The SEL-487E-5 Sampled Values Transformer Differential Relay provides three-phase differential protection for transformer applications with as many as five three-phase restraint current inputs. The SEL-487E SV Subscriber Relay subscribes to voltage and current information that is provided by remote merging units instead of PT and CT inputs to reduce cable lengths and labor costs and to improve the overall safety of the substation. 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 5 breakers and 20 disconnect switches by 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 as much as 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. Waveshape-based inrush detection addresses inrush conditions that contain low second and fourth harmonic content.
➤ **Turn-to-Turn Winding Fault Protection.** Innovative negative-sequence differential elements provide transformer windings protection from as little as two percent turn-to-turn winding faults.

➤ **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.** 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.

➤ **Reduced System Coordination Delays.** SEL-487E breaker failure protection with subsidence detection minimizes system coordination delays.

➤ **Simplified System Integration.** Ethernet communication that uses DNP3 LAN/WAN and IEC 61850 protocols simplifies 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. Synchronophaser data are provided in either SEL Fast Message or IEEE C37.118 format.

➤ **Input/Output Scaling.** The SEL-2600A 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.

➤ **IEC 61850 Sampled Values Subscription.** The SEL-487E supports as many as seven SV subscriptions. SV message subscription complies with UCA 61850-9-2LE guidelines. The SEL-487E only accepts 9-2LE-compliant SV messages with 1 application service data unit (ASDU). Each subscription includes four current and four voltage channels. The supported SV subscription message rate is 4.8 kHz for a 60 Hz power system and 4 kHz for a 50 Hz power system.

➤ **IEC 61850 Operating Modes.** The relay supports IEC 61850 standard operating modes such as Test, Blocked, On, and Off.

➤ **Current Summation.** The relay can combine multiple SV stream currents to simplify external wiring.

➤ **No Need for Auxiliary CTs.** The SEL-487E can accommodate a CT ratio mismatch as great as 35:1.

➤ **Parallel Redundancy Protocol (PRP).** The SEL-487E provides seamless recovery from any single Ethernet network failure with this protocol, in accordance with IEC 62439-3. The station bus Ethernet network and traffic are fully duplicated with both copies operating in parallel.

➤ **IEEE 1588, Precision Time Protocol.** The relay supports Precision Time Protocol version 2 (PTPv2). PTP provides high-accuracy timing over an Ethernet network.

➤ **IEC 60255-Compliant Thermal Model.** The SEL-487E can provide a configurable thermal model for the protection of a wide variety of devices.

➤ **Software-Invertible Polarities.** The SEL-487E can 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.
Functional Overview

The SEL-487E subscribes to IEC 61850-9-2LE data streams that are published by merging units, such as the SEL-421-7 Protection, Automation, and Control System With Sampled Values or SEL-401 Protection, Automation, and Control Merging Unit. The SEL-421-7 provides additional backup protection while the SEL-401 can provide basic backup protection with phase-overcurrent and breaker-failure protection in the absence of communication. The data may be synchronized via IRIG-B or IEEE 1588 Precision Time Protocol. As shown with blue lines in Figure 1, the SEL-487E performs breaker control via GOOSE communications.
SEL-487E Relay Functions

➤ SEL-487E three-phase differential protection sensing:
  ➢ Fifteen 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.

➤ The unrestrained differential element operates independent of the harmonic content of the differential current, providing fast, unrestrained tripping for high-current transformer faults, such as bushing faults. The unrestrained differential element compliments the phase differential elements, particularly during inrush conditions in which harmonics in the differential current might cause the restraint differential elements to operate slower. Waveshape-based inrush detection addresses inrush conditions that contain low second- and fourth-harmonic content.

➤ 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 (V/Hz) 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.

➤ 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

➤ IEEE C57.91-compliant transformer thermal model with hot-spot temperature and insulation aging factors

➤ IEC 60255-complaint configurable thermal model for the protection of a wide variety of devices.

➤ One expansion I/O boards in a 4U chassis

➤ Through-fault accumulation monitoring and alarm uses IEEE through-fault duration curves

➤ 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

➤ The 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.
Application Examples

The SEL-487E SV Subscriber Relay 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. Waveshape-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.

The SEL-487E SV Subscriber Relay can be used in applications with as many as five three-phase current inputs. For the application shown in Figure 2, the SEL-487E subscribes to a total of four IEC 61850 9-2 SV streams from two different merging units. The SV publishers and subscriber for this application are connected through a process bus network switch. The same network switch is being used to communicate GOOSE messages and time-synchronize the system by using a PTP time source.

Use the negative-sequence differential element for sensitive detection of inter-turn 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.

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 monitor-
ing and protection of the generator step-up (GSU) transformer in prime power, standby, base load, and peak shaving applications.

You can also apply the SEL-487E SV Subscriber Relay to an autotransformer with both HV and LV busbars installed in a breaker-and-a-half configuration. In the application shown in Figure 3, the SEL-487E subscribes to a total of five IEC 61850 9-2 SV streams from three different merging units. The SV publishers and subscriber for this application are connected through a process bus network switch. The same network switch communicates GOOSE messaging and time-synchronizes the system by using a PTP time source.

Figure 3  Autotransformer Application

**Synchrophasor Applications**

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

Transformer protection includes the following protection elements:

- Unrestrained, restrained, and negative-sequence differential
- Breaker-failure with subsidence detection for three-pole breakers
- 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 \((IOP_n, \text{ where } n = A, B, C)\) and restraint \((IRT_n)\) quantities that the relay calculates from the selected winding input currents. Figure 4 shows the characteristic of the filtered differential element as a straight line through the origin of the form:

\[
IOP_A (IRT_A) = SLP_c \cdot IRT_A
\]

For operating quantities \((IOP)\) exceeding the threshold level \(0.87P\) and falling in the operate region of Figure 4, 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 4 Adaptive Slope Differential Characteristics](image)

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.
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.

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). The directionality of each element can be controlled individually by means of a 67xxxTC 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 (five IEC and five U.S.). Each torque-controlled time-overcurrent element has two reset characteristics. One choice resets the elements if current drops below pickup for one cycle while the other choice emulates the reset characteristic of an electromechanical induction disk relay.

<table>
<thead>
<tr>
<th>U.S. Curves</th>
<th>IEC Curves</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1 (moderately inverse)</td>
<td>C1 (standard inverse)</td>
</tr>
<tr>
<td>U2 (inverse)</td>
<td>C2 (very inverse)</td>
</tr>
<tr>
<td>U3 (very inverse)</td>
<td>C3 (extremely inverse)</td>
</tr>
<tr>
<td>U4 (extremely inverse)</td>
<td>C4 (long-time inverse)</td>
</tr>
<tr>
<td>U5 (short-time inverse)</td>
<td>C5 (short-time inverse)</td>
</tr>
</tbody>
</table>

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: IAmFM, IBmFM, ICMFM
- Maximum filtered phase current: IMAXmF
- Combined filtered phase currents (any two terminals): IAmnmFM, IBnmFM, ICMnmFM
- Maximum filtered combined phase current: IMAXnmF
Filtered positive-, negative-, and zero-sequence: $I_1mFM$, $3I_2mFM$, $3I_0mFM$, $I_1mmM$, $3I_2mmM$, $3I_0mmM$

RMS currents: $I_AmRMS$, $I_BmRMS$, $I_CmRMS$, $IMAXmR$ $I_AmmRMS$, $I_BmmRMS$, $I_CmmRMS$, $IMAXmmR$

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 of A-, B-, and 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.

**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 ret trip, 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 7. This reduces breaker-failure coordination times and minimizes overall system coordination delays.

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 control 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-2600A 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 (CTCONm = 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 $I_2m$ and $I_0m$ ($m = S, T, U, W, X$).

Six Independent Settings Groups Increase Operation Flexibility

The relay stores six settings groups. Select the active settings group by control input, IEC 61850 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. You can also use the licensed version of ACSELERATOR QuickSet SEL-5030 Software 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.

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 push-buttons 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**

By using high-accuracy IRIG-B or IEEE 1588 from a global positioning satellite clock, the SEL-487E-5 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 high-accuracy IEEE C37.118 IRIG-B time-code input synchronizes the SEL-487E time to be within ±1 us 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. A convenient source for this time code is an SEL communications processor (via Serial Port 1 on the SEL-487E).

**PTP Time Synchronization**

In addition to using IRIG-B for high-accuracy timekeeping, the relay can use IEEE 1588 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.

**SNTP Time Synchronization**

Use SNTP to cost-effectively synchronize the SEL-487E equipped with Ethernet communication to as little as ±1 ms with no time source delay. Use SNTP as a primary time source or as a backup to a higher accuracy IRIG-B time input to the relay.

**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

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

**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 and disconnect switch position to give instant status and complete control of a bay. Figure 12 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.
The SEL-487E will provide control of as many as 5 breakers and 20 disconnect switches using the one-line diagram displays.

**Figure 12  Front-Panel One-Line Transformer Diagram**

The SEL-487E will provide control of as many as 5 breakers and 20 disconnect switches using the one-line diagram displays.

**Figure 13  Remote HV Breaker Application With MIRRORED BITS**

The SEL patented MIRRORED BITS technology provides bidirectional relay-to-relay digital communication. Figure 13 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.
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 IEEE 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 Ethernet card mounts directly in the SEL-487E. 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 provides four Ethernet ports: two ports for the station bus and two ports for the process bus.

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

The SEL-487E is equipped with an Ethernet communications card that supports Telnet and FTP communications. 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

DNP3 LAN/WAN 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.

PTP

The Ethernet card provides the ability for the SEL-487E to accept IEEE 1588 PTPv2 for data time-synchronization. PTP support includes both the Default and Power System (IEEE C37.238-2011) PTP Profiles.

PRP

The protocol provides seamless recovery from any single Ethernet network failure with this protocol, in accordance with IEC 62439-3. The station bus Ethernet network and traffic are fully duplicated with both copies operating in parallel.
IEC 61850-9-2LE Sampled Values

The SEL-487E supports IEC 61850-9-2 Sampled Values (SV) protocol. The SEL-487E SV Subscriber relay can subscribe to as many as seven Sampled Value streams from any source that conforms to the IEC 61850-9-2LE guideline. Self-monitoring of the Ethernet links validates the data quality and reduces the need for periodic testing of the communication network.

IEC 61850 Ethernet Communication

IEC 61850 Edition 2 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 supports embedded IEC 61850 Edition 2 protocols 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 Edition 2 Ethernet protocols 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 Configured IED Description (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 61850 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 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>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASCII</td>
<td>Plain-language commands for human and simple machine communication. Use for metering, setting, self-test status, event reporting, and other functions.</td>
</tr>
<tr>
<td>Compressed ASCII</td>
<td>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.</td>
</tr>
<tr>
<td>Extended SEL Fast Meter, SEL Fast Operate, and SEL Fast SER</td>
<td>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.</td>
</tr>
<tr>
<td>Ymodem</td>
<td>Support for reading event, settings, and oscillography files.</td>
</tr>
</tbody>
</table>
Table 4  Open Communications Protocol (Sheet 2 of 2)

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optional DNP3 Level 2 Outstation</td>
<td>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.</td>
</tr>
<tr>
<td><strong>MIRRORED BITS</strong></td>
<td>SEL protocol for exchanging digital and analog information among SEL relays and for use as low-speed terminal connection.</td>
</tr>
<tr>
<td>FTP and Telnet</td>
<td>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.</td>
</tr>
<tr>
<td>IEC 61850</td>
<td>Ethernet-based international standard for interoperability among intelligent devices in a substation.</td>
</tr>
<tr>
<td>SNTP</td>
<td>Ethernet-based simple network time protocol for time synchronization among relays.</td>
</tr>
</tbody>
</table>

Table 5  SEL-487E Metering Quantities (Sheet 1 of 2)

<table>
<thead>
<tr>
<th>Capabilities</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Instantaneous Quantities</strong></td>
<td></td>
</tr>
<tr>
<td>Voltages:</td>
<td>Voltages measured at the fundamental frequency of the power system. The relay compensates for delta-connected CTs when reporting primary values.</td>
</tr>
<tr>
<td>( V_{A,B,C} (V, Z), V_{\phi} ), ( 3V0, V1, 3V2 )</td>
<td></td>
</tr>
<tr>
<td><strong>RMS voltages:</strong></td>
<td>RMS voltages include fundamental plus all measurable harmonics.</td>
</tr>
<tr>
<td>( V_{A,B,C} (V, Z), V_{\phi} )</td>
<td></td>
</tr>
<tr>
<td><strong>Compensated fundamental currents:</strong></td>
<td></td>
</tr>
<tr>
<td>( I_{A,B,C} (S, T, U, W, X, Y), 3I0, I1, 3I2 ), ( I_{A,B,C} (ST, TU, UW, WX), 3I0, I1, 3I2 )</td>
<td>Currents measured at the fundamental frequency of the power system, with transformer phase-compensation applied.</td>
</tr>
<tr>
<td><strong>RMS currents:</strong></td>
<td>RMS currents include fundamental plus all measurable harmonics.</td>
</tr>
<tr>
<td>( I_{A,B,C} (S, T, U, W, X) ), ( I_{A,B,C} (ST, TU, UW, WX) )</td>
<td></td>
</tr>
<tr>
<td><strong>Power/Energy Metering Quantities</strong></td>
<td></td>
</tr>
<tr>
<td>Power quantities:</td>
<td>Power quantities calculated using fundamental voltage and current measurements; ( S = \text{MVA}, P = \text{MW}, Q = \text{MVAR} ).</td>
</tr>
<tr>
<td>( S_{A,B,C}, P_{A,B,C}, Q_{A,B,C} (S, T, U, W, X) ), ( S_{STU}, P_{STU}, Q_{STU} (S, T, U, W, X) )</td>
<td></td>
</tr>
<tr>
<td>Differential:</td>
<td></td>
</tr>
<tr>
<td>IOPA, IOPB, IOPC, IRTA, IRTB, IRTC</td>
<td>IOP, operate current magnitude (per unit). IRT, restraint current magnitude (per unit).</td>
</tr>
<tr>
<td><strong>Harmonics:</strong></td>
<td></td>
</tr>
<tr>
<td>2nd: IOPAF2, IOPBF2, IOPCF2</td>
<td>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.</td>
</tr>
<tr>
<td>4th: IOPAF4, IOPBF4, IOPCF4</td>
<td></td>
</tr>
<tr>
<td>5th: IOPAF5, IOPBF5, IOPCF5</td>
<td></td>
</tr>
</tbody>
</table>

**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 using the relay voltage inputs.
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 14), 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.

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

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

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

In addition to the transformer thermal monitor, the SEL-487E equipment monitor, in accordance with IEC 60255-149, provides a configurable model for the protection of a wide variety of devices.

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 $I^2t$ 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.

### 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 SER features simplify post-fault analysis and help improve your understanding of both simple and complex protective scheme operations. These features also aid in testing and troubleshooting relay settings and 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 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 or PTP clock input 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**

**QuickSet**

Use 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 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, such as the following:

- 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

The relay can serve read-only webpages displaying certain settings, metering, and status reports. As many as four users can access the embedded HTTP server simultaneously.

Control Inputs and Outputs

Select one interface board 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 4U chassis height. The 4U chassis requires the selection of 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 through the use of 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 16 SEL-487E HTTP Web Server Settings Screen
Diagrams and Dimensions

Figure 17 Commissioning Assistant Screen

Figure 18 SEL-487E Front Panel
Figure 19  SEL-487E SV Subscriber Relay Rear Panel

RACK-MOUNT CHASSIS

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.48</td>
<td>in</td>
</tr>
<tr>
<td>8.15</td>
<td>in</td>
</tr>
<tr>
<td>3.46</td>
<td>in</td>
</tr>
</tbody>
</table>

PANEL-MOUNT CHASSIS

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.48</td>
<td>in</td>
</tr>
<tr>
<td>1.12</td>
<td>in</td>
</tr>
</tbody>
</table>

LEGEND

- in
- [mm]

Figure 20  SEL-487E Dimensions for Rack- and Panel-Mount Models
Specifications

Note: The SEL-487E SV Subscriber Relay uses a SV-based remote data acquisition system. Operating times will be delayed by the configured channel delay, CH_DLY. Use caution when setting the relay coordination times to account for this added delay. See SV Network Delays on page 17.19 in the SEL-400 Series Relays Instruction Manual for more details on this setting.

Note: The metering and protection element accuracies specified for the SEL-487E SV Subscriber Relay are valid only when using SEL SV publisher relays. Third-party SV publisher devices are supported, but hardware accuracies and analog filtering need to be considered to determine the effect on SEL-487E performance.

Compliance

Design 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

RCM Mark

General

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


Update Rate: 1/8 cycle

Make (Short Duration Contact Current): 30 Adc

Limiting Making Capacity: 1000 W at 250 Vdc (L/R = 40 ms)

Mechanical Endurance: 10,000 operations

Standard

Rated Voltage: 24–250 Vdc, 110–240 Vrms

Operational Voltage Range: 0–300 Vdc, 0–264 Vrms

Operating Time: Pickup ≤6 ms (resistive load); Dropout ≤6 ms (resistive load)

Short-Time Thermal Withstand: 50 A for 1 s

Continuous Contact Current: 6 A at 70°C, 4 A at 85°C

Contact Protection: MOV protection across open contacts

264 Vrms continuous voltage

300 Vdc continuous voltage

Limiting Breaking Capacity/Electrical Endurance: 10,000 operations

10 operations in 4 seconds, followed by 2 minutes idle

Rated Voltage | Resistive Break | Inductive Break L/R = 40 ms (DC) PF = 0.4 (AC)
---|---|---
24 Vdc | 0.75 Adc | 0.75 Adc
48 Vdc | 0.63 Adc | 0.63 Adc
125 Vdc | 0.30 Adc | 0.30 Adc
250 Vdc | 0.20 Adc | 0.20 Adc
110 Vrms | 0.30 Arms | 0.30 Arms
240 Vrms | 0.20 Arms | 0.20 Arms

Fast Hybrid (High-Speed High-Current Interrupting)

Rated Voltage: 48–250 Vdc

Operational Voltage Range: 0–300 Vdc

Operating Time: Pickup ≤50 µs (resistive load); Dropout ≤8 ms (resistive load)

Short Time Thermal Withstand: 50 A for 1 s

Continuous Contact Current: 6 A at 70°C, 4 A at 85°C

Contact Protection: MOV protection across open contacts

300 Vdc continuous voltage

Limiting Breaking Capacity/Electrical Endurance: 10,000 operations

4 operations in 1 second, followed by 2 minutes idle

Rated Voltage | Resistive Break | Inductive Break
---|---|---
24 Vdc | 10 Adc | 10 Adc (L/R = 40 ms)
48 Vdc | 10 Adc | 10 Adc (L/R = 40 ms)
125 Vdc | 10 Adc | 10 Adc (L/R = 40 ms)
250 Vdc | 10 Adc | 10 Adc (L/R = 20 ms)

Note: Do not use hybrid control outputs to switch ac control signals. These outputs are polarity-dependent.
Control Inputs
Optoisolated (For Use With AC or DC Signals)
- INT2 Interface Board: 8 inputs with no shared terminals
- INT4 Interface Board: 6 inputs with no shared terminals
  (2 groups of 9 inputs with each group sharing one terminal)
Voltage Options: 24, 48, 110, 125, 220, 250 V
Current Draw: <5 mA at nominal voltage
<8 mA for 110 V option
Sampling Rate: 2 kHz
DC Thresholds (Dropout thresholds indicate level-sensitive option)
- 24 Vdc: Pickup 19.2–30.0 Vdc; Dropout <28.8 Vdc
- 48 Vdc: Pickup 38.4–60.0 Vdc; Dropout <20.3 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)
- 24 Vdc: Pickup 16.4–30.0 Vdc
- 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 150.3–264.0 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 the 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
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:
Profiles: IEEE 1588 PTPv2
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: 6.5 kg (14.5 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) 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:

<table>
<thead>
<tr>
<th>Connection Type</th>
<th>Min. Wire Size</th>
<th>Max. Wire Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grounding (Earthing)</td>
<td>14 AWG (2.5 mm²)</td>
<td>N/A</td>
</tr>
<tr>
<td>Contact I/O</td>
<td>18 AWG (0.8 mm²)</td>
<td>10 AWG (5.3 mm²)</td>
</tr>
<tr>
<td>Other Connection</td>
<td>18 AWG (0.8 mm²)</td>
<td>10 AWG (5.3 mm²)</td>
</tr>
</tbody>
</table>

Type Tests
Installation Requirements
Overvoltage Category: 3
Pollution Degree: 2
Safety
Product Standards:
- IEC 60255-27:2013
- IEEE C37.90-2005
- 21 CFR 1040.10
Dielectric Strength:
- IEC 60255-27:2013, Section 10.6.4.3
  2.5 kVac, 50/60 Hz for 1 min: Analog Inputs, Contact Outputs, Digital Inputs
  3.6 kVdc for 1 min: Power Supply, Battery Monitors
  2.5 kVdc for 1 min: IRIG-B
  1.1 kVdc for 1 min: Ethernet

Schweitzer Engineering Laboratories, Inc.  SEL-487E Data Sheet
## Impulse Withstand
- **IEEE C37.90-2005**
- **Common Mode:**
  - ±1.0 kV: Ethernet
  - ±2.5 kV: IRIG-B
  - ±5.0 kV: All other ports
- **Differential Mode:**
  - 0 kV: Analog Inputs, Ethernet, IRIG-B, Digital Inputs
  - ±5.0 kV: Standard Contact Outputs, Power Supply Battery Monitors
  - +5.0 kV: Hybrid Contact Outputs

## Insulation Resistance
- IEC 60255-27:2013, Section 10.6.4.4
  - >100 MΩ @ 500 Vdc

## Protective Bonding
- IEC 60255-27:2013, Section 10.6.4.5.2
  - <0.1 Ω @ 12 Vdc, 30 A for 1 min

## Object Penetration
  - Protection Class: IP30

## Max Temperature of Parts and Materials
- IEC 60255-27:2013, Section 7.3

## Flammability of Insulating Materials
- IEC 60255-27:2013, Section 7.6
  - Compliant

## Electromagnetic (EMC) Immunity
### Surge Withstand Capability (SWC):
- IEEE C37.90-2005
  - Slow Damped Oscillatory, Common and Differential Mode:
    - ±1.0 kV
    - ±2.5 kV
  - Fast Transient, Common and Differential Mode:
    - ±4.0 kV

### Electrostatic Discharge (ESD):
- IEEE C37.90-2005
  - Contact: ±8 kV
  - Air Discharge: ±15 kV

### Radiated RF Immunity:
- IEEE C37.90-2004
  - 20 V/m (>35 V/m, 80% AM, 1 kHz)
  - Sweep: 80 MHz to 1 GHz
  - Spot: 80, 160, 450, 900 MHz
  - 10 V/m (>15 V/m, 80% AM, 1 kHz)
  - Sweep: 80 MHz to 1 GHz
  - Spot: 1.4 GHz to 2.7 GHz
  - 80, 160, 380, 450, 900, 1850, 2150 MHz

### Electrical Fast Transient Burst (EFTB):
- IEEE C37.90-2004
  - Zone A:
    - ±2 kV: Communication ports
    - ±4 kV: All other ports

### Surge Immunity:
- IEEE C37.90-2005
  - Zone A:
    - ±2 kV L-L
    - ±4 kV L-G
    - ±4 kV: Communication Ports
  - **Note:** Cables connected to IRIG-B ports shall be less than 10 m in length for Zone A compliance.
  - Zone B:
    - ±2 kV: Communication Ports

### Conducted Immunity:
- IEEE C37.90-2005
  - 20 V/m (>35 V/m, 80% AM, 1 kHz)
  - Sweep: 150 kHz–80 MHz
  - Spot: 27, 68 MHz
  - ±500 Vrms: Power Frequency Immunity (DC Inputs):
    - Zone A:
      - Differential: 150 Vrms
      - Common Mode: 300 Vrms
  - ±50 Vrms: Power Frequency Magnetic Field:
    - Level 5:
      - 100 A/m; 260 Seconds; 50/60 Hz
      - 1000 A/m 1 to 3 Seconds; 50/60 Hz
      - **Note:** 50G1P ≥0.05 (ESS = N, 1, 2)
      - 50G1P ≥0.1 (ESS = 3, 4)

### Power Supply Immunity:
- IEEE C37.90-2005
  - AC Dips & Interruptions
  - Ripple on DC Power Input
  - DC Dips & Interruptions
  - Gradual Shutdown/Startup (DC only)
  - Discharge of Capacitors
  - Slow Ramp Down/Up
  - Reverse Polarity (DC only)

### Radiated RF Immunity:
- IEEE C37.90-2005
  - 47 CFR Part 15.109
  - IEC 61000-4-29:2013
  - 20 V/m; (>35 V/m, 80% AM, 1 kHz)
  - Sweep: 150 kHz–80 MHz
  - Spot: 27, 68 MHz
  - 10 V/m; (>15 V/m, 80% AM, 1 kHz)
  - Sweep: 80 MHz to 1 GHz
  - Spot: 80, 160, 380, 450, 900, 1850, 2150 MHz

### Electrical Fast Transient Burst (EFTB):
- IEEE C37.90-2004
  - Zone A:
    - ±150 V/L-L
    - ±300 V/L-E
    - ±300 V: Communication Ports
    - ±3 kV: Power Supplies
    - ±6 kV: AC Dips & Interruptions

### Power Supply Immunity:
- IEEE C37.90-2005
  - AC Dips & Interruptions
  - Ripple on DC Power Input
  - DC Dips & Interruptions
  - Gradual Shutdown/Startup (DC only)
  - Discharge of Capacitors
  - Slow Ramp Down/Up
  - Reverse Polarity (DC only)

### 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 S RATE 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 1/8 cycle for all elements

Processing Specifications
AC Voltage and Current Inputs
8000 samples per second
Full-cycle cosine filtering

Subscribed AC Input Current (Nominal Secondary)
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)

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

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

Relay Element Pickup Ranges and Accuracies
Differential Elements (General)
Number of Zones: 1 (A, B, and C elements)
Number of Windings: 5
TAP Setting Range: (0.1–32.0) • I NOM A secondary
TAP Limit: TAP MAX/TAP MIN ≤5
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
(If E87UNB = N): 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% to 100%
Accuracy: ±5% ±0.02 • I NOM
Slope 2
Setting Range: 5% to 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
1.2 maximum cycle
Pickup Time (Raw Unrestraint): 0.5 typical cycle
1.0 maximum cycle

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

Harmonic Elements (2nd, 4th, 5th)
Pickup Range: OFF, 5–100% of fundamental
Pickup Accuracy: 1 A nominal ±5% ±0.02 A
5 A nominal ±5% ±0.10 A
Time-Delay Accuracy: ±0.1% plus ±0.125 cycle

Negative-Sequence Differential Element
Pickup Range: 0.05–1 per unit
Slope Range: 5% to 100%
Pickup Accuracy: ±5% of user setting, ±0.02 • I NOM A
Maximum Pickup/Dropout Time: 4 cycles
Winding Coverage: 2%

Incremental Restriction 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

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, ±0.02 A
Time-Delay 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

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 current (3I2)
Sensitivity: 0.05 * I_{KOM} A of secondary 3I2
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_{KOM} 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
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

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

Phased-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 VLN (Wye) or VLL (Open-Delta)
Pickup Accuracy, Undervoltage Blocking: ±2% ±0.5 V

Volts/Hertz Elements (24)

Definite-Time Element
Pickup Range: 100% to 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% ±2.4 ms @ 60 Hz
Reset Time-Delay Range: 0.00–400.00 s

User-Definable Curve Element
Pickup Range: 100% to 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

Directional Overpower/Underpower Element
Operating Quantities: OFF, 3PmF, 3QmF; 3PqpF, 3QqpF
(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 ±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: 24–250 Vdc
Operational Voltage Range: 0–300 Vdc
Sampling Rate: 2 kHz
Processing Rate: 1/8 cycle
Operating Time: Less than 1.5 cycles (all elements except ac ripple)
Less than 1.5 seconds (ac ripple element)

Setting Range
15–300 Vdc, 1 Vdc steps (all elements except ac ripple)
1–300 Vac, 1 Vac steps (ac ripple element)
Accuracy
Pickup Accuracy: ±3% ± 2 Vdc (all elements except ac ripple)
±10% ± 2 Vac (ac ripple element)

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 sec)
1 A Model: ±0.3% plus ±0.8 mA (0.1–20 A sec)
Sequence Current Angle
All Models: ±0.3°

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: ±1.0° (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)
Power

MW (P), Per Phase (Wye), 3φ (Wye or Delta) Per Terminal
±1% (0.1–1.2) \( \pm I_{\text{INOM}} \) 33.5–300 Vac, PF = 1, 0.5 lead, lag (1φ)
±0.7% (0.1–1.2) \( \pm I_{\text{INOM}} \) 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) \( \pm I_{\text{INOM}} \) 33.5–300 Vac, PF = 0, 0.5 lead, lag (1φ)
±0.7% (0.1–1.2) \( \pm I_{\text{INOM}} \) 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) \( \pm I_{\text{INOM}} \) 33.5–300 Vac, PF = 1, 0.5 lead, lag (1φ)
±0.7% (0.1–1.2) \( \pm I_{\text{INOM}} \) 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) \( \pm I_{\text{INOM}} \) 33.5–300 Vac, PF = 1, 0.5 lead, lag (1φ)
±0.7% (0.1–1.2) \( \pm I_{\text{INOM}} \) 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) \( \pm I_{\text{INOM}} \) 33.5–300 Vac, PF = 1, 0.5 lead, lag (1φ)
±0.7% (0.1–1.2) \( \pm I_{\text{INOM}} \) 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) \( \pm I_{\text{INOM}} \) 33.5–300 Vac, PF = 0, 0.5 lead, lag (1φ)
±0.7% (0.1–1.2) \( \pm I_{\text{INOM}} \) 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: ±2% ±0.0008 \( \pm I_{\text{INOM}} \)
(0.1–1.2) \( \pm I_{\text{INOM}} \)
3I2 per Terminal
3I0 (IG) per Terminal (Wye-Connected Only): ±3% ±0.0008 \( \pm I_{\text{INOM}} \)
(0.1–20) \( \pm I_{\text{INOM}} \)

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: \( \pm1\% \) Total Vector Error (TVE)
Range 30–150 V, \( \pm5\% \) \( I_{\text{INOM}} \)
Current Accuracy: \( \pm1\% \) Total Vector Error (TVE)
Range (0.1–2.0) \( \pm5\% \) \( I_{\text{INOM}} \)
Synchrophasor Recording: Records as much as 120 s

Breaker Monitoring

Running Total of Interrupted
Current (kA) per Pole: \( \pm5\% \) \( \pm0.02\% \) \( I_{\text{INOM}} \)
Percent kA Interrupted for Trip Operations: \( \pm5\% \)
Percent Breaker Wear per Pole: \( \pm5\% \)
Compressor/Motor Start and Run Time: \( \pm1\% \)
Time Since Last Operation: \( \pm1\% \)
Technical Support

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

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