SEL

SEL-451-5 Protection, Automation, and Bay Control System


Major Features and Benefits

The SEL-451-5 Protection, Automation, and Bay Control System integrates bay control for breakers and disconnect switches with full automation and protection in one device.

➤ **Protection.** Customize distribution protection with multiple instantaneous and time-overcurrent elements with SELOGIC® control equations. Best Choice Ground Directional Element® logic optimizes directional element performance and eliminates the need for many directional settings. Provide comprehensive protection for two breakers with one relay.

➤ **Commissioning.** Rapidly commission your Bay Control with preconfigured bay arrangements. Choose among different bus configurations, including single- and dual-busbar, transfer bus, tie breaker, breaker-and-a-half, ring-bus, double-bus/double-breaker, and source transfer configurations. These bus arrangements allow easy status and control of as many as ten disconnect switches and two breakers. Additional user-selectable bay types are available via ACSELERATOR QuickSet® SEL-5030 Software that can be downloaded at selinc.com.

➤ **Automation.** Take advantage of enhanced automation features that include 32 programmable elements for local control, remote control, protection latching, and automation latching. Local metering on the large format front-panel LCD

eliminates the need for separate panel meters. Serial and Ethernet links efficiently transmit key information, including metering data, protection element and control input/output (I/O) status, IEEE C37.118 Synchrophasors, IEC 61850 Edition 2 GOOSE messages, Sequential Events Recorder (SER) reports, breaker monitor, relay summary event reports, and time synchronization. Apply expanded SELOGIC control equations with math and comparison functions in control applications. Incorporate as many as 1000 lines of automation logic to speed and improve control actions.

➤ **Software-Invertible Polarities.** Invert individual or grouped CT and PT polarities to account for field wiring or zones of protection changes. CEV files and all metering and protection logic use the inverted polarities, whereas COMTRADE event reports do not use inverted polarities but rather record signals as applied to the relay.

➤ **Synchrophasors.** Make informed load dispatch decisions based on actual real-time phasor measurements from SEL-451 Relays across your power system. Record streaming synchrophasor data from SEL-451 Relays for system-wide disturbance recording. Control the power system using local and remote synchrophasor data.

➤ **High-impedance Fault Detection.** The optional high-impedance fault (HIF) detection element operates for small current ground faults typically caused by downed conductors on surfaces such as earth, concrete or other poorly conductive materials. HIF event data are made available in standard COMTRADE format.

➤ **Ethernet Access.** Access all relay functions with the optional Ethernet card. Interconnect with automation systems by using IEC 61850 Edition 2 or DNP3 protocol directly. Use file transfer protocol (FTP) for high-speed data collection. Connect to substation or corporate LANs to transmit synchrophasors in the IEEE C37.118–2005 format by using TCP or UDP Internet protocols.

➤ **Parallel Redundancy Protocol (PRP).** Provide seamless recovery from any single Ethernet network failure, in accordance with IEC 62439-3. The Ethernet network and all traffic are fully duplicated with both copies operating in parallel.

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

➤ **Digital Relay-to-Relay Communications.** Enhanced MIRRORED BITS® communications can monitor internal element conditions between bays within a station, or between stations, using SEL fiber-optic transceivers. Send digital, analog, and virtual terminal data over the same MIRRORED BITS channel.

➤ **Monitoring.** Schedule breaker maintenance when accumulated breaker duty (independently monitored for each pole of two circuit breakers) indicates possible excess contact wear. Electrical and mechanical operating times are recorded for both the last operation and the average of operations since function reset. Two independent DC monitors provide notification of substation battery voltage problems even if voltage is low only during trip or close operations.

➤ **Breaker Failure.** High-speed (less than one cycle) open-pole detection logic reduces coordination times for critical breaker failure applications. Apply the SEL-451 to supply breaker failure protection for one or two breakers. Logic for breaker failure retrip and initiation of transfer tripping is included.

➤ **Sequential Events Recorder (SER).** Record the last 1000 events, including setting changes, power-ups, and selectable logic elements.

➤ **Dual CT Input.** Apply with ring bus, breaker-and-a-half, or other two-breaker schemes. Combine currents within the relay from two sets of CTs for protection functions, but keep them separately available for monitoring and station integration applications.

➤ **Comprehensive Metering.** Improve feeder loading by using built-in, high-accuracy metering functions. Watt and VAR measurements optimize feeder operation. Minimize equipment needs with full metering capabilities including rms, maximum/minimum, demand/peak, energy, and instantaneous values.

➤ **High-Accuracy Time-Stamping.** Time-tag binary COMTRADE event reports with real-time accuracy of better than 10 µs. View system state information to an accuracy of better than 1/4 of an electrical degree.

➤ **Oscillography and Event Reporting.** Record voltages, currents, and internal logic points at a sampling rate as fast as 8 kHz. Off line phasor and harmonic-analysis features allow investigation of bay and system performance.

➤ **Reclosing.** Incorporate programmable reclosing of one or two breakers into an integrated substation control system. Synchronism and voltage checks from multiple sources provide complete bay control.

➤ **Fault Locator.** Efficiently dispatch line crews to quickly isolate line problems and restore service faster.

➤ **IEC 60255-Compliant Thermal Model.** Use the relay to provide a configurable thermal model for the protection of a wide variety of devices.

➤ **Rules-Based Settings Editor.** Communicate with and set the relay by using an ASCII terminal, or use QuickSet to configure the SEL-451 and analyze fault records with relay element response.

➤ **Auxiliary Trip/Close Pushbuttons.** These optional pushbuttons are electrically isolated from the rest of the relay. They function independently from the relay and do not need relay power.

➤ **Low-Energy Analog (LEA) Inputs.** Reduce costs and save space with as many as six C37.92-compliant LEA voltage inputs.

➤ **Time-Domain Link (TiDL®) Technology.** The relay supports remote data acquisition through use of an SEL-2240 Axion®. The Axion provides remote analog and digital data over an IEC 61158 EtherCAT® TiDL network. This technology provides very low and deterministic latency over a fiber point-to-point architecture. The SEL-451 relay can receive fiber links from as many as eight Axion remote data acquisition nodes.

Figure 1   Functional Diagram
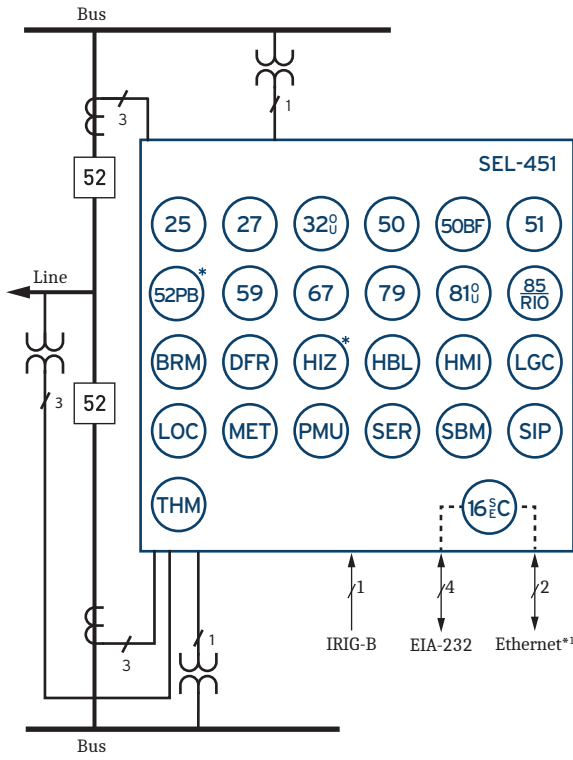
ANSI NUMBERS/ACRONYMS AND FUNCTIONS

25	Synchronism Check
27	Undervoltage
32 (O, U)	Over- and Underpower
50	Overcurrent
50BF	Dual Breaker Failure Overcurrent
51	Time-Overcurrent
52PB	Trip/Close Pushbuttons*
59	Overvoltage
67	Directional Overcurrent
79	Autoreclosing
81 (O, U)	Over- and Underfrequency

ADDITIONAL FUNCTIONS

16 SEC	Access Security (Serial, Ethernet)
50G	Best Choice Ground
85 RIO	SEL Mirrored Bits Communications
BRM	Breaker Wear Monitor
DFR	Event Reports
HBL	Harmonic Blocking
HIZ	High-Impedance Fault Detection Arc Sense™ Technology (AST)*
HMI	Operator Interface
LDE	Load Encroachment
LGC	Expanded SELogic Control Equations
LOC	Fault Locator
MET	High-Accuracy Metering
PMU	Synchrophasors
SBM	Station Battery Monitor
SER	Sequential Events Recorder
SIP	Software-Invertible Polarities
THM	IEC 60255-Compliant Thermal Model
TiDL	Time-Domain Link Remote Data Acquisition

[1]Copper or Fiber-Optic   * Optional Feature

Product Overview

PROTECTION	AUTOMATION	BAY CONTROL

• Synchrophasors
• Directional Overcurrent (67)
• Dual Circuit Breaker Failure (50 BF)
• Synchronism Check (25)
• Instantaneous Overcurrent (50)
• Time Overcurrent (51)
• Over/Undervoltage (27/59)
• Over/Underpower (32)
• Frequency (81)
• Reclosing (79)
• Expanded SELogic Control Equations
• Event Reports and Oscillography
• Sequential Events Recorder (SER)
• Dual Breaker Condition Monitor
• Station Battery Monitor
• Fault Locator
• Load-Encroachment Supervision
• TiDL Remote Data Acquisition
	• Ethernet Communications Protocols
	  IEC 61850 Edition 2
	  DNP3 LAN/WAN
	  FTP
	  Telnet
	  PRP
	  PTP
	  C37.118 Synchrophasors
	• Ethernet Media Options
	  10/100BASE-T Twisted Pair Network
	  100BASE-FX Fiber-Optic Network
	• Serial Communications Protocols
	  SEL ASCII Commands
	  SEL Mirrored Bits Communications
	  SEL Fast Messages
	  DNP3
	  IEEE C37.118 Synchrophasors V7.3
	• Password Separation of Automation and Protection
		• Configurable Bay Screen Display
		• Local Control–Up to Two Breakers
		• Status Indication–Up to Three Breakers
		• Local Control and Status Indication–Up to 20 Disconnect Switches
		• Bay Screen Displays–Up to 24 Analog Quantities
		• Configurable Labels for Bus, Breakers, Disconnect Switches, and Bay
		• Password-Protected Control Functions
		• Local and Remote Modes
		• Control Confirmation Request
		• Operation Alarm for Breaker and Disconnect Switch
		• As many as 10 individual one-line diagrams available to HMI

Figure 2   Product Overview

Protection Features

Software-Invertible Polarities Save Commissioning Time and Costs

The SEL-451 provides software-invertible CT and PT polarities. You can invert individual phase CT and PT inputs to account for field wiring or invert whole CT terminals to change a relay zone of protection without having to change field wiring.

All signal processing uses the software-inverted polarities for CEV file generation, metering, and protection logic. COMTRADE file generation is isolated from the impacts of the inverted polarities, and records signals as applied to the relay terminals.

Directional Elements Increase Sensitivity and Security

The SEL-451 provides multiple directional elements to optimize security and sensitivity. Use ground and negative-sequence directional overcurrent elements to detect high-resistance faults when using communications-assisted tripping schemes.

The SEL-451 includes a number of directional elements for supervision of overcurrent elements. The negative-sequence directional element uses the same patented principle proven in our SEL-351 Relay. This directional element can be applied in virtually any application, regardless of the amount of negative-sequence voltage available at the relay location.

Ground overcurrent elements are directionally controlled by three directional elements working together:

➤ Negative-sequence voltage-polarized directional element

➤ Zero-sequence voltage-polarized directional element

➤ Zero-sequence current-polarized directional element

Our patented Best Choice Ground Directional Element selects the best ground directional element for the system conditions and simplifies directional element settings (you can override this automatic setting feature for special applications).

Communications-Assisted Tripping Schemes

Use communications to improve tripping time for better customer service. The SEL-451 is the ideal relay for use in pilot-based tripping schemes. Enhanced MIRRORED BITS communications with SEL fiber-optic transceivers provide 3–6 ms relay-to-relay transmission time. Among the schemes supported are the following:

➤ Permissive Overreaching Transfer Tripping (POTT)

➤ Directional Comparison Unblocking (DCUB)

➤ Directional Comparison Blocking (DCB)

Use the SELOGIC control equation TRCOMM to program specific elements, combinations of elements, inputs, etc., to perform communications scheme tripping and other scheme functions. The logic readily accommodates the following conditions:

➤ Current reversals

➤ Breaker open at one terminal

➤ Weak-infeed conditions at one terminal

➤ Switch-onto-fault conditions

Overcurrent Elements

The SEL-451 includes four phase, four negative-sequence, and four ground instantaneous overcurrent elements. The SEL-451 also includes six selectable operating quantity inverse-time overcurrent elements. You can select the operating quantities from the following:

IA, IB, IC, MAX(IA, IB, IC), I1, 3I2, IG

where IA, IB, IC can be fundamental or rms quantities from either circuit breaker or combined currents.

The time-overcurrent curves (listed in *Table 1*) have two reset characteristic choices for each time-overcurrent element. One choice resets the elements if current drops below pickup for one cycle. The other choice emulates the reset characteristic of an electromechanical induction disc relay.

Table 1 Time-Overcurrent Curves

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

Breaker Failure Protection

Incorporated into the SEL-451 is a full function breaker failure system. Current can be individually monitored in two breakers. High-speed open-pole detection logic allows you to set the pickup current below minimum load for sensitivity without sacrificing high-speed dropout. Even in cases with delayed current zero in the secondary of the CT caused by trapped flux, high-speed detection of circuit breaker opening is achieved. This feature is essential if breaker failure is initiated on all circuit breaker trips. A reset of less than one cycle reduces coordination times, improving stability.

Thermal Overload Protection

The SEL-451 supports three independent thermal elements that conform to the IEC 60255-149 standard. Use these elements to activate a control action or issue an alarm or trip when your equipment overheats as a result of adverse operating conditions.

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

Loss-of-Potential (LOP) Logic Supervises Directional Elements

The SEL-451 includes logic to detect an LOP caused by failures such as blown fuses, which can cause an incorrect operation in directional elements. Simple settings configure the LOP logic to either block or force forward ground and phase directional elements under these conditions. The logic checks for a sudden change in positive-sequence voltage without a corresponding change in positive- or zero-sequence current. Tests and field experience show that this principle is very secure and is faster than the tripping elements.

High-Impedance Fault Detection

High-impedance faults are short-circuit faults with fault currents smaller than what a traditional overcurrent protective relay can detect. The SEL-451 includes logic used to detect HIF signatures without being affected by loads

and other system operation conditions. A running average provides a stable prefault reference and adaptive tuning learns and tunes out feeder ambient noise conditions. Decision logic differentiates an HIF condition from other system conditions such as switching operations and noisy loads. As much as 40 minutes of high-impedance fault activity is stored in high-resolution COMTRADE format and a summary of HIF activity is available using ASCII commands. View important high-impedance fault data from available metering commands.

Six Independent Settings Groups Increase Operation Flexibility

The relay stores six settings groups. Select the active settings group by control input, command, or other programmable conditions. Use these settings groups to cover a wide range of control contingencies. Selectable settings groups make the SEL-451 ideal for applications requiring frequent settings changes and for adapting the bay to changing system conditions.

Selecting a group also selects logic settings. Program group logic to adjust settings for different operating conditions, such as station maintenance, seasonal operations, emergency contingencies, loading, source changes, and adjacent relay settings changes.

Combined Current for Protection Flexibility

In traditional relays, when protecting a line fed from two breakers, such as a breaker-and-a-half system or double-breaker system, you needed to combine the CT inputs before connecting these inputs to the relay. The SEL-451 can accept separate inputs from two separate CTs and mathematically combine the currents. This allows collecting separate current metering and breaker monitor information for each breaker. Breaker monitoring functions for two breakers are done within one relay. Individual breaker currents allow for breaker failure functions on a per-breaker basis within the SEL-451. Breaker diagnostics are reported on a comparative basis allowing for advanced, proactive troubleshooting.

Custom Control Capabilities

Customize control capabilities, adding stability and security to your system.

➤ Use expanded SELOGIC control equations to create advanced stability enhancements such as VAR-flow controlled time undervoltage load shedding.

➤ Combine frequency elements with voltage supervision for added security with underfrequency load-shedding systems.
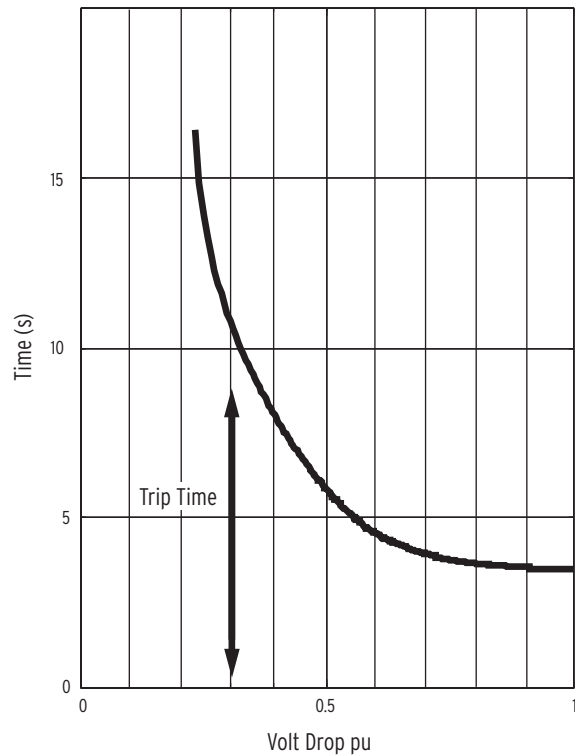
**Figure 3   VAR-Flow Controlled Time Undervoltage Load Shedding**

Control Inputs and Outputs

The standard SEL-451 includes five independent and two common inputs, two Form A and three Form C standard interrupting outputs, and three Form A high-current interrupting outputs. The following additional I/O boards are currently available.

➤ Eight independent inputs, 13 standard Form A and two standard Form C contact outputs.

➤ Eight independent inputs, eight high-speed, high-current interrupting Form A contact outputs.

➤ Eight independent inputs, 13 high-current interrupting Form A outputs and two standard Form C contact outputs.

➤ Twenty-four inputs, six high-speed and two standard Form A contact outputs.

Assign the control inputs for protection and control functions, monitoring logic, and general indication. Each control output is programmable using SELOGIC control equations. No additional I/O boards can be added to the 3U chassis; however, one board can be added to the 4U chassis, and two additional I/O boards can be added to the 5U chassis.

Multifunction Reclosing With Flexible Applications
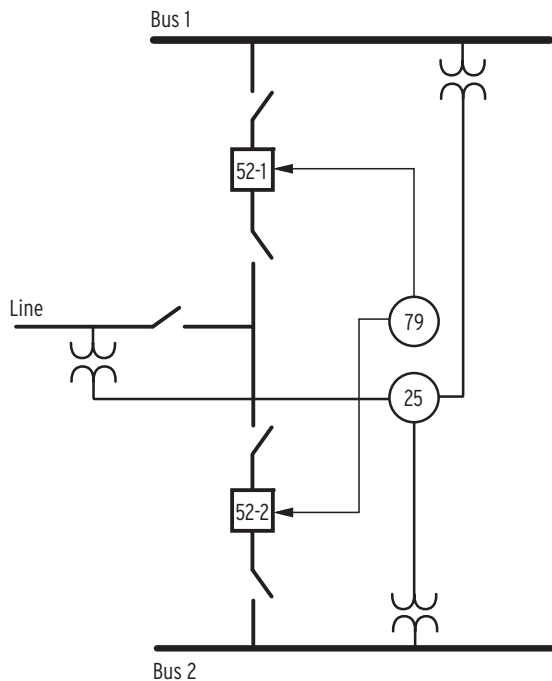
Figure 4   Two-Breaker Reclosing With Synchronism Check

The SEL-451 includes three-pole trip and reclose functions, for either one or two breakers (*Figure 4*). Synchronism check is included for breaker control. Synchronizing and polarizing voltage inputs are fully programmable with Dead Line/Dead Bus closing logic as well as zero-closing-angle logic to minimize system stress upon reclosing. Program as many as four reclose attempts. Select Leader and Follower breakers directly, or use a SELOGIC control equation to determine reclosing order based on system conditions.

Two-Breaker Control

The SEL-451 contains analog voltage inputs for multiple sources and control inputs to indicate both breaker and disconnect position, as well as the logic required to provide full control for two breakers. This includes separate monitoring functions as well as separate elements for tripping and closing the two breakers to allow for leader/follower operation or other desired control schemes. All analog values are monitored on a per-breaker basis to allow station control access to complete information for individual components of the system.

Backup Protection

Add reliability and dependability by providing independent backup protection without increasing relay count. Use each SEL-451 to provide primary directional overcurrent protection with backup nondirectional overcurrent protection on the adjacent feeder. For additional flexibility, use the available I/O or MIRRORED BITS to switch protection upon loss of one relay.
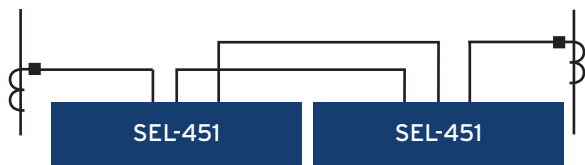
Figure 5   Using Two Cross-Connected SEL-451-5 Relays to Provide Primary and Backup Protection for Two Feeders

Bay Control

The SEL-451 Bay Control provides dynamic bay one-line diagrams on the front-panel screen with disconnect and breaker control capabilities for numerous predefined user-selectable bay types. Additional user-selectable bay types are available via a QuickSet interface that can be downloaded at selinc.com. The bay control is equipped to control as many as 10 disconnects and two breakers, depending on the one-line diagram selected. Certain one-line diagrams provide status for as many as three breakers and ten disconnect switches. Operate disconnects and breakers with ASCII commands, SELOGIC control equations, Fast Operate Messages, and from the one-line diagram. The one-line diagram includes user-configurable apparatus labels and as many as 24 user-definable Analog Quantities.

One-Line Bay Diagrams

The SEL-451 offers a variety of preconfigured one-line diagrams for common bus 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. Most 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 breakers and 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-451.

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. The SEL-451 will not only prevent the operator from making an incorrect control decision, but can notify and/or alarm when an incorrect operation is initiated.
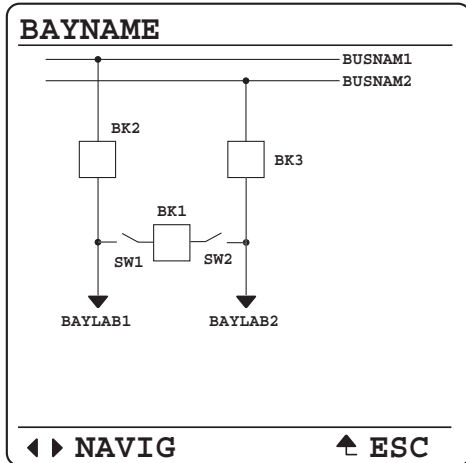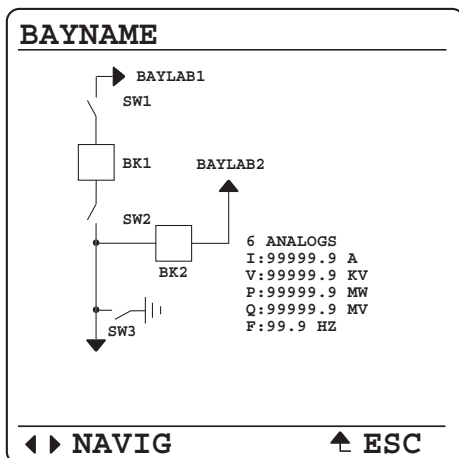

Figure 6   Breaker-and-a-Half
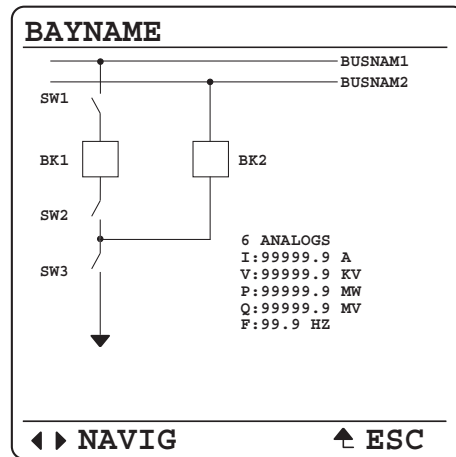

Figure 7   Ring Bus With Ground Switch

Figure 8   Double Bus/Double Breaker
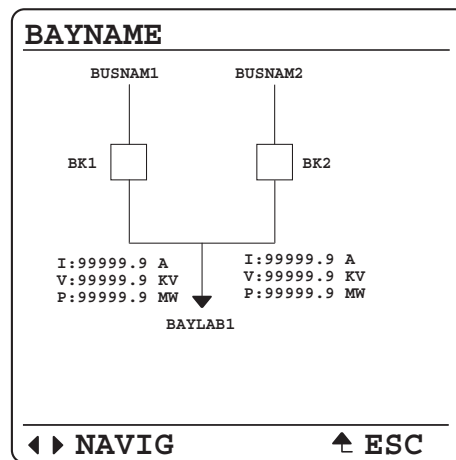
Figure 9   Source Transfer Bus

Circuit Breaker Operations From the Front Panel

Figure 6 through *Figure 9* are examples of some of the many selectable one-line diagrams in the SEL-451. The one-line diagram is selectable from the Bay settings. Additional settings for defining labels and analog quantities are also found in the Bay settings. One-line diagrams are composed of the following:

➤ Bay Names and Bay Labels (Bay Labels available in one-line diagrams 14, 17, 18, and 23. All other one-line diagrams use the Bay Name.)

➤ Busbar and Busbar Labels

➤ Breaker and Breaker Labels

➤ Disconnect Switches and Disconnect Switch Labels

➤ Analog Display Points

Figure 10 shows the Breaker Control Screens available when the **ENT** pushbutton is pressed with the circuit breaker highlighted as shown in *Figure 10* (a). After pressing the **ENT** pushbutton with the breaker highlighted

and the LOCAL Relay Word bit asserted, the Breaker Control Screen in *Figure 10* (b) is displayed. After entering the screen in *Figure 10* (b), the relay performs the circuit breaker operations as outlined in the SEL-451-5 *User's Guide*. If the LOCAL Relay Word bit is not asserted when the **ENT** pushbutton is pressed, the screen in *Figure 10* (c) is displayed for three seconds, then the bay control displays again the screen in *Figure 10* (a).
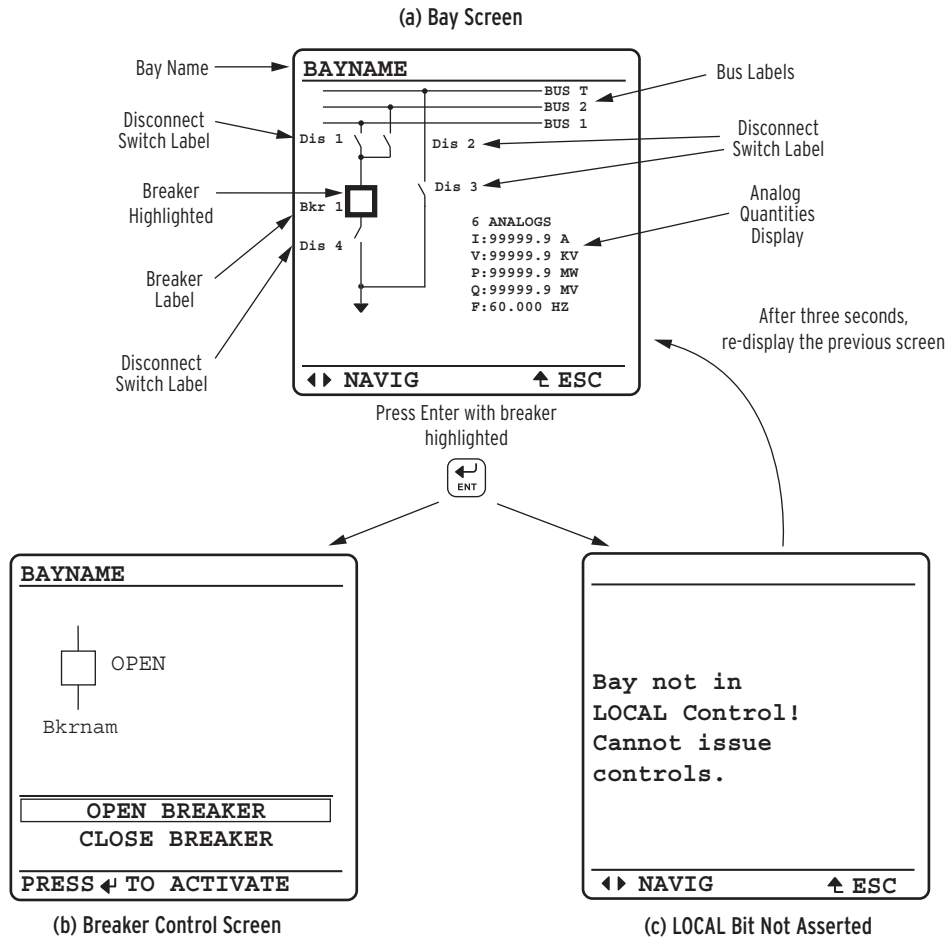
(a) Bay Screen

Bay Name
Disconnect Switch Label
Breaker Highlighted
Breaker Label
Disconnect Switch Label

BAYNAME
BUS T
BUS 2
BUS 1
Dis 1
Dis 2
Dis 3
Bkr 1
Dis 4
6 ANALOGS
I:99999.9 A
V:99999.9 KV
P:99999.9 MW
Q:99999.9 MV
F:60.000 HZ
◀▶ NAVIG   ⬆ ESC

Bus Labels
Disconnect Switch Label
Analog Quantities Display

After three seconds, re-display the previous screen

Press Enter with breaker highlighted

ENT

BAYNAME

OPEN

Bkrnam

OPEN BREAKER
CLOSE BREAKER

PRESS ↵ TO ACTIVATE

(b) Breaker Control Screen

Bay not in
LOCAL Control!
Cannot issue
controls.

◀▶ NAVIG   ⬆ ESC

(c) LOCAL Bit Not Asserted

Figure 10   Screens for Circuit Breaker Selection

Rack-Type Breakers Mosaics

The SEL-451 supports the display of rack-type (also referred to as truck-type) circuit breakers. The rack-type breakers have three positions: racked out, test, and racked in. When in the test or racked-in positions, the breaker can be displayed as open or closed. When racked out, there is no breaker open/close display. The rack-type breakers are a display-only functionality and do not impact any circuit breaker control capabilities.

Status-Only Disconnects

The SEL-451 has the ability to designate a disconnect as having control functionality or being status-only. When a disconnect is designated as having control functionality, the disconnect can be selected and controlled from the relay front-panel HMI. When a disconnect is designated as status-only, the disconnect is displayed in the one-line diagram of the relay front-panel HMI, but it is not selectable when navigating the front-panel HMI. Three-position disconnects are also supported with control/display functionality on a per position basis.

Rules-Based Settings Editor

QuickSet develops settings on- or offline. The system automatically checks interrelated settings and highlights out-of-range settings. Settings are transferred by using a PC communications link with the SEL-451. The QuickSet interface supports Server 2008, Windows® 7 and Windows 8 operating systems, and can be used to open COMTRADE files from SEL and other products. Convert binary COMTRADE files to ASCII format for portability and ease of use. View real-time phasors and harmonic values.

QuickSet Bay Control Settings Interface

There are two ways to enter Bay Control settings by using the QuickSet settings interface. The standard style settings are displayed in traditional form under the Bay Control form. QuickSet also provides an interactive bay control setting entry method. The interactive method works by clicking on the one-line diagram labels. This action automatically displays all the settings for the device selected. This method provides an easy way of organizing and verifying all settings associated with the device.

Figure 11 illustrates the interactive bay control setting form in QuickSet. Click on an apparatus in the one-line diagram, and a form with apparatus-specific settings is displayed.

QuickSet Templates

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

➤ Lock and hide unused settings.

➤ Lock settings to match your standard for protection, I/O assignment, 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.

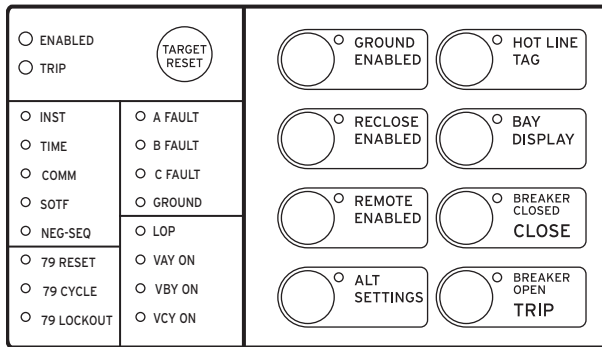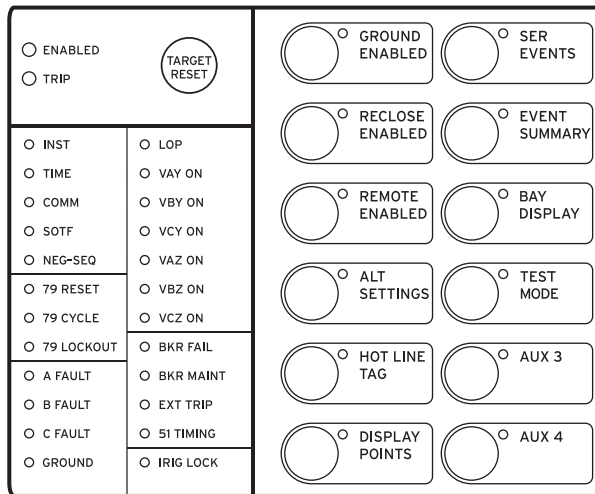**Figure 11   Interactive Bay Control Setting Form**

Front-Panel Display

The LCD shows event, metering, settings, and relay self-test status information. The target LEDs display relay target information as described in *Figure 12* and explained in *Table 2*.

Figure 12   Factory-Default Status and Trip Target LEDs (8 Pushbutton, 16 Target Option)

Figure 13   Factory-Default Status and Trip Target LEDs (12 Pushbutton, 24 Target Option)

The LCD is controlled by the navigation pushbuttons (*Figure 14*), automatic messages the relay generates, and programmable analog and digital display points. The rotating display scrolls through the bay screen, alarm points, display points, and metering screens. Each display remains for an adjustable time (1–15 seconds) before the display continues scrolling. Any message generated by the relay because of an alarm condition takes precedence over the rotating display.
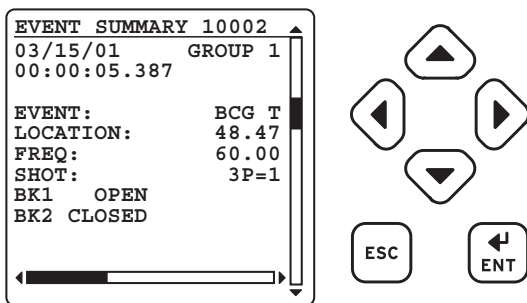
Figure 14   Front-Panel Display and Pushbuttons

Close-up views of the front panel of the SEL-451 are shown in *Figure 12*, *Figure 13*, and *Figure 14*. The front panel includes a 128 x 128 pixel, 3" x 3" LCD screen;

LED target indicators; and pushbuttons with indicating LEDs for local control functions. The asserted and deasserted colors for the LEDs are programmable. Configure any of the direct-acting pushbuttons to navigate directly to an HMI menu item, such as events, bay display, alarm points, display points, or the SER.

Status and Trip Target LEDs

The SEL-451 includes programmable target LEDs, as well as programmable direct-action control pushbuttons/LEDs on the front panel. These LEDs and pushbuttons are shown in *Figure 12* and *Figure 13*. Default Target LED assignments are explained in *Table 2*.

The SEL-451 features a versatile front panel that you can customize to fit your needs. Use SELOGIC control equations and slide-in configurable front-panel labels to change the function and identification of target LEDs and operator control pushbuttons and LEDs. The blank slide-in label set is included with the SEL-451. Label sets can be printed from a laser printer using templates supplied with the relay or hand labeled on supplied blank labels.

Table 2   Description of Factory-Default Target LEDs

Target LED	Function
ENABLED	Relay powered properly and self-tests okay
TRIP	Indication that a trip occurred
INST	High-speed rip
TIME	Time-delayed trip
COMM	Communications-assisted trip
SOTF	Switch-onto-fault trip
RECLOSER 79 RESET 79 CYCLE 79 LOCKOUT	Ready for reclose cycle Control in cycle state Control in lockout state
PHASE A, B, C GROUND	Phases involved in fault Ground involved in fault
LOP	Loss-of-potential condition
VOLTAGES VAY ON, VBY ON, VCY ON VAZ ON[a], VBZ ON[a], VCZ ON[a]	VY phase filtered instantaneous voltages applied VZ phase filtered instantaneous voltages applied
BKR FAIL[a]	Breaker Failure trip
BKR MAINT[a]	Breaker maintenance needed
EXT TRIP[a]	External trip detected
51 TIMING[a]	51 element picked up and timing
IRIG LOCKED[a]	IRIG synchronization detected

[a] Only available in 24-LED models.

Advanced Display Points

Create custom screens showing metering values, special text messages, or a mix of analog and status information with programmable display points. *Figure 15* shows an example of how display points can be used to show circuit breaker information and current metering. As many as 96 display points can be created. All display points occupy one, and only one, line on the display at all times. The height of the line is programmable as either single or double as shown in *Figure 15*. These screens become part of the autoscrolling display when the front panel times out.
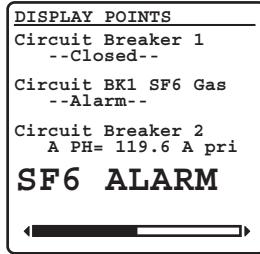

Figure 15   Sample Display Points Screen

Alarm Points

You can display messages on the SEL-451 front-panel LCD that indicate alarm conditions in the power system. The relay uses alarm points to place these messages on the LCD.

Figure 16 shows a sample alarm points screen. The relay is capable of displaying as many as 66 alarm points. The relay automatically displays new alarm points while in manual-scrolling mode and in autoscrolling mode. The alarm point messages are assigned using SER Points settings. The asterisk next to the alarm point indicates an active alarm. The inactive alarms can be acknowledged and cleared using the front-panel navigation buttons.
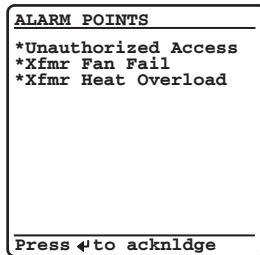

Figure 16   Sample Alarm Points Screen

Auxiliary Trip/Close Pushbuttons and Indicating LEDs

Optional auxiliary trip and close pushbuttons (see *Figure 17*) and indicating LEDs allow breaker control independent of the relay. The auxiliary trip/close pushbuttons are electrically separate from the relay, operating even if the relay is powered down. Make the extra connections at terminals **201** through **208**. See *Figure 28* for a rear-panel view. *Figure 18* shows one possible set of connections.

The auxiliary trip/close pushbuttons incorporate an arc suppression circuit for interrupting dc trip or close current. To use these pushbuttons with ac trip or close circuits, disable the arc suppression for either pushbutton by changing jumpers inside the SEL-451. The operating voltage ranges of the breaker **CLOSED** and breaker **OPEN** indicating LEDs are also jumper-selectable.

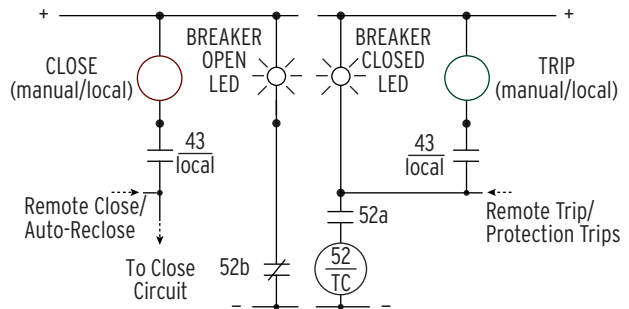**Figure 17   Operator Controls (Auxiliary Trip/Close Model)**

Figure 18   Optional Breaker Trip/Close Control Switches and Indicating Lamps

Monitoring and Metering

Complete Metering Capabilities

The SEL-451 provides extensive metering capabilities as listed in *Table 3*.

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 bay settings and control schemes. Oscillograms are available in binary COMTRADE and ASCII COMTRADE formats.

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. Decide how much detail is necessary when an event report is triggered: 8 kHz, 4 kHz, 2 kHz, or 1 kHz resolution analog data. The relay stores from 24 seconds of data per fault at 1 kHz resolution to 3 seconds per fault at 8 kHz resolution. Reports are stored in nonvolatile memory. Settings operational in the relay at the time of the event are appended to each event report.

Event Summary

Each time the SEL-451 generates a standard event report, it also generates a corresponding Event Summary. This is a concise description of an event that includes bay/terminal identification, event date and time, fault location, phase voltages, fault type at time of trip, and trip and close times of day.

With an appropriate setting, the relay will automatically send an Event Summary in ASCII text to one or more relay communications 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 input/output change of state, element pickup/dropout, recloser state changes, etc. The relay SER stores the latest 1,000 entries.

Voltage Sag, Swell, Interruption Records

The SEL-451 can perform automatic voltage disturbance monitoring for three-phase systems. The voltage sag/swell/interruption (VSSI) recorder uses the VSSI Relay Word bits to determine when to start (trigger) and when to stop recording. The VSSI recorder uses nonvolatile memory, so de-energizing the relay will not erase any stored VSSI data.

The recorded data are available through the VSSI report, which includes date, time, current, voltage, and voltage sag/swell/interruption (VSSI) element status during voltage disturbances, as determined by programmable settings VINT, VSAG, and VSWELL. When the relay is recording a disturbance, entries are automatically added to the VSSI report at one of four rates, depending on the length of the disturbance:

➤ Once per quarter cycle

➤ Once per cycle

➤ Once per 64 cycles

➤ Once per day

High-Accuracy Time Keeping

Using a combination of IRIG-B and a global positioning satellite, the SEL-451 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 single IRIG-B time-code input synchronizes the SEL-451 time to within ± 1 ms of the time-source input. A convenient source for this time code is the SEL-2032 Communications Processor (via Serial Port 1 on the SEL-451).

Precision Time Protocol (PTP) Time Synchronization

In addition to IRIG-B, the relay can be time-synchronized through the Ethernet network by using IEEE 1588 Precision Time Protocol, version 2 (PTPv2). When connected directly to a grandmaster clock providing PTP at 1-second sync inter-

vals, the relay can be synchronized to an accuracy of ±100 ns. The relay is capable of receiving as many as 32 sync messages per second.
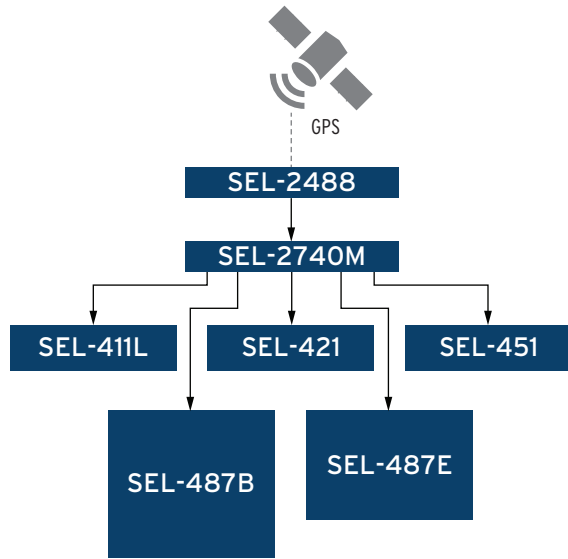

Figure 19   Example PTP Network

SNTP Time Synchronization

Use simple network time protocol (SNTP) to cost-effectively synchronize SEL-451 relays 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.
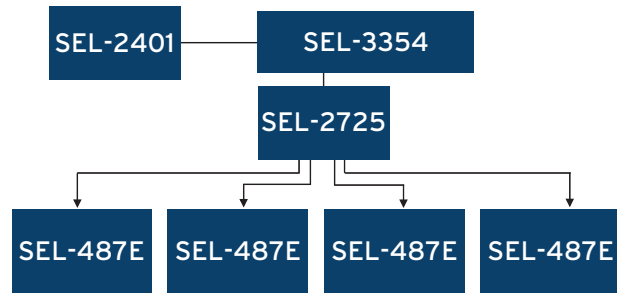

Figure 20   SNTP Diagram

Substation Battery Monitor for DC Quality Assurance

The SEL-451 measures and reports the substation battery voltage for two battery systems. Two sets of programmable threshold comparators and associated logic provide alarm and control of two separate batteries and chargers. The relay also provides dual ground detection. Monitor DC system status alarms with an SEL Communications Processor and trigger messages, telephone calls, or other actions.

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

Table 3   Metering Capabilities (Sheet 1 of 2)

| Capabilities	Description
Instantaneous Quantities	
Voltages $V_{A,B,C}$ (Y), $V_{A,B,C}$ (Z), V$\phi\phi$, 3V0, V1, 3V2	0–300 V with phase quantities for each of the six voltage sources available as a separate quantity.
Currents $I_{A,B,C}$ (W), $I_{A,B,C}$ (X) I_AL, I_BL, I_CL, (combined currents) IGL, I1L, 3I2L (combined currents)	Phase quantities for each of the two current sources available as a separate quantity or combined as line quantities.
Power/Energy Metering Quantities	
MW, MWh, MVAR, MVA, PF, single-phase and three-phase	Available for each input set and as combined quantities for the line.
Demand/Peak Demand Metering	
$I_{A,B,C}$, $3I_2$, $3I_0$	Thermal or rolling interval demand and peak demand.
MW, MVAR, MVA, single-phase	Thermal or rolling interval demand and peak demand.
MW, MVAR, MVA, three-phase	Thermal or rolling interval demand and peak demand.

Table 3   Metering Capabilities (Sheet 2 of 2)

Capabilities	Description
Synchrophasors	
Voltages (Primary Magnitude, Angle) $V_{A,B,C}$ (Y), $V_{A,B,C}$ (Z)	Primary phase quantities (kV) for each of the six voltage sources available.
Currents (Primary Magnitude, Angle) $I_{A,B,C}$ (W), $I_{A,B,C}$ (X)	Primary phase quantities (A) for each of the six current sources available.
Frequency FREQ dF/dT	Frequency (Hz) as measured by frequency source potential inputs. Rate-of-change of frequency (Hz/s).

Breaker Monitor Feature Allows for Wear-Based Breaker Maintenance Scheduling

Circuit breakers experience mechanical and electrical wear at each operation. Effective scheduling of breaker maintenance takes into account the manufacturer's published data of contact wear versus interruption levels and operation count. The SEL-451 dual breaker monitor feature compares the breaker manufacturer's published data to the integrated actual interrupted current and number of operations.

➤ Every time the breaker trips, the relay integrates interrupted current. When the result of this integration exceeds the threshold set by the breaker wear curve (*Figure 21*), the bay can alarm via an output contact or the optional front-panel display. With this information, you can schedule breaker maintenance in a timely, economical fashion.

➤ The relay monitors last and average mechanical and electrical interruption time. You can easily determine if operating time is increasing beyond reasonable tolerance to schedule proactive breaker maintenance. You can activate an alarm point if operation time goes beyond a preset value.

➤ Breaker motor run time and breaker inactivity are also monitored.
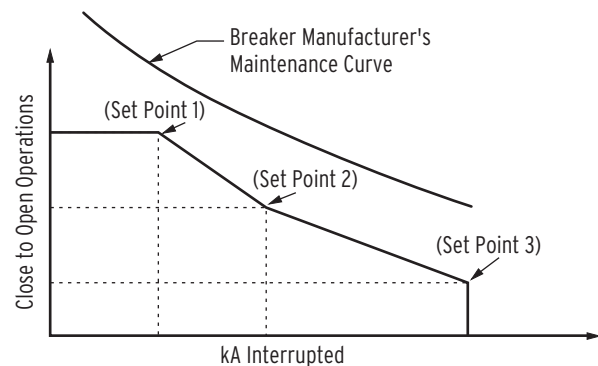
Figure 21   Breaker Contact Wear Curve and Settings

Automation

Time-Domain Link (TiDL) Technology

The SEL-451 supports remote data acquisition through use of an SEL Axion with a technology known as TiDL. The Axion provides remote analog and digital data over an IEC 61158 EtherCAT TiDL network. This technology provides very low and deterministic 1.5 ms latency over a point-to-point architecture. The SEL-451 can receive as many as eight fiber links from as many as eight Axion remote data acquisition nodes.

The relay supports a number of fixed topologies. The relay maps the voltage and current inputs from the Axion to existing analog quantities in the SEL-451 based on the connected topology. This limits the number of settings and makes converting an existing system to TiDL easy. *Figure 22* show sample TiDL topologies. The SEL-451-5 Instruction Manual shows all supported topologies.
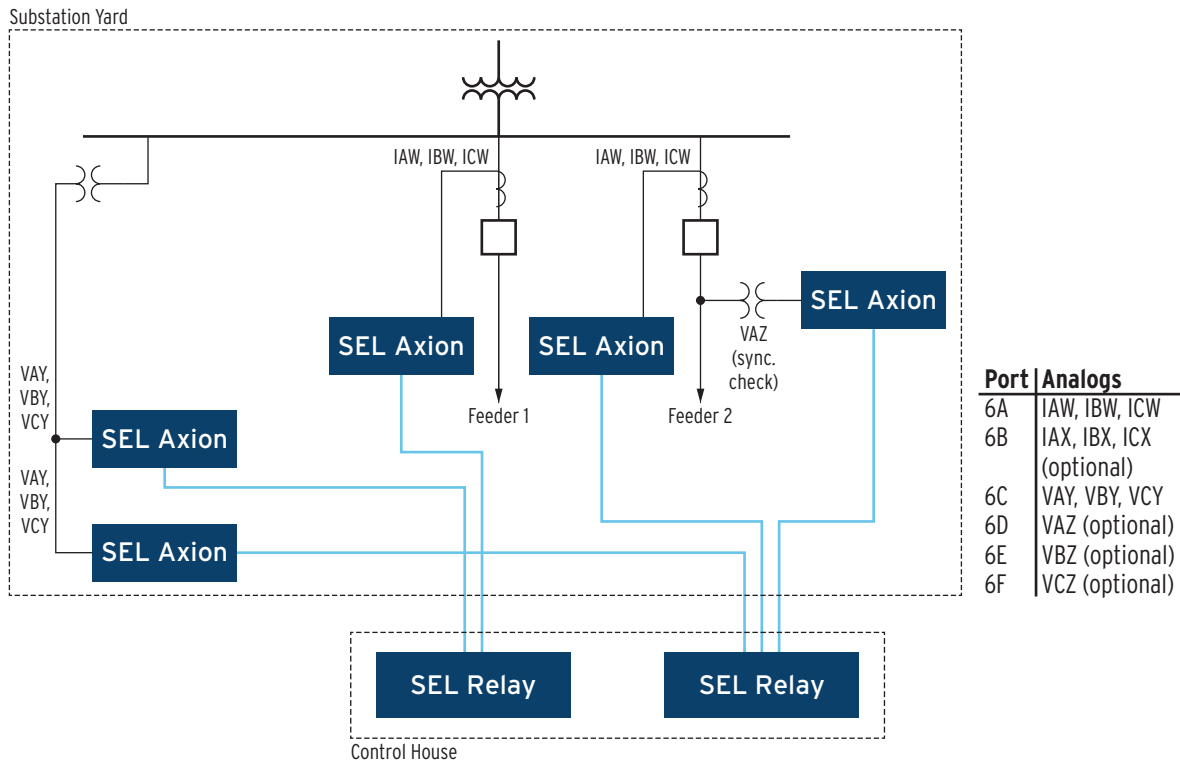
Figure 22 Sample SEL-451 Topology

Port	Analogs
6A	IAW, IBW, ICW
6B	IAX, IBX, ICX (optional)
6C	VAY, VBY, VCY
6D	VAZ (optional)
6E	VBZ (optional)
6F	VCZ (optional)

Flexible Control Logic and Integration Features

The SEL-451 control logic can be used to perform the following:

➤ Replace traditional panel control switches

➤ Eliminate remote terminal unit (RTU)-to-bay wiring

➤ Replace traditional latching relays

➤ Replace traditional indicating panel lights

Eliminate traditional panel control switches with 32 local control points. Set, clear, or pulse local control points with the front-panel pushbuttons and display. Program the local control points to implement your control scheme via SELOGIC control equations. Use the local control points for such functions as trip testing, enabling/disabling reclosing, and tripping/closing circuit breakers.

Eliminate RTU-to-bay wiring with 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, close, 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 latch control points retain states when the relay loses power.

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

Open Communications Protocols

The SEL-451 does not require special communications software. ASCII terminals, printing terminals, or a computer supplied with terminal emulation and a serial communications port are all that is required. *Table 4* lists a brief description of the terminal protocols.

Table 4   Open Communications Protocol

Type	Description
ASCII	Plain-language commands for human and simple machine communications. Use for metering, setting, self-test status, event reporting, and other functions.
Compressed ASCII	Comma-delimited ASCII data reports. Allows external devices to obtain bay data in an appropriate format for direct import into spreadsheets and database programs. Data are checksum protected.
Extended Fast Meter, Fast Operate, and Fast SER	Binary protocol for machine-to-machine communication. Quickly updates SEL-2032 Communications Processors, RTUs, and other substation devices with metering information, bay element, I/O status, time-tags, open and close commands, and summary event reports. Data are checksum protected. Binary and ASCII protocols operate simultaneously over the same communications lines so that control operator metering information is not lost while a technician is transferring an event report.
Ymodem	Support for reading event, settings, and oscillography files.
DNP3 Level 2 Outstation	Distributed Network Protocol with point remapping. Includes access to metering data, protection elements, contact I/O, targets, SER, relay summary event reports, and settings groups.
IEEE C37.118	Phasor measurement protocol.
IEC 61850 Edition 2	Ethernet-based international standard for interoperability between intelligent devices in a substation.

Table 5   SELOGIC Control Equation Operators

Operator Type	Operators	Comments
Boolean	AND, OR, NOT	Allows combination of measuring units.
Edge Detection	F_TRIG, R_TRIG	Operates at the change of state of an internal function.
Comparison	>, >=, =, <=, <, < >	
Arithmetic	+, −, *, /	Uses traditional math functions for analog quantities in an easily programmable equation.
Numerical	ABS, SIN, COS, LN, EXP, SQRT LOG	
Precedence Control	( )	Allows multiple and nested sets of parentheses.
Comment	# (* *)	Provides for easy documentation of control and protection logic.

SELOGIC Control Equations With Expanded Capabilities and Aliases

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

Programming SELOGIC control equations consists of combining relay elements, inputs, and outputs with SELOGIC control equation operators (*Table 5*). Any element in the Relay Word can be used in these equations. For complex or unique applications, these expanded SELOGIC functions allow superior flexibility.

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

```
=>>SET T <Enter>
 1: PMV01,THETA
```
(assign the alias "THETA" to math variable PMV01)
```
 2: PMV02,TAN
```
(assign the alias "TAN" to math variable PMV02)
```
=>>SET L <Enter>
 1: # CALCULATE THE TANGENT OF THETA
 2: TAN:=SIN(THETA)/COS(THETA)
```
(use the aliases in an equation)

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

➤ Emulate a motor-driven reclose timer, including stall, reset, and drive-to-lockout conditions (refer to *Figure 23*).

➤ Scale analog values for SCADA retrieval.

➤ Initiate remedial action sequence based on load flow before fault conditions.
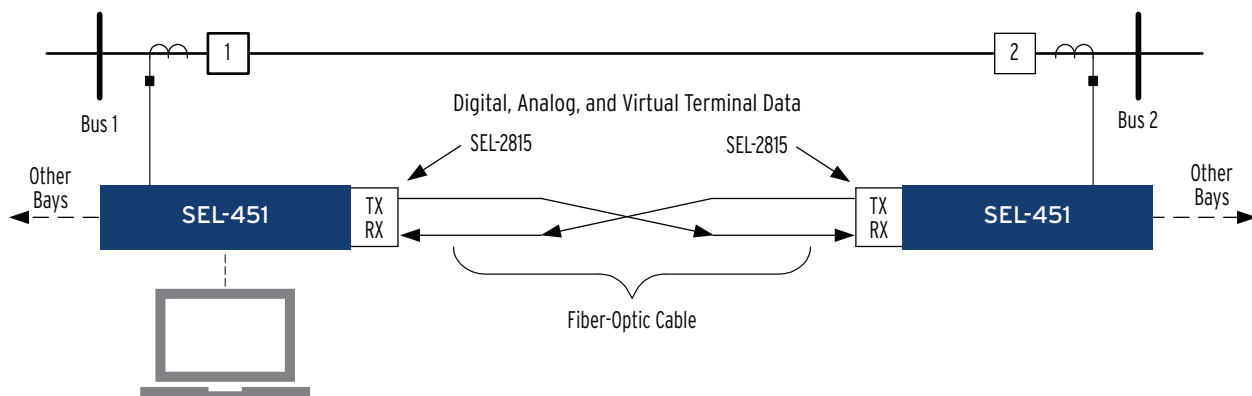
➤ Interlock breakers and disconnect switches.

➤ Restrict breaker tripping in excessive duty situations without additional relays.

➤ Construct a compensated overvoltage element for open line overvoltage protection.

➤ Hold momentary change-of-state conditions for SCADA polling.

➤ Provide a combination of frequency or rate-of-change-of-frequency functions.
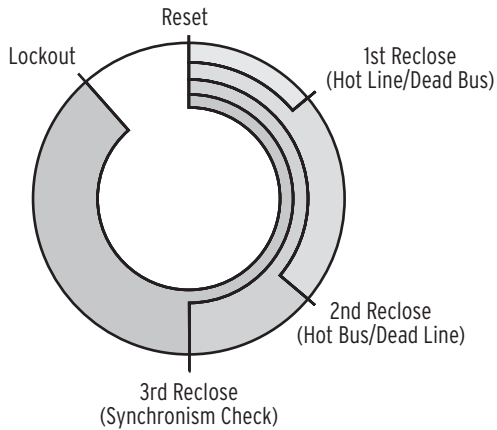
Figure 23   Motor-Driven Reclose Timer

Relay-to-Relay Digital Communications (MIRRORED BITS)

The SEL patented MIRRORED BITS technology provides bidirectional relay-to-relay digital communication (*Figure 24*). In the SEL-451, MIRRORED BITS can operate simultaneously on any two serial ports for three-terminal power system operation.
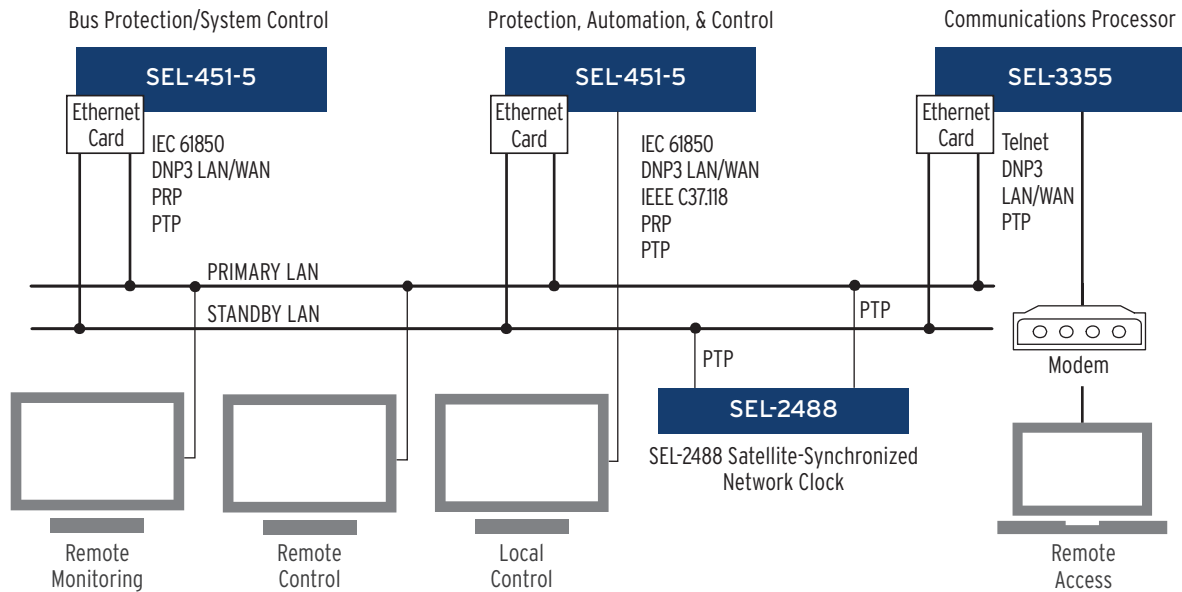
This bidirectional digital communication creates additional outputs (transmitted MIRRORED BITS) and additional inputs (received MIRRORED BITS) for each serial port operating in the MIRRORED BITS communications mode. Communicated information can included digital, analog, and virtual terminal data. Virtual terminal allows operator access to remote bays through the local bay. These MIRRORED BITS can be used to transfer information between line terminals to enhance coordination and achieve faster tripping. MIRRORED BITS also help reduce total pilot scheme operating time by eliminating the need to close output contacts and debounce contact outputs. Use the dual-port MIRRORED BITS communications capabilities for high-speed communications-assisted schemes applied to three-terminal transmission lines.

Communication

The SEL-451 offers the following serial communication features.

➤ Four independent EIA-232 serial ports.

➤ Full access to event history, relay status, and meter information.

➤ Settings and group switching have three levels of password protection.

➤ DNP3 Level 2 Outstation.

➤ Patented SEL Fast Message Interleaving of ASCII and binary data for SCADA communications, including access to SER, relay element targets, event data and more.

➤ Communication of synchronized phasor measurement data using either SEL Fast Messaging for Synchrophasors or IEEE C37.118–2005 *Standard for Synchrophasors for Power Systems*.

Figure 24   Integral Communication Provides Secure Protection, Monitoring, and Control, as Well as Terminal Access to Both Relays Through One Connection

Network Connection and Integration

Figure 25   Network Connection and Integration

Connect the SEL-451 to Local Area Networks (LANs) by using the optional Ethernet card. The integrated Ethernet card supports both copper and/or fiber connections with failover protection.

Ethernet Card

The optional Ethernet card mounts directly in the SEL-451. Use popular Telnet applications for easy terminal communications with SEL relays and other devices. Transfer data at high speeds (10 Mbps or 100 Mbps) for fast HMI updates and file uploads. The Ethernet card communicates using File Transfer Protocol (FTP) applications for easy and fast file transfers.

Provide operations with situational awareness of the power system by using IEEE C37.118-2005 Standard for Synchrophasors for Power Systems. Communicate with SCADA and other substation intelligent electronic devices (IEDs) by using DNP3 or IEC 61850 logical nodes and GOOSE messaging.

Choose Ethernet connection media options for primary and standby connections:

➤ 10/100BASE-T Twisted Pair Network

➤ 100BASE FX Fiber-Optic Network

Telnet and FTP

Order the SEL-451 with Ethernet communication and use the built-in Telnet and File Transfer Protocol (FTP) that come standard with Ethernet to enhance relay com-

munications sessions. Use Telnet to access relay settings, and metering and event reports remotely using the ASCII interface. Transfer settings files to and from the relay via the high-speed Ethernet port through use of FTP.

IEEE C37.118 Synchrophasors

The latest IEEE Synchrophasor Protocol provides a standard method for communicating synchronized phasor measurement data over Ethernet or serial media. The integrated Ethernet card in the SEL-451 provides two independent connections by using either TCP/IP, UDP/IP, or a combination thereof. Each connection supports unicast or multicast options for serving data to one or multiple clients simultaneously. Each data stream can support data streams at as fast as 60 frames per second.

DNP3 LAN/WAN

The DNP3 LAN/WAN option provides the SEL-451 with DNP3 Level 2 Outstation functionality over Ethernet. Custom DNP3 data maps can be configured for use with specific DNP3 masters. The PTP power profile is also supported over PRP.

Precision Time Protocol (PTP)

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

Parallel Redundancy Protocol (PRP)

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

HTTP Web Server

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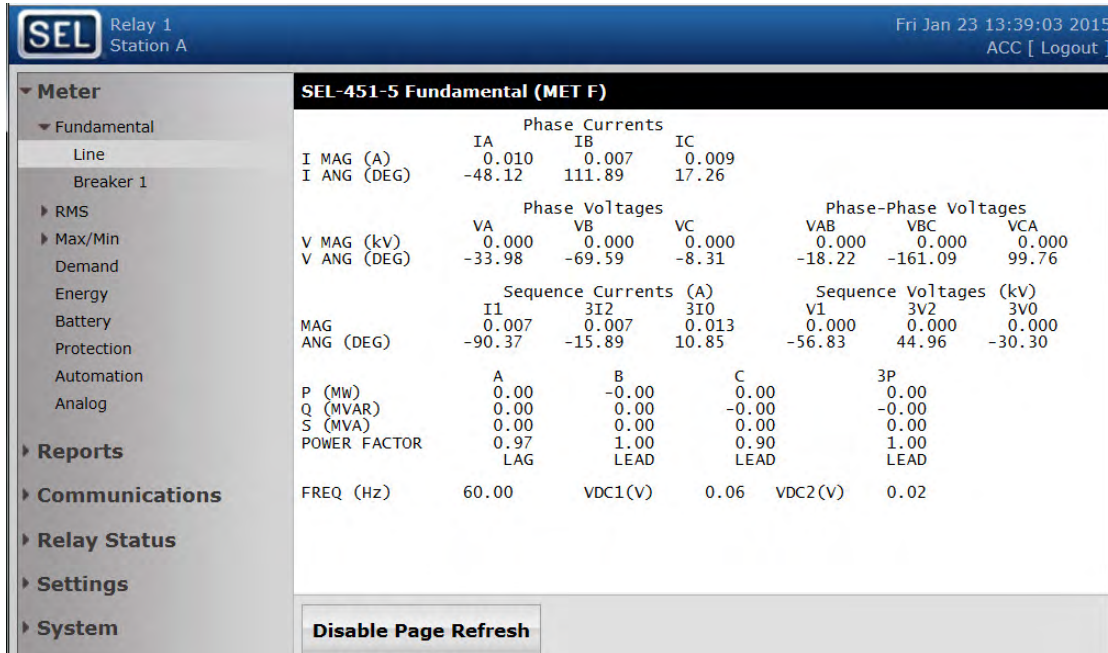

Figure 26   Typical Web Server Default Menu Screen

IEC 61850 Edition 2 Ethernet Communications

IEC 61850 Edition 2 Ethernet-based communications provide interoperability among IEDs within the substation. Logical nodes using IEC 61850 allow standardized interconnection of IEDs from different manufacturers for monitoring and control of the substation. Reduce wiring among various manufacturers' devices and simplify operating logic with IEC 61850. Eliminate system RTUs by streaming monitoring and control information from IEDs directly to remote SCADA client devices.

The SEL-451 can be ordered with embedded IEC 61850 Edition 2 protocol operating on 100 Mbps Ethernet. Use the IEC 61850 Edition 2 Ethernet protocol for relay monitoring and control functions, including the following:

➤ As many as 128 incoming GOOSE messages. The incoming GOOSE messages can be used to control as many as 256 control bits and 256 analog quantities 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 and/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 Edition 2 Data Server. The SEL-451 is equipped with embedded IEC 61850 Ethernet protocol that provides data according to pre-defined 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 control equations can be monitored using the IEC 61850 data server provided in the relay.

MMS File Services

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

MMS Authentication

When enabled via a setting in the CID file, the relay will require authentication from any client requesting to initiate an MMS session. The client request must be accompanied by the 2AC level password.

ACSELERATOR Architect

Use ACSELERATOR Architect® SEL-5032 Software to manage the logical node data for all IEC 68150 devices on the network. This Windows-based software provides easy-to-use displays for identifying and binding IEC 61850 network data between logical nodes by using IEC 61850-compliant Configured IED Description (CID) files. Architect uses CID files to describe the data the IEC 61850 logical node provides within each relay.

Front- and Rear-Panel Diagrams
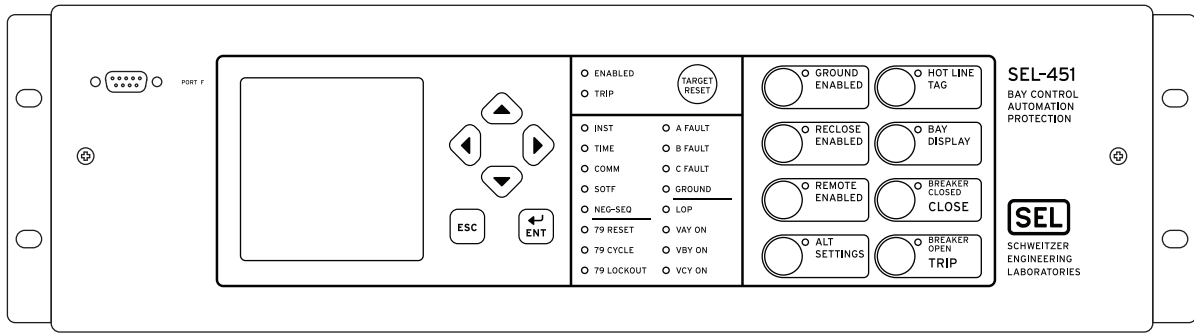
3U Front Panel, Rack-Mount Option With Optional Bay Control Overlay
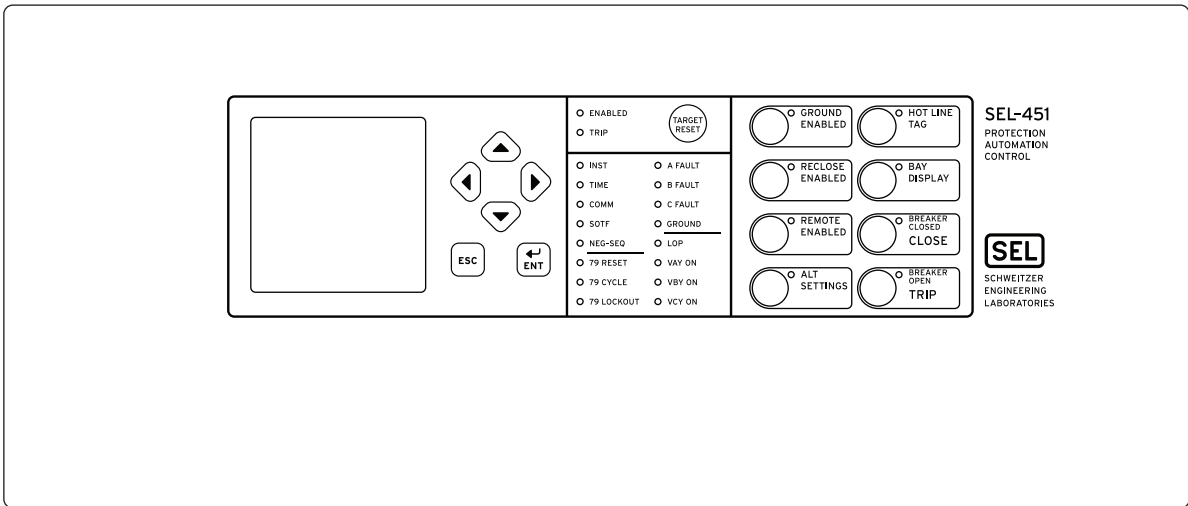
4U Front Panel, Panel-Mount Option
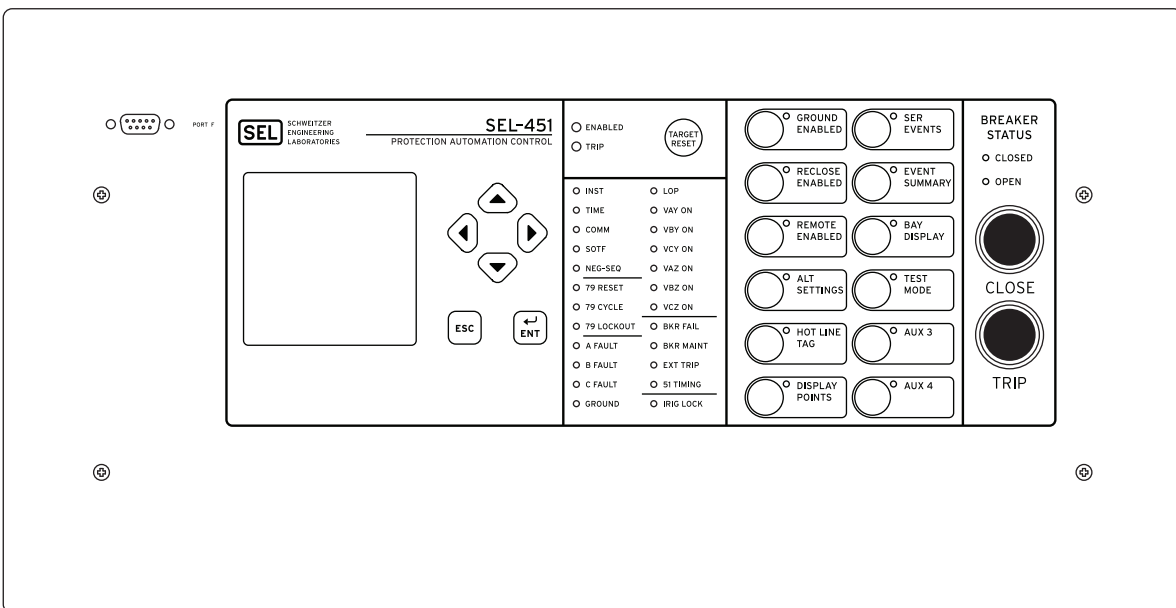
5U Front Panel, Panel-Mount Option With Auxiliary Trip/Close Pushbuttons

Figure 27   Typical SEL-451 Front-Panel Diagrams
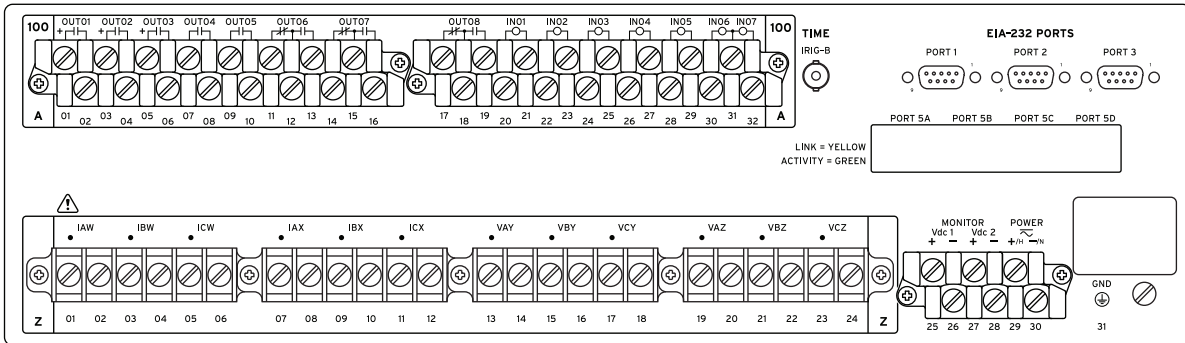
3U Rear Panel, Main Board

i7014c
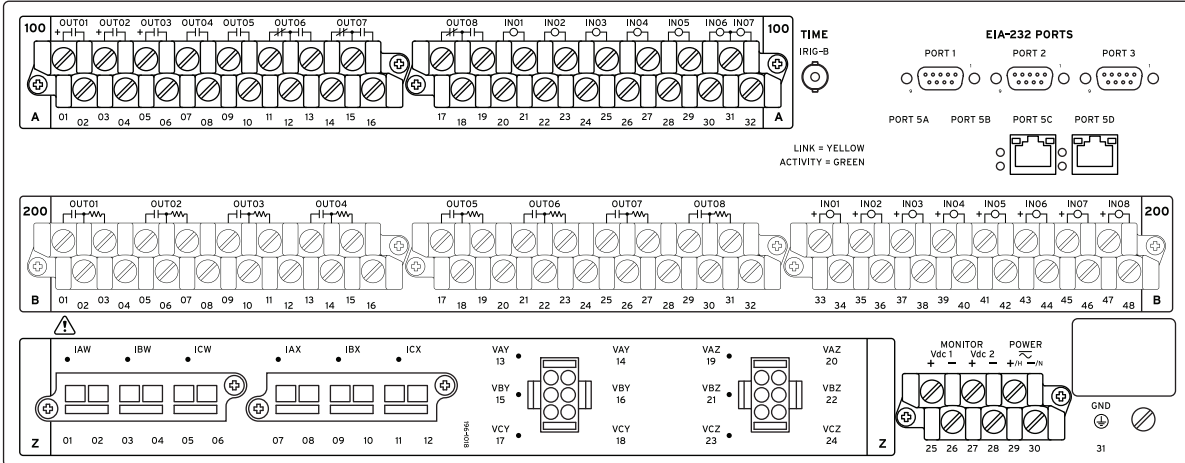
4U Rear Panel, Main Board, Connectorized® Option, INT5 I/O Board
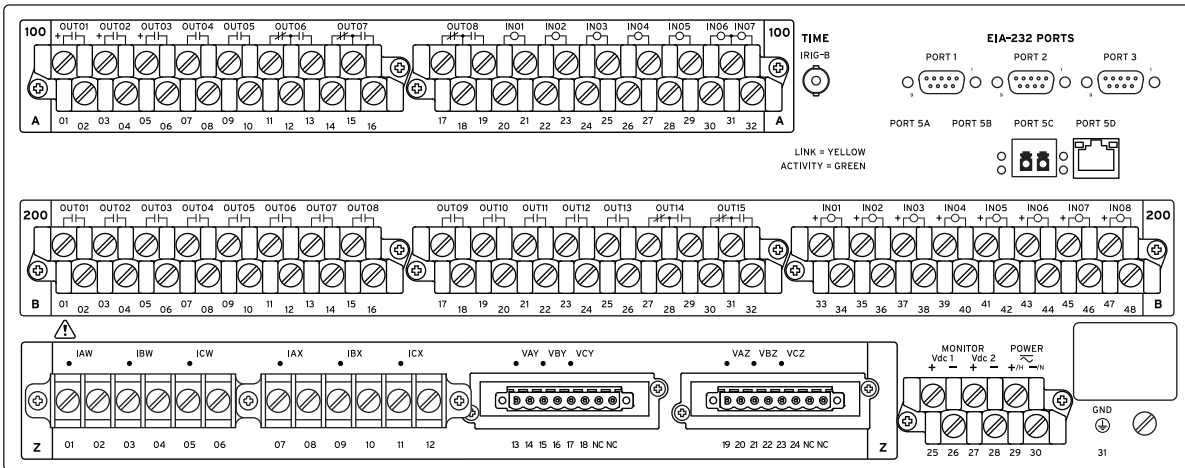
i7015c

4U Rear Panel, Main Board, INT1 I/O Board, Low Energy Analog (LEA) Voltage Inputs

i7015c

Figure 28   Typical 3U and 4U SEL-451 Rear-Panel Diagrams
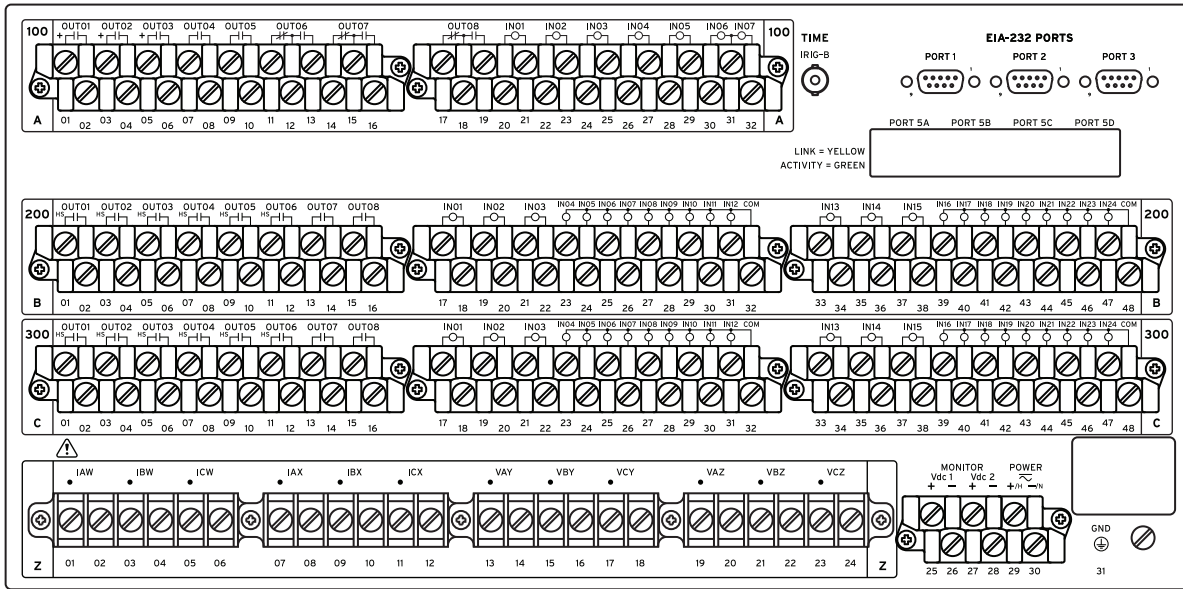
5U Rear Panel, Main Board, With Two INT4 I/O Boards

Figure 29   Typical 5U SEL-451 Rear-Panel Diagram
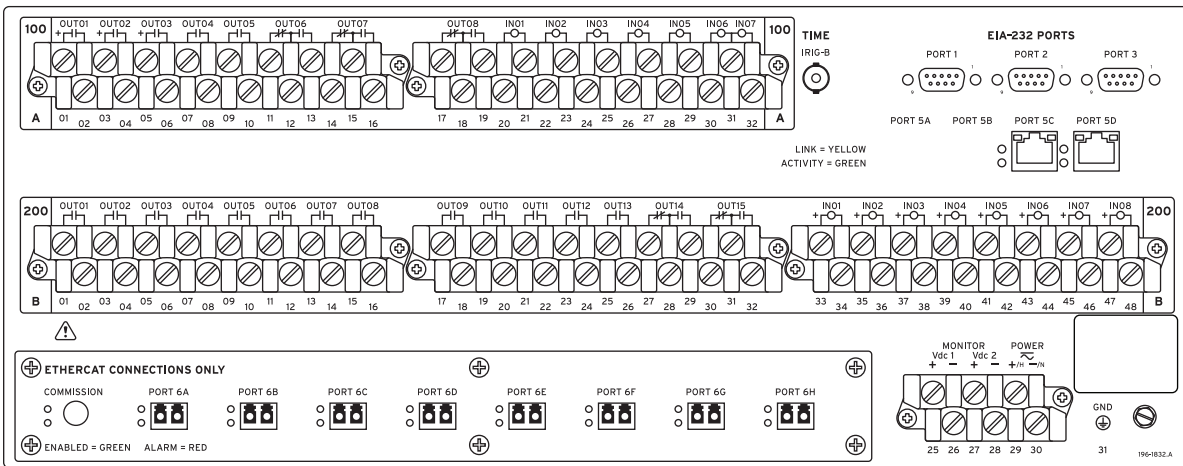
Figure 30   Rear Panel With EtherCAT Board

Relay Dimensions

RACK-MOUNT CHASSIS

RACK
MOUNT

PROJECTION
RACK MOUNT

* 8.50
(215.9)

TOP

* 6.10
(154.9)

** 3.52
(89.4)

** 1.12
(28.4)

19.00
(482.6)

A

FRONT

B

18.31
(465.1)

DIMENSION	MAIN BOARD ONLY (3U)	ONE I/O BOARD (4U)	TWO I/O BOARD (5U)
A	5.22 (132.6)	6.97 (177.0)	8.72 (221.5)
B	2.25 (57.2)	4.00 (101.6)	5.75 (146.0)
C	6.65 (168.9)	8.40 (213.4)	10.15 (257.8)
D	5.10 (129.5)	6.85 (174.0)	8.60 (218.4)

*ADD 0.30 (7.6) FOR CONNECTORIZED RELAYS

PANEL-MOUNT CHASSIS

* 8.50
(215.9)

TOP

#10-32
STUD

** 1.12
(28.4)

19.80
(502.9)

C

FRONT

SIDE

17.63
(447.8)

Ø1/4
(Ø6.4)

LEGEND
in
(mm)

D

PANEL CUTOUT

B

18.31
(465.1)

**ADD 0.50 (12.7) FOR PUSHBUTTON OPTION
ADD 1.00 (25.4) FOR PUSHBUTTON WITH GUARD
---OPTIONAL PUSHBUTTON

(Horizontal Mounting Shown; Dimensions Also Apply to Vertical Mounting)

Figure 31   SEL-451 Dimensions for Rack- and Panel-Mount Models

Specifications

Note: If the relay is using a remote data acquisition system, such as TiDL, the operating times will be delayed by 1.5 ms. Use caution when setting the relay coordination times to account for this added delay. Element operate times will also have this small added delay.

Compliance

Designed and manufactured under an ISO 9001 certified quality management system

47 CFR 15B Class A

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

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

CE Mark

General

AC Analog Inputs

Sampling Rate:	8 kHz

AC Current Input (Secondary Circuits)

Note: Current transformers are Measurement Category II.

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

1 A Nominal:	18.2 A
5 A Nominal:	91 A

Continuous Thermal Rating

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

Saturation Current (Linear) Rating

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

A/D Current Limit

Note: Signal clipping may occur beyond this limit.

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

One-Second Thermal Rating

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

One-Cycle Thermal Rating

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

Burden Rating

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

AC Voltage Inputs

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

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

LEA Voltage Inputs

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

Common Mode Voltage

Operation:	50 Vac
Without Damage:	300 Vac

Frequency and Rotation

Nominal Frequency Rating:	50 ±5 Hz 60 ±5 Hz
Phase Rotation:	ABC or ACB
Frequency Tracking Range:	40–65 Hz < 40 Hz = 40 Hz > 65 Hz = 65 Hz
Default Slew Rate:	15 Hz/s

Power Supply

24-48 Vdc

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

48-125 Vdc or 110-120 Vac

Rated Voltage:	48–125 Vdc, 110–120 Vac
Operational Voltage Range:	38–140 Vdc 85–140 Vac
Rated Frequency:	50/60 Hz
Operational Frequency Range:	30–120 Hz
Vdc Input Ripple:	15% per IEC 60255-26:2013
Interruption:	14 ms at 48 Vdc, 160 ms at 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 at 125 Vdc, 250 ms at 250 Vdc per IEC 60255-26:2013
Burden:	< 35 W, < 90 VA

Control Outputs

Standard

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

Breaking Capacity (10,000 Operations):

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):

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

Hybrid (High-Current Interrupting)

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

Breaking Capacity (10,000 Operations):

48 Vdc	10.0 A	L/R = 40 ms
125 Vdc	10.0 A	L/R = 40 ms
250 Vdc	10.0 A	L/R = 20 ms

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

48 Vdc	10.0 A	L/R = 40 ms
125 Vdc	10.0 A	L/R = 40 ms
250 Vdc	10.0 A	L/R = 20 ms

Note: Do not use hybrid control outputs to switch ac control signals. These outputs are polarity-dependent.

High-Speed High-Current Interrupting

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

Breaking Capacity (10,000 Operations):

48 Vdc	10.0 A	L/R = 40 ms
125 Vdc	10.0 A	L/R = 40 ms
250 Vdc	10.0 A	L/R = 20 ms

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

48 Vdc	10.0 A	L/R = 40 ms
125 Vdc	10.0 A	L/R = 40 ms
250 Vdc	10.0 A	L/R = 20 ms

Note: Per IEC 60255‑23:1994, using the simplified method of assessment.

Note: Make rating per IEEE C37.90‑2005.

Note: Per IEC 61810‑2:2005.

Auxiliary Breaker Control Pushbuttons

Quantity:	2
Pushbutton Functions:	One (1) pushbutton shall be provided to open the breaker.
	One (1) pushbutton shall be provided to close the breaker.

Resistive DC or AC Outputs With Arc Suppression Disabled

Make:	30 A per IEEE C37.90‑2005
Carry:	6 A continuous carry
1 s Rating:	50 A
MOV Protection:	250 Vac/330 Vdc/130 J

Breaking Capacity (10,000 Operations):

48 V	0.50 A	L/R = 40 ms
125 V	0.30 A	L/R = 40 ms
250 V	0.20 A	L/R = 40 ms

High-Interrupt DC Outputs With Arc Suppression Enabled

Make:	30 A per IEEE C37.90‑2005
Carry:	6 A continuous carry
1 s Rating:	50 A
MOV Protection:	330 Vdc/130 J

Breaking Capacity (10,000 Operations):

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

Breaker Open/Closed LEDs:

48 Vdc: on for 30–60 Vdc;
125 Vdc: on for 80–150 Vdc; 96–144 Vac
250 Vdc: on for 150–300 Vdc; 192–288 Vac

Note: With nominal control voltage applied, each LED draws 8 mA (max.). Jumpers may be set to 125 Vdc for 110 Vdc input and set to 250 Vdc for 220 Vdc input.

Control Inputs

Direct Coupled (Use With DC Signals)

INT1, INT5, and INT6 Interface Boards:	8 inputs with no shared terminals
Range:	15–265 Vdc, independently adjustable
Accuracy:	±5% ±3 Vdc
Maximum Voltage:	300 Vdc
Sampling Rate:	2 kHz
Typical Burden:	0.24 W @125 Vdc

Optoisolated (Use With AC or DC Signals)

Main Board:	5 inputs with no shared terminals
	2 inputs with shared terminals
INT2, INT7, and INT8 Interface Boards:	8 inputs with no shared terminals
INT3 and INT4 Interface Boards:	6 inputs with no shared terminals
	18 inputs with shared terminals (2 groups of 9 inputs, with each group sharing one terminal)
Voltage Options:	24 V standard
	48, 110, 125, 220, 250 V level sensitive

DC Thresholds

(Dropout thresholds indicate level-sensitive option.)

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

AC Thresholds

(Ratings met only when recommended control input settings are used)

24 Vac:	Pickup 16.4–30.0 Vac rms
48 Vac:	Pickup 32.8–60.0 Vac rms; Dropout < 20.3 Vac rms
110 Vac:	Pickup 75.1–132.0 Vac rms; Dropout < 46.6 Vac rms
125 Vac:	Pickup 89.6–150.0 Vac rms; Dropout < 53.0 Vac rms
220 Vac:	Pickup 150.3–264 Vac rms; Dropout < 93.2 Vac rms
250 Vac:	Pickup 170.6–300 Vac rms; Dropout < 106 Vac rms
Current Drawn:	< 5 mA at nominal voltage < 8 mA for 110 V option
Sampling Rate:	2 kHz

Communications Ports

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

Communications Card Slot for Optional Ethernet Card

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

Communications Ports for Optional TiDL Interface

EtherCAT Fiber-Optic Ports:	8
Data Rate:	Automatic
Connector Type:	LC fiber
Protocols:	Dedicated EtherCAT

Class 1 LASER/LED

Wavelength:	1300 nm
Fiber Type:	Multimode
Link Budget:	11 dB
Min. TX Power:	–20 dBm
Min. RX Sensitivity:	–31 dBm
Fiber Size:	50–200 μm
Approximate Range:	2 km
Data Rate:	100 Mbps
Typical Fiber Attenuation:	–2 dB/km

Time Inputs

IRIG Input–Serial Port 1

Input:	Demodulated IRIG-B
Rated I/O Voltage:	5 Vdc
Operating 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
Operating Voltage Range:	0–8 Vdc
Logic High Threshold:	≥2.2 Vdc
Logic Low Threshold:	≤0.8 Vdc
Input Impedance:	50 Ω or > 1 kΩ
Dielectric Test Voltage:	0.5 kVac

PTP–Ethernet Port 5A, 5B

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

Operating Temperature

–40° to +85°C (–40° to +185°F)

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

Humidity

5% to 95% without condensation

Weight (Maximum)

3U Rack Unit:	8.0 kg (17.7 lb)
4U Rack Unit:	9.8 kg (21.6 lb)
5U Rack Unit:	11.6 kg (25.6 lb)

Terminal Connections

Rear Screw-Terminal Tightening Torque, #8 Ring Lug

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

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

Wire Sizes and Insulation

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

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

Type Tests

These tests do not apply to contacts rated for 24 Vdc.

Electromagnetic Compatibility (EMC)

Emissions:	IEC 60255-25:2000

Electromagnetic Compatibility Immunity

Conducted RF Immunity:	IEC 60255-22-6:2001, 10 Vrms IEC 61000-4-6:2008, 10 Vrms
Electrostatic Discharge Immunity:	IEEE C37.90.3-2001 Levels 2, 4, 8 kV contact; Levels 4, 8, 15 kV air IEC 60255-22-2:2008 IEC 61000-4-2:2008 Levels 2, 4, 6, and 8 kV contact; Levels 2, 4, 8, and 15 kV air

Fast Transient/Burst Immunity:	IEC 60255‑22‑4:2008 4 kV at 5 kHz and 2 kV at 5 kHz (Comm. Ports) IEC 61000‑4‑4:2011 4 kV at 5 kHz
Magnetic Field Immunity:	IEC 61000‑4‑8:2009 1000 A/m for 3 s 100 A/m for 1 min IEC 61000‑4‑9:2001 1000 A/m
Power Supply Immunity:	IEC 61000‑4‑11:2004 IEC 60255‑11:2008 IEC 61000‑4‑29:2000
Radiated Digital Radio Telephone RF Immunity:	ENV 50204:1995 10 V/m at 900 MHz and 1.89 GHz
Radiated Radio Frequency Immunity:	IEC 60255‑22‑3:2007, 10 V/m IEC 61000‑4‑3:2010, 10 V/m IEEE C37.90.2‑2004, 35 V/m
Surge Immunity:	IEC 60255‑22‑5:2008 IEC 61000‑4‑5:2005 1 kV line-to-line, 2 kV line-to-earth

Note: Cables connected to EIA-232 communications ports shall be less than 10 m in length for Zone A compliance.

Damped Oscillatory Magnetic Field:	IEC 61000‑4‑10:2001 Severity Level: 100 A/m
Surge Withstand Capability Immunity:	IEC 60255‑22‑1:2007 2.5 kV peak common mode 1.0 kV peak differential mode IEEE C37.90.1‑2002 2.5 kV oscillatory 4.0 kV fast transient

Environmental

Cold:	IEC 60068‑2‑1:2007 16 hours at –40°C
Damp Heat, Cyclic:	IEC 60068‑2‑30:2005 25° to 55°C, 6 cycles, 95% humidity
Dry Heat:	IEC 60068‑2‑2:2007 16 hours at +85°C
Vibration:	IEC 60255‑21‑1:1988 Severity Level: Class 2 (endurance); Class 2 (response) IEC 60255‑21‑2:1988 Severity Level: Class 1 (shock withstand, bump); Class 2 (shock response) IEC 60255‑21‑3:1993 Severity Level: Class 2 (quake response)

Safety

Dielectric Strength:	IEC 60255‑5:2000 IEEE C37.90‑2005 2500 Vac on contact inputs, contact outputs, and analog inputs 3100 Vdc on power supply
Impulse:	IEC 60255‑5:2000 IEEE C37.90‑2005 0.5 J, 5 kV
IP Code:	IEC 60529:2001 + CRGD:2003 IP3X

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, *IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems.*

Event Reports

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

Event Summary

Storage:	100 summaries

Breaker History

Storage:	128 histories

Sequential Events Recorder

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

Processing Specifications

AC Voltage and Current Inputs

8000 samples per second, 3 dB low-pass analog filter cutoff frequency of 3000 Hz.

Digital Filtering

Full-cycle cosine and half-cycle Fourier filters after low-pass analog and digital filtering.

Protection and Control Processing

Eight 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

Instantaneous/Definite-Time Overcurrent Elements

Phase, Residual Ground, and Negative-Sequence

Pickup Range

5 A Model:	OFF, 0.25–100.00 A secondary, 0.01 A steps
1 A Model:	OFF, 0.05–20.00 A secondary, 0.01 A steps

Accuracy (Steady State)

5 A Model:	±0.05 A plus ±3% of setting
1 A Model:	±0.01 A plus ±3% of setting
Transient Overreach:	< 5% of pickup
Time Delay:	0.000–16000 cycles, 0.125 cycle steps
Timer Accuracy:	±0.125 cycle plus ±0.1% of setting
Maximum Operating Time:	1.5 cycles

Time-Overcurrent Elements

Pickup Range

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

Accuracy (Steady State)

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

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)
Reset:	1 power cycle or Electromechanical Reset Emulation time

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

Ground Directional Elements

Neg.-Seq. Directional Impedance Threshold (Z2F, Z2R)

5 A Model:	–64 to 64 Ω secondary
1 A Model:	–320 to 320 Ω secondary

Zero-Seq. Directional Impedance Threshold (Z0F, Z0R)

5 A Model:	–64 to 64 Ω secondary
1 A Model:	–320 to 320 Ω secondary

Supervisory Overcurrent Pickup (50FP, 50RP)

5 A Model:	0.25 to 5.00 A 3I0 secondary 0.25 to 5.00 A 3I2 secondary
1 A Model:	0.05 to 1.00 A 3I0 secondary 0.05 to 1.00 A 3I2 secondary

Directional Power Elements

Pickup Range

5 A Model:	–20000.00 to 20000 VA, 0.01 VA steps
1 A Model:	–4000.00 to 4000 VA, 0.01 VA steps
Accuracy (Steady State):	±5 VA plus ±3% of setting at nominal frequency and voltage
Time-Delay:	0.00–16000.00 cycles, 0.25 cycle steps
Timer Accuracy:	±0.25 cycle plus ±0.1% of setting

Undervoltage and Overvoltage Elements

Pickup Ranges

300 V Maximum Inputs

Phase Elements:	2–300 V secondary, 0.01 V steps
Phase-to-Phase Elements:	4–520 V secondary, 0.01 V steps

8 V LEA Maximum Inputs
(See *Voltage-Related Settings and LEA Inputs (Group Settings) on page 14* for information on setting voltage elements when using LEA inputs.)

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

Accuracy (Steady State)

Phase Elements:	±0.5 V plus ±3% of setting
Sequence Elements:	±0.5 V plus ±5% of setting
Transient Overreach:	< 5% of pickup

Underfrequency 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:	0.04–400.0 s, 0.01 s increments
Time-Delay Accuracy:	±0.1% ± 0.0042 s

Pickup Range, Undervoltage Blocking:	20–200 V_{LN} (Wye)
Pickup Accuracy, Undervoltage Blocking:	±2% ±0.5 V

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

Pickup Range:	Off, –50 to 250°C, 1°C step
Accuracy:	±2°C

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

Breaker Failure Instantaneous Overcurrent

Setting Range

5 A Model:	0.50–50.0 A, 0.01 A steps
1 A Model:	0.10–10.0 A, 0.01 A steps

Accuracy

5 A Model:	±0.05 A plus ±3% of setting
1 A Model:	±0.01 A plus ±3% of setting
Transient Overreach:	< 5% of setting
Maximum Pickup Time:	1.5 cycles
Maximum Reset Time:	1 cycle
Timers Setting Range:	0–6000 cycles, 0.125 cycle steps (All but BFIDO*n*, BFISP*n*) 0–1000 cycles, 0.125 cycle steps (BFIDO*n*, BFISP*n*)
Time-Delay Accuracy:	0.125 cycle plus ±0.1% of setting

Synchronism-Check Elements

Slip Frequency Pickup Range:	0.005–0.500 Hz, 0.001 Hz steps
Slip Frequency Pickup Accuracy:	±0.0025 Hz plus ±2% of setting
Close Angle Range:	3–80°, 1° steps
Close Angle Accuracy:	±3° plus ±5% of setting

Load-Encroachment Detection

Setting Range

5 A Model:	0.05–64 Ω secondary, 0.01 Ω steps
1 A Model:	0.25–320 Ω secondary, 0.01 Ω steps
Forward Load Angle:	–90° to +90°
Reverse Load Angle:	+90° to +270°

Accuracy

Impedance Measurement:	±3%
Angle Measurement:	±2°

Timer Specifications

Setting Ranges

Breaker Failure:	0–6000 cycles, 0.125 cycle steps (All but BFIDO*n*, BFISP*n*) 0–1000 cycles, 0.125 cycle steps (BFIDO*n*, BFISP*n*)
Communications-Assisted Tripping Schemes:	0.000–16000 cycles, 0.125 cycle steps
Pole Open Timer:	0.000–60 cycles, 0.125 cycle steps
Recloser:	1–999999 cycles, 1 cycle steps

Switch-Onto-Fault

CLOEND, 52AEND:	OFF, 0.000–16000 cycles, 0.125 cycle steps
SOTFD:	0.500–16000 cycles, 0.125 cycle steps

Synchronism-Check Timers

TCLSBK1, TCLSBK2:	1.00–30.00 cycles, 0.25 cycle steps

Station DC Battery System Monitor Specifications

Operating Range:	0–350 Vdc
Input Sampling Rate:	DC1: 2 kHz DC2: 1 kHz
Processing Rate:	1/8 cycle
Maximum Operating Time:	≤ 1.5 cycles
Setting Range	
DC Settings:	15–300 Vdc, 1 Vdc steps
AC Ripple Setting:	1–300 Vac, 1 Vac steps
Accuracy	
Pickup Accuracy:	±3% plus ±2 Vdc (all elements but DC1RP and DC2RP) ±10% plus ±2 Vac (DC1RP and DC2RP)

Metering Accuracy

All metering accuracy is at 20°C, and nominal frequency unless otherwise noted.

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 A sec)

Phase Current Angle

All Models:	±0.2° in the current range $0.5 \cdot I_{NOM}$ to $3.0 \cdot I_{NOM}$

Sequence Currents Magnitude

5 A Model:	±0.3% plus ± 4 mA (2.5–15 A sec)
1 A Model:	±0.3% plus ± 0.8 mA (0.5–3 A sec)

Sequence Current Angle

All Models:	±0.3° in the current range $0.5 \cdot I_{NOM}$ to $3.0 \cdot I_{NOM}$

Voltages

300 V Maximum Inputs

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

8 V LEA Maximum Inputs

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

Frequency (Input 40–65 Hz)

Accuracy:	±0.01 Hz

Power

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

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

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

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

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

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

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

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

Energy

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

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

Synchrophasors

Number of Synchrophasor Data Streams:	5
Number of Synchrophasors for Each Stream: 15 Phase Synchrophasors (6 Voltage and 9 Currents) 5 Positive-Sequence Synchrophasors (2 Voltage and 3 currents)	
Number of User Analogs for Each Stream:	16 (any analog quantity)
Number of User Digitals for Each Stream:	64 (any Relay Word bit)
Synchrophasor Protocol:	IEEE C37.118, SEL Fast Message (Legacy)
Synchrophasor Data Rate:	As many as 60 messages per second
Synchrophasor Accuracy	
Voltage Accuracy:	±1% Total Vector Error (TVE) Range 30–150 V, f_{NOM} ±5 Hz
Current Accuracy:	±1% Total Vector Error (TVE) Range $(0.1–2.0) \cdot I_{NOM}$ A, f_{NOM} ±5 Hz
Synchrophasor Data Recording:	Records as much as 120 s IEEE C37.232, File Naming Convention

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