IEEE C37.90-2005 Severity Level: 0.5 Joule, 5 kV
IP Code:	IEC 60529:2001 + CRGD:2003 Severity Level: IP3X

Safety Agency Certifications

Product Safety:	C22.2 No 14 cUL Listed Protective Relay, Product Category NRGU7 UL 508 UL Listed Protective Relay, Product Category NRGU

Certifications

ISO 9001:	This product was designed and manufactured under an ISO 9001 certified quality management system.

Event Reports

High-Resolution Data

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

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

Event Reports

Length:	15/30 cycles
Maximum Duration:	2 seconds of back-to-back event reports and a total of 5 seconds.
Resolution:	1/4 and 1/8 samples/cycle
Digital Inputs:	2 kHz

Event Summary

Storage:	100 summaries

Breaker History

Storage:	128 histories

Sequential Events Recorder

Storage:	1000 entries
Trigger Elements:	250 relay elements

Processing Specifications

AC Voltage and Current Inputs

8000 samples per second, 3 dB low-pass analog filter cut-off frequency at 646 Hz, ±5%
Digital Filtering
Full-cycle cosine after low-pass analog filtering

Protection and Control Processing

4, 8, and 32 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:	1.25 minimum cycle 1.38 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:	0.7 minimum cycle 0.85 typical cycle 1.2 maximum cycle

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: 0.05–1.00 A

5 A nominal: 0.25–5.00 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)
Zero-Sequence Ground Directional Elements	
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

Phase Under- and Overvoltage Elements—Wye-Connected PTs

Based on maximum of the VA, VB, and VC phase voltages.

Setting Range:	2.00–300 V_{LN} in 0.1 steps
Accuracy:	±3% of setting, ±0.5 V
Transient Overreach:	±5% of pickup
Maximum Delay:	1.5 cycles

Sequence Undervoltage/Overvoltage Wye-Connected PTs

Pickup Range:	2.00–300 V_{LN} in 0.1 steps
Pickup Accuracy, Steady State:	±5% of setting 1 V
Pickup Accuracy, Transient Overreach:	±5%
Maximum Pickup/Dropout Time:	1.5 cycles

Phase-Phase Undervoltage/Overvoltage Delta-Connected PTs

Pickup Range:	4–520 V
Pickup Accuracy:	±2% of setting, ±1 V
Pickup Accuracy, Transient Overreach:	±5%
Maximum Pickup/Dropout Time:	1.5 cycles

Positive-Sequence Undervoltage/Overvoltage Delta-Connected PTs

Pickup Range:	2–520 V
Pickup Accuracy:	±5% of setting, ±2 V
Pickup Accuracy, Transient Overreach:	±5%

Negative-Sequence Undervoltage/Overvoltage Delta-Connected PTs

Pickup Range:	2–520 V
Pickup Accuracy:	±5% of setting, ±2 V
Pickup Accuracy, Transient Overreach:	±5%

Under- and Overfrequency Elements

Pickup Range:	40.00–70.00 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:	25.00–300.00 V_{LN} (Wye) or V_{LL} (Open-Delta)
Pickup Accuracy, Undervoltage Blocking:	±2% ±2 V

Volts/Hertz Elements (24)

Definite-Time Element

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

User-Definable Curve Element

Pickup Range:	100–200%
Pickup Accuracy:	±1% of setpoint
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 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):	8 (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

Operating Range:	0–350 Vdc
Processing Rate:	1/8 cycle
Maximum Pickup/Dropout Time:	1.5 seconds (element dc ripple) 1.5 cycles (all elements but dc ripple)
Setting Range	
DC Settings:	OFF, 15–300 Vdc, 1 Vdc steps
AC Ripple Setting:	1–300 Vac, 1 Vac steps
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:	5 A nominal ±0.2% plus ± 4 mA (0.5–100 A sec)
1 A Model:	1 A nominal ±0.2% plus ± 0.8 mA (0.1–20 A sec)

Sequence Current Magnitude

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

Sequence Current Angle

All Models:	±0.3°
Phase Current Angle:	±0.5° in the current range (0.1–20) • I_{NOM}

Voltages

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° (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° (33.5–200) 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% ±0.008 • I_{NOM}, (0.1–1.2) • I_{NOM}
3I2 per Terminal 3I0 (IG) per Terminal (wye-connected only):	±0.3% ±0.008 • I_{NOM}, (0.1–1.2) • 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

Up to 500 m Fiber-Optic Cable to SEL-2600 Series RTD Module

Synchrophasor Metering

24 channels (6 voltage and 18 currents)

20 messages per second via SEL Fast Message protocol

Up to 60-messages/second via IEEE Standard C37.118 protocol.

Voltage Accuracy:	range 30–150 V ±1% Total Vector Error (TVE) as specified in C37.118 at f_{NOM} ±5 Hz
Current Accuracy (Current range 0.1–20 • I_{NOM}):	±1% TVE at f_{NOM} ±5 Hz
Voltage Magnitude Accuracy:	±0.1%
Voltage Angle Accuracy:	±0.125°

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

Notes

This product is covered by the standard SEL 10-year warranty. For warranty details, visit www.selinc.com or contact your customer service representative.

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