SEL-421 Protection and Automation System

High-Speed Line Protection, Automation, and Control System

Major Features and Benefits

The SEL-421 Protection, Automation, and Control System combines high-speed distance and directional protection with complete control for a two-breaker bay.

- **Protection.** Protect any transmission line using a combination of five zones of phase- and ground-distance and directional overcurrent elements. Use the optional high-speed elements and series compensation logic to optimize protection for critical lines or series-compensated lines. Use the ACSELERATOR QuickSet® SEL-5030 Software (a graphical user interface) to speed and simplify setting the relay. Patented Coupling Capacitor Voltage Transformer (CCVT) transient overreach logic enhances the security of Zone 1 distance elements. Best Choice Ground Directional Element® logic optimizes directional element performance and eliminates the need for many directional settings.
- **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 Liquid Crystal Display (LCD) eliminates the need for separate panel meters. Use serial and Ethernet links to efficiently transmit key information, including metering data, protection element and control I/O status, IEEE C37.118 Synchrophasors, IEC 61850 GOOSE messages, Sequential Events Recorder (SER) reports, breaker monitor, relay summary event reports, and time synchronization. Use expanded SELOGIC® control equations with math and comparison functions in control applications. High-isolation control input circuits feature settable assertion levels for easy combinations of elements from other systems. Incorporate up to 1000 lines of automation logic (depending on the model) to speed and improve control actions.
- **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.

- **Digital Relay-to-Relay Communications.** Use MIRRORED BITS® communications to monitor internal element conditions between relays within a station, or between stations, using SEL Fiber-Optic Transceivers. Send digital, analog, and virtual terminal data over the same MIRRORED BITS channel.
- **Primary Potential Redundancy.** Multiple voltage inputs to the SEL-421 provide primary input redundancy. Upon loss-of-potential (LOP) detection, the relay can use inputs from an electrically equivalent source connected to the relay. Protection remains in service without compromising security.
- **Ethernet Access.** Access all relay functions with the optional Ethernet card. Interconnect with automation systems using IEC 61850 or DNP3 protocol directly. Optionally connect to DNP3 networks through an SEL-2032 Communications Processor. 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 using TCP or UDP internet protocols.
- **Dual CT Input.** Combine currents within the relay from two sets of CTs for protection functions, but keep them separately available for monitoring and station integration applications.
- **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. Alarm contacts provide notification of substation battery voltage problems (two independent battery monitors) even if voltage is low only during trip or close operations.
- **Reclosing Control.** Incorporate programmable single-pole or three-pole trip and reclose of one or two breakers into an integrated substation control system. Synchronism and voltage checks from multiple sources provide complete bay control.
- **Breaker Failure.** Use high-speed (5/8 cycle) open-pole detection logic to reduce coordination times for critical breaker failure applications. Apply the SEL-421 to supply single and/or three-pole breaker failure for one or two breakers. Necessary logic for single-pole and three-pole breaker failure retrip and initiation of transfer tripping is included. Logic to use different delay settings for multiphase and single phase is included.
- **Out-of-Step Blocking and Tripping.** Select out-of-step blocking of distance elements or tripping on unstable power swings. Multizone elements and logic are included for detection of an out-of-step condition.
- **Switch-Onto-Fault and Stub Bus Protection.** Use disconnect status inputs and voltage elements to enable high-speed protection.
- **Fault Locator.** Efficiently dispatch line crews to quickly isolate line problems and restore service faster.
- **Oscillography.** Record voltages, currents, and internal logic points at up to 8 kHz sampling rate. Phasor and harmonic analysis features allow investigation of relay and system performance.
- **Rules-Based Settings Editor.** In addition to communicating and setting the relay using an ASCII terminal, use the PC-based ACSELERATOR QuickSet to configure the SEL-421 and analyze fault records with relay element response. View real-time phasors and harmonic levels.
- **Sequential Events Recorder (SER).** Record the last 1000 entries, including setting changes, power-ups, and selectable logic elements.
- **Thermal Overload Modeling.** Use the SEL-421 with the SEL-2600 Series RTD Module for dynamic overload protection using SELOGIC control equations.
- **Comprehensive Metering.** Improve feeder loading by using built-in, high-accuracy metering functions. Use watt and VAR measurements to optimize feeder operation. Minimize equipment needs with full metering capabilities, including: rms, maximum/minimum, demand/peak, energy, and instantaneous values.
- **Synchrophasors.** Make informed load dispatch decisions based on actual real-time phasor measurements from across your power system. Use synchrophasors to determine actual stability margins with standard spreadsheet, graphics programs, or data management systems. Control the power system using local and remote synchrophasor data.
- **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.

Functional Overview

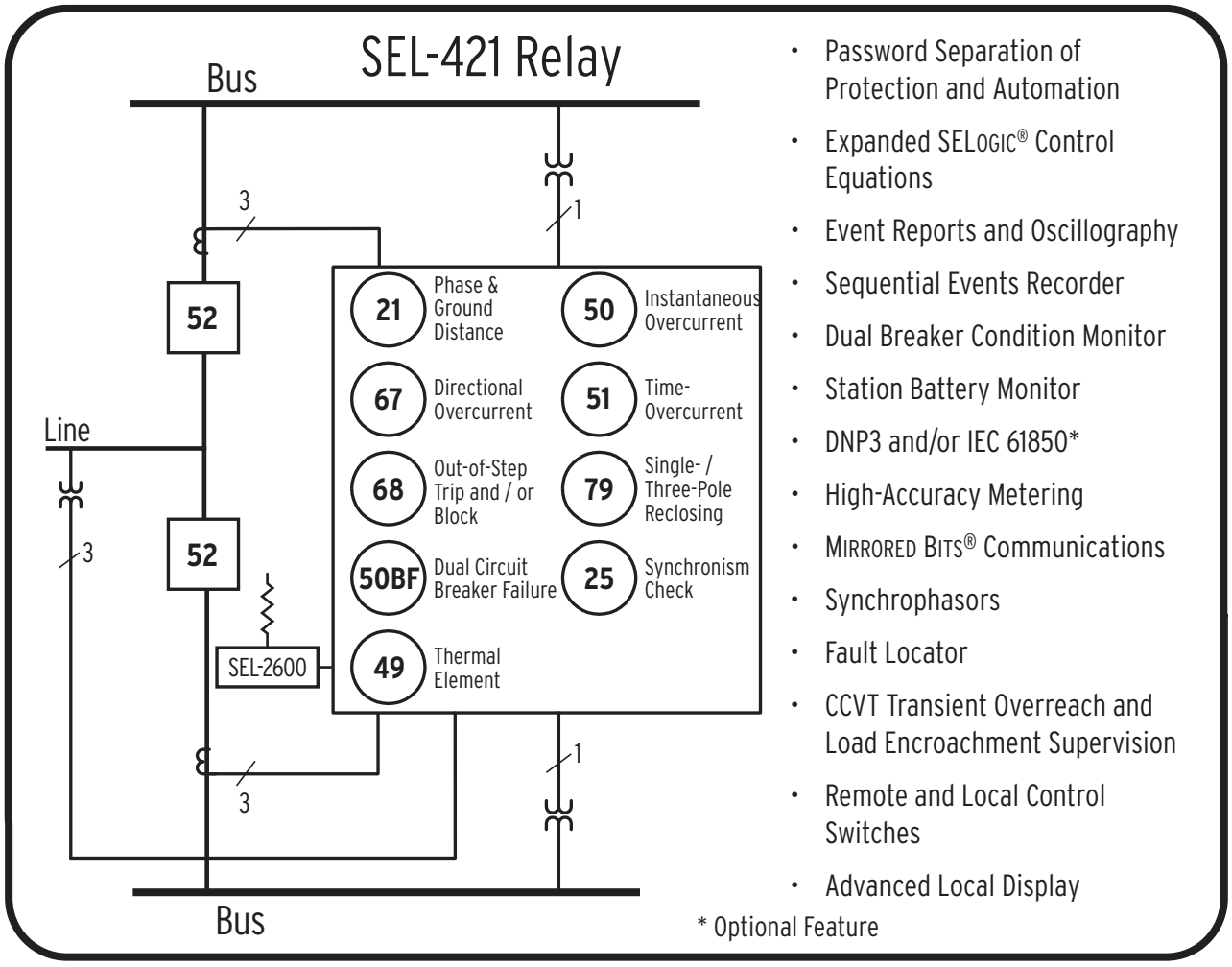


Figure 1 Functional Diagram

Protection Features

The SEL-421 contains all the necessary protective elements and control logic to protect overhead transmission lines and underground cables (see *Figure 1*). The relay simultaneously measures five zones of phase and ground mho distance plus five zones of ground quadrilateral distance. These distance elements, together with optional high-speed directional and faulted phase selection and high-speed distance elements, are applied in communications-assisted and step-distance protection schemes. You can further tailor the relay to your particular application using expanded SELOGIC control equations. Performance times of the high-speed and standard distance elements for a range of faults, locations, and source impedance ratios (SIR) are shown in *Figure 2*, *Figure 3*, and *Figure 4*. As transmission systems are pushed to operational limits by both competitive and regulatory pressures, line protection must be able to adapt to changing conditions. The SEL-421 is easy to set and use for typical lines, while the high-speed and logic settings make it applicable for critical and hard-to-protect lines.

Subcycle Tripping Times Using Optional High-Speed Elements

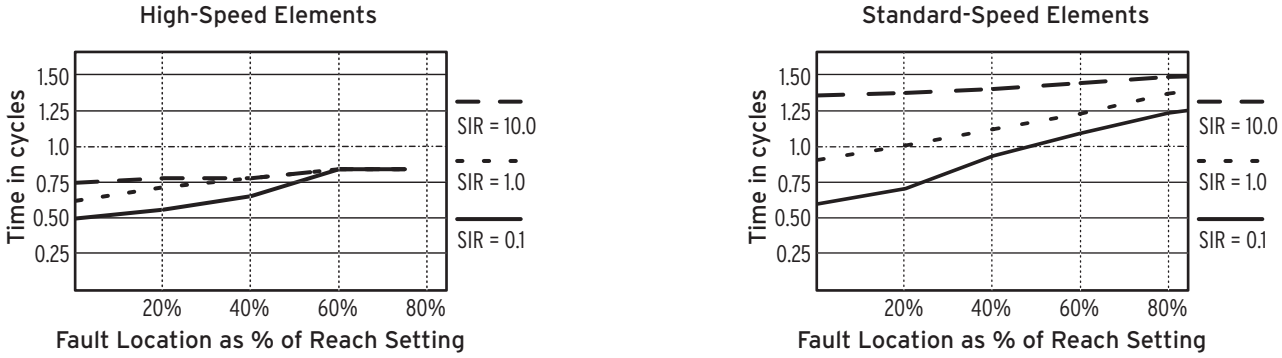


Figure 2 Single Phase to Ground Faults

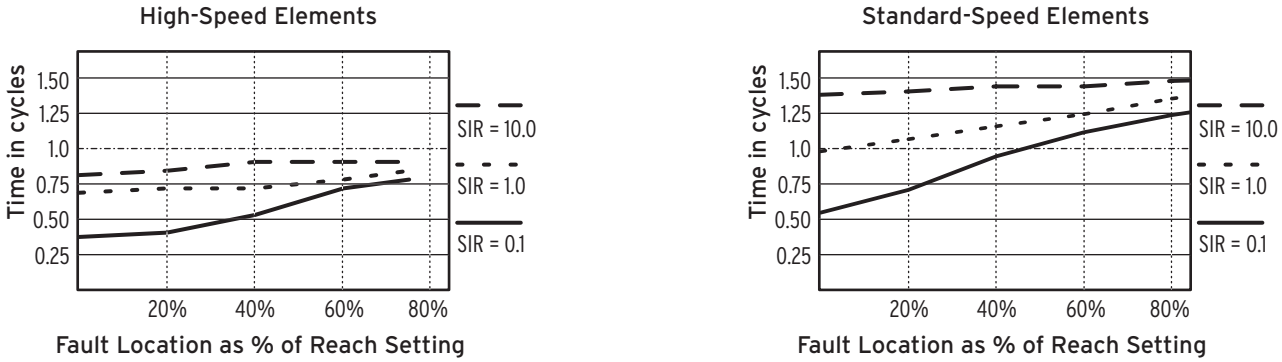


Figure 3 Phase-to-Phase Faults

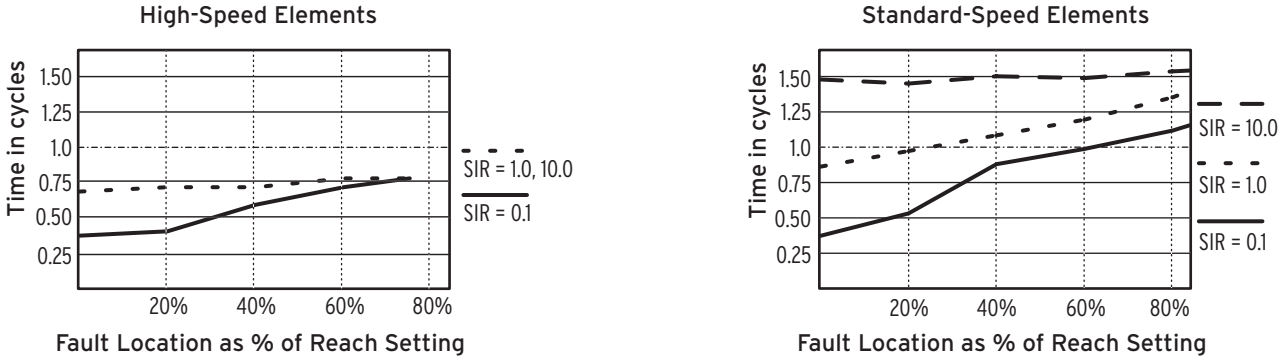


Figure 4 Three-Phase Faults

Mho Distance Elements

The SEL-421 uses mho characteristics for phase- and ground-distance protection. Two zones are fixed in the forward direction, and the remaining three zones can be set for either forward or reverse. All mho elements use positive-sequence memory polarization that expands the operating characteristic in proportion to the source impedance (*Figure 5*). This provides dependable, secure operation for close-in faults. The mho circle expands to the source impedance, Z_S, but this expansion never exceeds the set relay reach, Z_R.

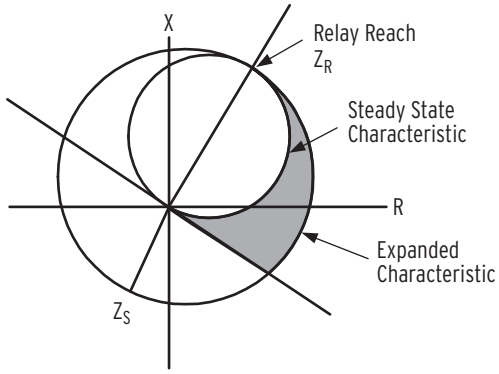


Figure 5 Mho Characteristic

As an optional addition to the standard distance elements, there are three zones (either three forward, or two forward and one reverse) of high-speed distance elements. These high-speed elements use voltage and current phasors derived from a fast half-cycle filter to provide subcycle tripping times. Settings are automatically associated with the standard element zone reach; no additional settings are required.

The SEL-421 includes optional series-compensated line logic and polarizing to prevent overreach of the Zone 1 distance element resulting from the series capacitor transient response.

Load-Encroachment Logic

Load-encroachment logic (*Figure 6*) prevents operation of the phase-distance elements under high load conditions. This unique SEL feature permits load to enter a predefined area of the phase-distance characteristic without causing a trip.

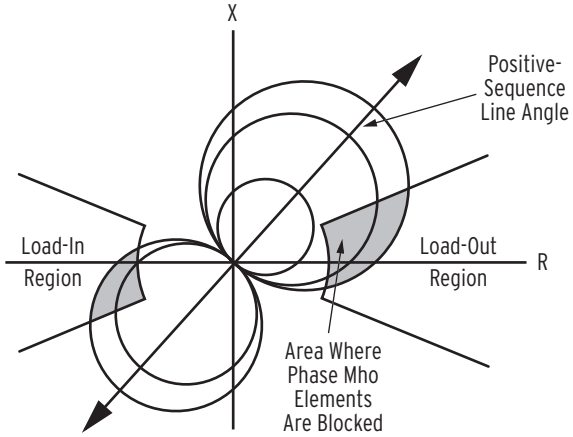


Figure 6 Load-Encroachment Logic

CCVT Transient Detection Logic

CCVT transient detection, once enabled, automatically prevents incorrect operation of the direct tripping (Zone 1) distance elements. The relay determines the Source Impedance Ratio (SIR), and a smoothness detection system acts to inhibit Zone 1 only for those conditions that indicate a CCVT transient exists. No user settings are required.

Quadrilateral Distance Elements

The SEL-421 provides five zones of quadrilateral ground-distance characteristics for improved fault resistance coverage and reach-limiting action on short lines. The top line of the quadrilateral characteristic automatically tilts with load flow to avoid under- and overreaching. Available settings prevent overreaching of the quadrilateral characteristic from nonhomogeneous infeed. The ground mho and quadrilateral distance elements can be used separately, concurrently, or not at all.

Each of the 15 ground-distance elements has a specific reach setting. The ground-distance elements include three zero-sequence compensation factor settings (k01, k0R, and k0F) to calculate ground fault impedance accurately. Setting k01 adjusts the zero-sequence transmission line impedance for accurate measurement using positive-sequence quantities. Settings k0F and k0R account for forward and reverse zero-sequence mutual coupling between parallel transmission lines.

Directional Elements Increase Sensitivity and Security

The SEL-421 provides multiple directional elements to optimize security and sensitivity. Directional overcurrent elements provide increased sensitivity, complementing distance elements that provide well-controlled reach. Use ground and negative-sequence directional overcurrent elements to detect high-resistance faults when using communications-assisted tripping schemes.

The SEL-421 includes a number of directional elements for supervision of overcurrent elements and distance elements. The negative-sequence directional element uses the same patented principle proven in our SEL-321 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.)

Optional High-Speed Directional and Faulted Phase Selection (HSDPS) Element

In addition to standard directional elements, the SEL-421 optionally includes a HSDPS function using incremental voltage and current phasors. The incremental quantities are derived by comparing the measured signal to the same signal a short time earlier. The HSDPS provides directional and faulted phase selection outputs much faster than conventional algorithms and allows faster (less than one cycle) relay operation.

Communications-Assisted Tripping Schemes

The SEL-421 is the ideal relay for use in transmission pilot-based tripping schemes. Use MIRRORED BITS communications with SEL fiber-optic transceivers for 3–6 ms relay-to-relay transmission time. Among the schemes supported are:

- ➤ Permissive Overreaching Transfer Tripping (POTT) for two- or three-terminal lines
- ➤ Directional Comparison Unblocking (DCUB) for two- or three-terminal lines
- ➤ Directional Comparison Blocking (DCB)

Use the SEL 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

Step distance and time-overcurrent protection provide reliable backup operation should the channel be lost.

Overcurrent Elements

The SEL-421 includes four phase, four negative-sequence, and four ground instantaneous overcurrent elements. The SEL-421 also includes three 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|

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

US	IEC
Moderately Inverse	Standard Inverse
Inverse	Very Inverse
Very Inverse	Extremely Inverse
Extremely Inverse	Long-Time Inverse
Short-Time Inverse	Short-Time Inverse

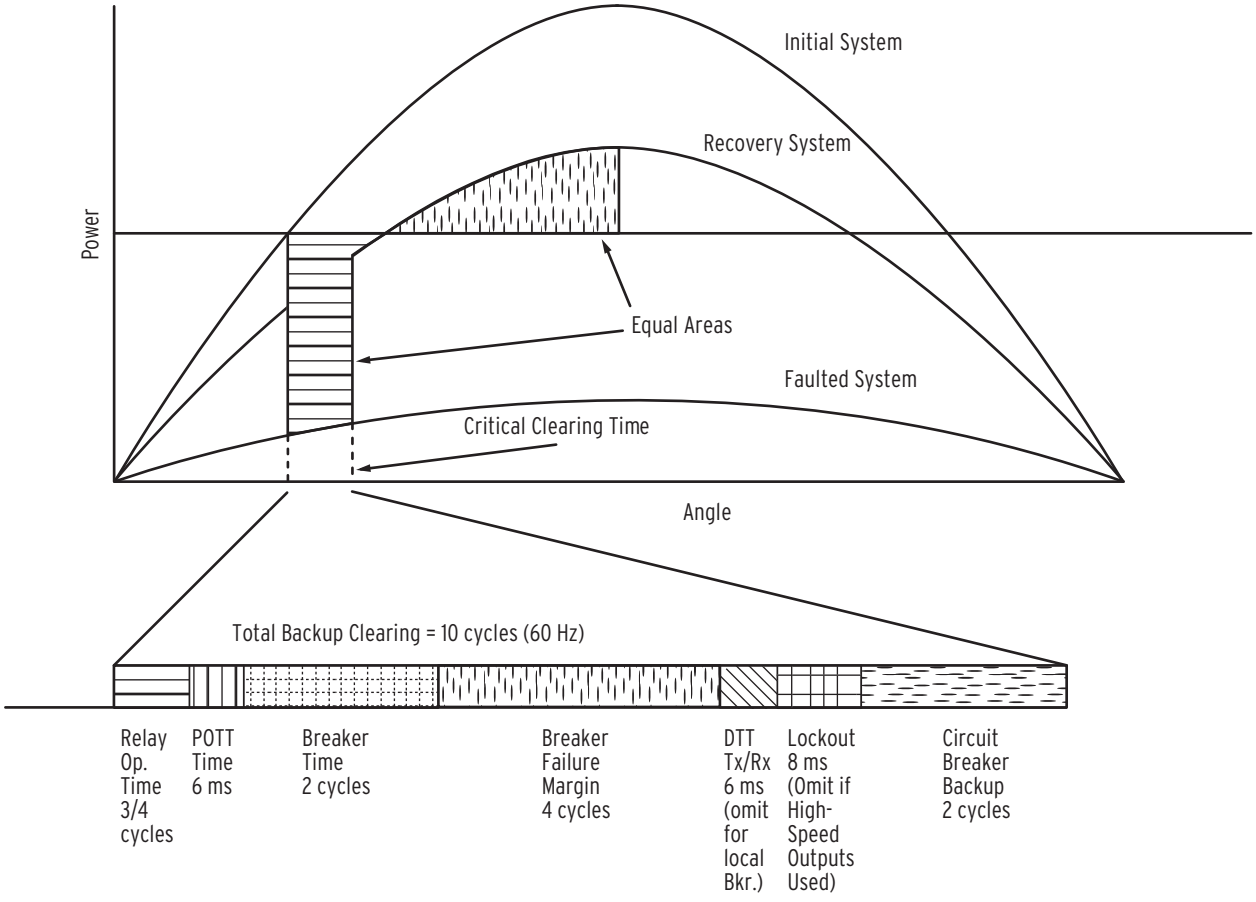


Figure 7 Combining High-Speed Tripping, MIRRORED BITS Communications, and High-Speed Open-Pole Detection in the SEL-421 Relay Provides for Faster Total Clearing Time

Breaker Failure Protection

Incorporated into the SEL-421 is a full-function breaker failure system. Current can be individually monitored in two breakers. Single- and three-pole logic allows flexible operation. 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. If breaker failure is initiated on all circuit breaker trips, this feature is essential. A 5/8-cycle reset reduces coordination times, improving stability.

Thermal Overload Protection

The SEL-421 supports the receipt of the SEL-2600 Fast Messages. Magnitude information from the SEL-2600 will be placed in pre-defined analog values and status information will be stored in pre-defined Relay Word bits. For more information, see SEL Application Guide *AG2003-06, Implementation of the SEL-49 Relay Line Thermal Protection Using the SEL-421 Relay SELOGIC Equations*.

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

The SEL-421 includes logic to detect a loss-of-potential (LOP) caused by failures such as blown fuses, which can cause an incorrect operation in distance and 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.

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 protection and control contingencies. Selectable settings groups make the SEL-421 ideal for applications requiring frequent settings changes and for adapting the protection 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-421 can accept separate inputs from two separate CTs (CTs must be the same ratio) 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-421. Breaker diagnostics are reported on a comparative basis allowing for advanced, proactive troubleshooting.

Control Inputs and Outputs

The basic SEL-421 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 input/output (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 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. Order standard and additional I/O as either universal (15–265 Vdc settable pickup) or optoisolated type.

Multifunction Recloser With Flexible Applications

The SEL-421 includes both single-pole and three-pole trip and reclose functions, for either one or two breakers (*Figure 8*). 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 up to two single-pole reclose attempts and four three-pole reclose attempts as well as combined single-/three-pole reclosing sequences. Select Leader and Follower breakers directly, or use a SELOGIC control equation to determine reclosing order

based on system conditions. When coupled with independent-pole-operating circuit breakers, this reclosing system gives maximum flexibility for present system conditions and for future requirements to meet changing demands on your power system.

Remote Voltage for Second Contingency Operation

An LOP condition within the relay can initiate a transfer of voltage information from another voltage source connected to the relay. The logic maintains normal protection operation of all directional elements in the relay with the LOP condition. You can program an LOP alarm contact to signal an operator that an error has occurred in the system to allow operator action to find and repair the faulty element.

Two-Breaker Control

The SEL-421 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.

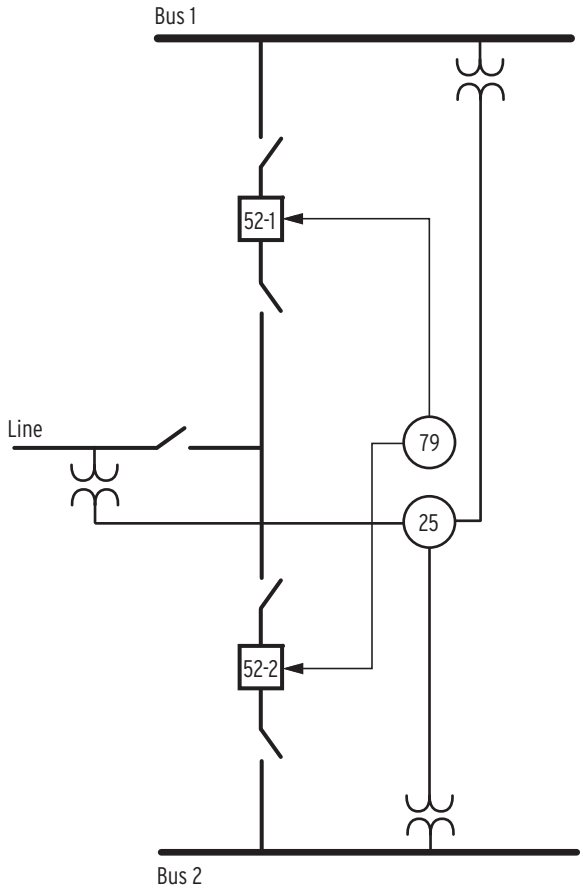


Figure 8 Two-Breaker Reclosing With Synchronism Check

Functional Overview: System

The SEL-421 is a complete stand-alone protection, automation, and control device. It can also act as an integral part of a full station protection, control, and monitoring system. Each relay can be tied to a communications processor that integrates the individual unit protections for overall protection integration (*Figure 9*).

Backup protection such as the SEL-321 Relay or SEL-311 Relay can also be connected to an SEL communications processor (*Figure 9*). The SEL-421 has four serial ports that can be used for connection to a communications processor, ASCII terminal, fiber-optic transceiver, or PC.

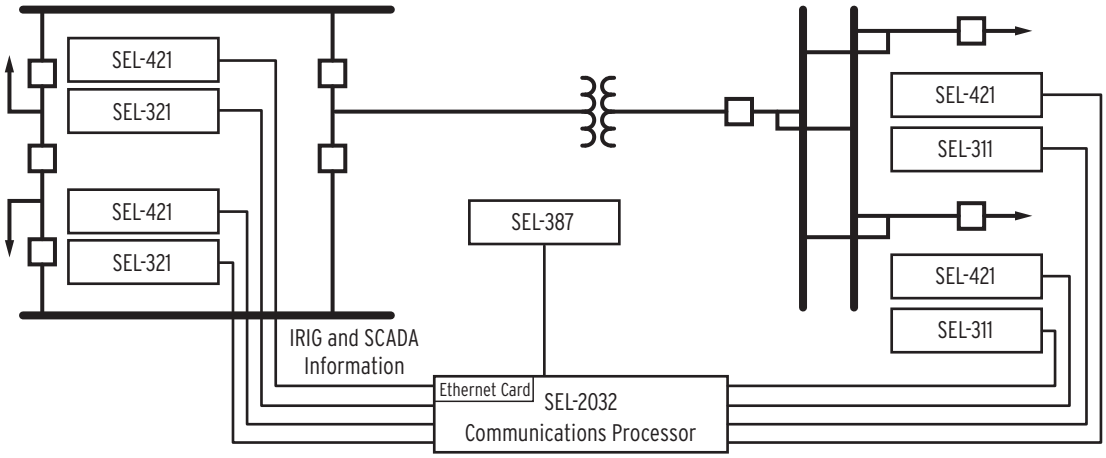


Figure 9 System Functional Overview

Network Connection and Integration

Connect the SEL-421 to Local Area Networks (LANs) using the optional Ethernet card. The Ethernet card also allows connection of an SEL communications processor to a single or dual LAN (see *Figure 10*). The integrated Ethernet card supports both copper and/or fiber connections with fail-over protection.

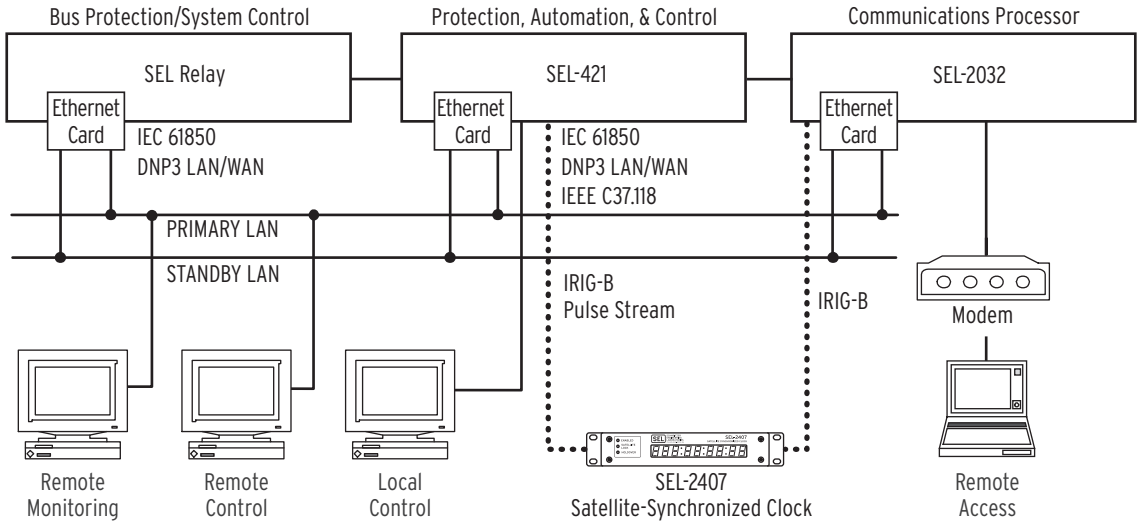


Figure 10 Network Connection and Integration

Ethernet Card

The optional Ethernet card mounts directly in the SEL-421. 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 using IEEE C37.118-2005 Standard for Synchrophasors for Power Systems. Communicate with SCADA and other substation IEDs using DNP3 or IEC 61850 Logical Nodes and GOOSE messaging.

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

- 10/100BASE-T twisted pair Network
- 100BASE FX Fiber-Optic Network

Telnet and FTP

Order the SEL-421 with Ethernet communications and use the built-in Telnet and FTP (File Transfer Protocol) that come standard with Ethernet to enhance real communication sessions. Use Telnet to access relay settings, and metering and event reports remotely using the ASCII interface. Transfer settings files to and from the relay via the high-speed Ethernet port using FTP.

IEEE C37.118 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-421 provides two independent connections using either TCP/IP, UDP/IP, or a combination thereof. Each connection supports unicast data for serving data to a single client. The connections also receive data for control applications. Each data stream can support up to 60 frames per second.

DNP3 LAN/WAN

The DNP3 LAN/WAN option provides the SEL-421 with DNP3 Level 2 slave functionality over Ethernet. Custom DNP3 data maps can be configured for use with specific DNP3 masters.

IEC 61850 Ethernet Communications

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

The SEL-421-2, -3 can be ordered with embedded IEC 61850 protocol operating on 100 Mbps Ethernet. Use the IEC 61850 Ethernet protocol for relay monitoring and control functions, including the following.

- As many as 24 incoming GOOSE messages. The incoming GOOSE messages can be used to control up to 128 control bits in the relay with <3 ms latency from device to device. These messages provide binary control inputs to the relay for high-speed control functions and monitoring.
- As many as 8 outgoing GOOSE messages. Outgoing GOOSE messages can be configured for Boolean or analog data. Boolean data is provided with <3 ms latency from device to device. Use outgoing GOOSE messages for high-speed control and monitoring of external breakers, switches, and other devices.
- IEC 61850 Data Server. The SEL-421-2, -3, equipped with embedded IEC 61850 Ethernet protocol, provides data according to pre-defined logical node objects. As many as six simultaneous client associations are supported by each relay. Relevant Relay Word bits are available within the logical node data, so status of relay elements, inputs, outputs, or SELOGIC equations can be monitored using the IEC 61850 data server provided in the relay.

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

Metering and Monitoring

Complete Metering Capabilities

The SEL-421 provides extensive metering capabilities as listed in *Table 2*.

Table 2 Metering Capabilities

Capabilities	Description
Instantaneous Quantities	
Voltages $V_{A,B,C}$ (Y) $V_{A,B,C}$ (Z) Vϕϕ 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, MVARh, 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.

Event Reporting and Sequential Events Recorder (SER)

Event Reports and Sequential Events Recorder features simplify post-fault analysis and help improve your understanding of both simple and complex protective scheme operations. These features also aid in testing and troubleshooting relay settings and protection schemes. 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 5 seconds of data per fault at 1 kHz resolution to 2 seconds per fault at 8 kHz resolution. Reports are stored in nonvolatile memory. Relay settings operational in the relay at the time of the event are appended to each event report.

Event Summary

Each time the SEL-421 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
- Fault location
- Recloser shot count at time of trigger
- System frequency at time of trigger
- Phase voltages
- Fault type at time of trip
- Prefault, fault phase, and polarizing current levels
- Prefault and fault calculated zero- and negative-sequence currents
- Active group targets
- Status of all MIRRORED BITS channels
- Trip and close times of day
- Breaker status (open/close)

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

High-Accuracy Time Keeping

Using high accuracy IRIG-B from a global positioning satellite clock, the SEL-421 can time-tag oscillography to within 10 µs accuracy. This high accuracy can be combined with the high sampling rate of the relay to synchronize data from across the system with an accuracy of better than 1/4 electrical degree. This allows examination of the power system state at given times, including load angles, system swings, and other system-wide events. Triggering can be via external signal (contact or communications port), set time, or system event. Optimal calibration of this feature requires a knowledge of primary input component (VT and CT) phase delay and error.

A standard accuracy IRIG-B time-code input synchronizes the SEL-421 time to within ±500 µs of the time-source input. A convenient source for this time code is an SEL communications processor (SEL-2032, SEL-2030, or an SEL-2020) (via Serial Port 1 on the SEL-421).

Substation Battery Monitor for DC Quality Assurance

The SEL-421 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 these thresholds 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.

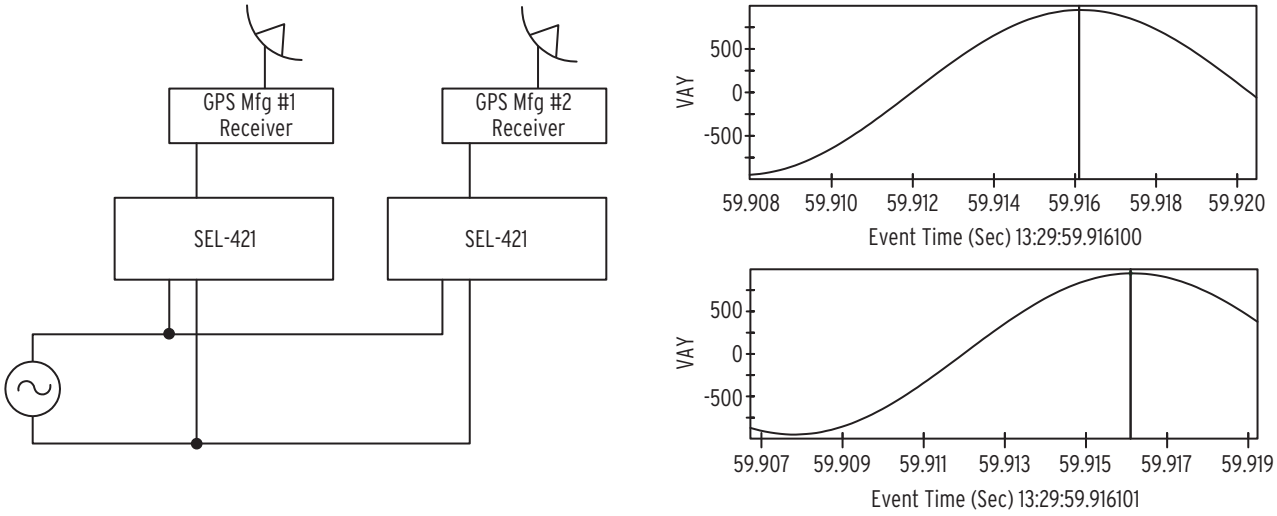


Figure 11 Actual Data From Back-to-Back Testing Using Two Different Manufacturers' Time Clocks. Voltage Peak Is Measured to 1 Microsecond Accuracy in this Example

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-421 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 12*), the relay can alarm via an output contact or the optional front-panel display. With this information, you can schedule breaker maintenance in a timely, economical fashion.
- The relay monitors last and average mechanical and electrical interruption time per pole. You can easily determine if operating time is increasing beyond reasonable tolerance to schedule proactive breaker maintenance. You can activate an alarm point if operation time goes beyond a preset value.

Breaker motor run time, pole scatter, pole discrepancy, and breaker inactivity are also monitored quantities.

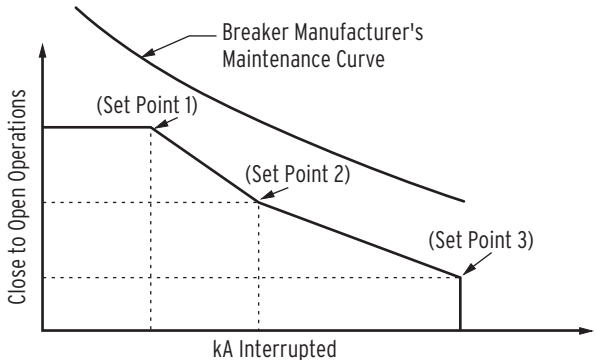


Figure 12 Breaker Contact Wear Curve and Settings

Automation

Flexible Control Logic and Integration Features

Use the SEL-421 control logic to do the following:

- Replace traditional panel control switches
- Eliminate RTU-to-relay 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-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, 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 up to 24 latching target LEDs and up to 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-421 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 3* lists a synopsis of the terminal protocols.

Rules-Based Settings Editor

Use ACSELERATOR QuickSet to develop settings off-line. The system automatically checks interrelated settings and highlights out-of-range settings. Settings created off-line can be transferred by using a PC communications link with the SEL-421. The relay converts event reports to oscillograms with time-coordinated element assertion and phasor/sequence element diagrams. The ACSELERATOR QuickSet interface supports Windows 95, 98, 2000, and NT® operating systems. 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.

ACSELERATOR QuickSet® Designer SEL-5031 Software

Use the ACSELERATOR QuickSet Designer to create custom views of settings, called Application Designs, to reduce complexity, decrease the chance of errors, and increase productivity:

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

Table 3 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 relay 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, relay 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.
Optional DNP3 Level 2 Slave	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	Ethernet-based international standard for interoperability between intelligent devices in a substation.

SELOGIC Control Equations With Expanded Capabilities and Aliases

Expanded SELOGIC control equations put relay logic in the hands of the protection engineer. 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 (*Table 4*). Any element in the Relay Word can be used in these equations. The SEL-421 is factory set for use without additional logic in most situations. For complex or unique applications, these expanded SELOGIC functions allow superior flexibility.

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

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

Table 4 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	
Precedence Control	( )	Allows multiple and nested sets of parentheses.
Comment	#	Provides for easy documentation of control and protection logic.

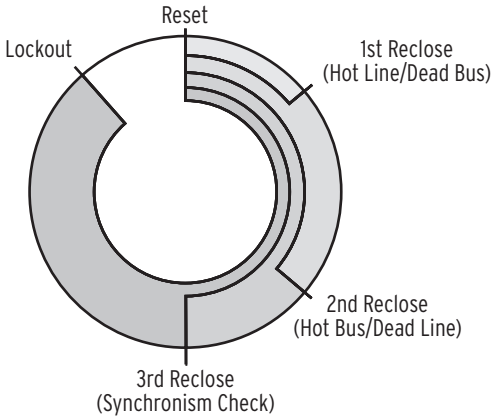


Figure 13 Motor-Driven Reclose Timer

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

- Emulate a motor-driven reclose timer, including stall, reset, and drive-to-lockout conditions (refer to *Figure 13*).
- 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.

Relay-to-Relay Digital Communications (MIRRORED BITS)

The SEL patented MIRRORED BITS technology provides bidirectional relay-to-relay digital communication (*Figure 14*). In the SEL-421, 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 include dig-

ital, analog, and virtual terminal data. Virtual terminal allows operator access to remote relays through the local relay. 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.

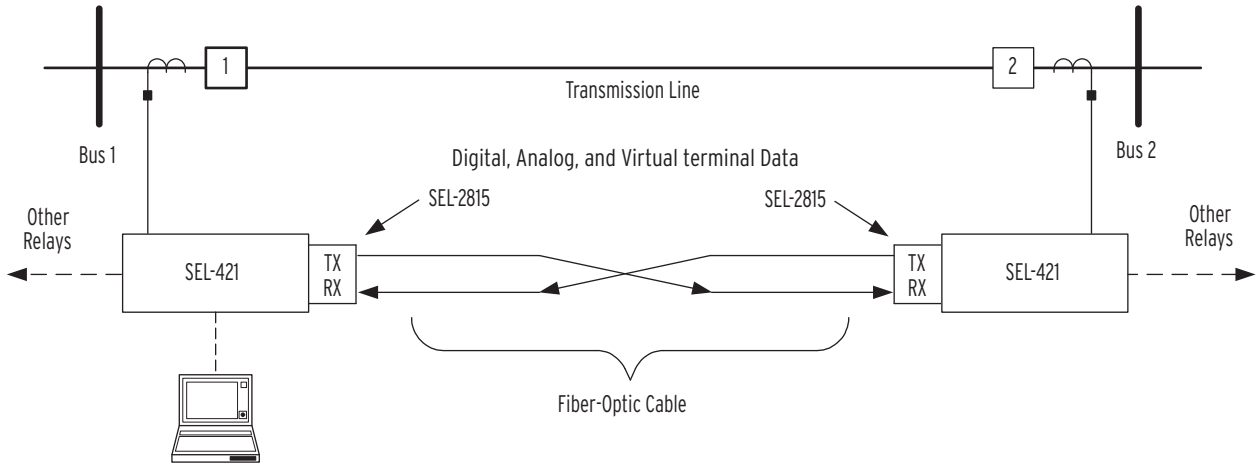


Figure 14 Integral Communication Provides Secure Protection, Monitoring, and Control, as Well as Terminal Access to Both Relays Through One Connection

Communication

The SEL-421 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 strong password protection.
- DNP3 Level 2 Slave
- 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.

Advanced Front-Panel Operation

Front-Panel Display

The liquid crystal display (LCD) shows event, metering, setting, and relay self-test status information. The target LEDs display relay target information as described in *Figure 15* and *Figure 16* and explained in *Table 5*.

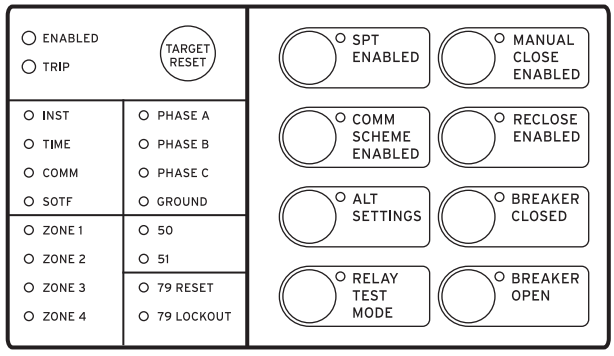


Figure 15 Factory Default Status and Trip Target LEDs (8 Pushbutton, 16 Target LED Option)

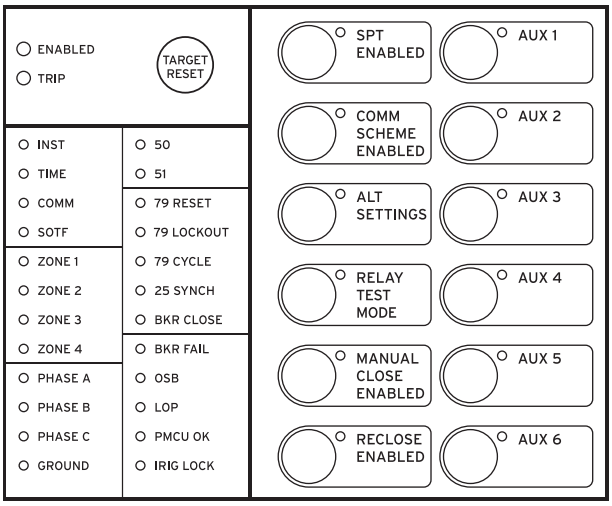


Figure 16 Factory Default Status and Trip Target LEDs (12 Pushbutton, 24 Target LED Option)

The LCD is controlled by the navigation pushbuttons (*Figure 17*), automatic messages the relay generates, and user-programmed analog and digital display points. The Rotating Display scrolls through alarm points, display points, and metering screens. If none are active, the relay scrolls through displays of the fundamental and rms metering screens. Each display remains for a user-programmed time (1–15 seconds) before the display continues scrolling. Any message generated by the relay because of an alarm condition takes precedence over the Rotating Display.

Close-up views of the front panel of the SEL-421 are shown in *Figure 15*, *Figure 16* and *Figure 17*. The front panel includes a 128 x 128 pixel, 3" x 3" LCD screen; LED target indicators; and pushbuttons with indicating LEDs for local control functions. The asserted and deasserted colors for the LEDs are programmable. Configure any of the direct acting pushbuttons to navigate directly to any HMI menu item. Quickly view events, alarm points, display points, or the SER.

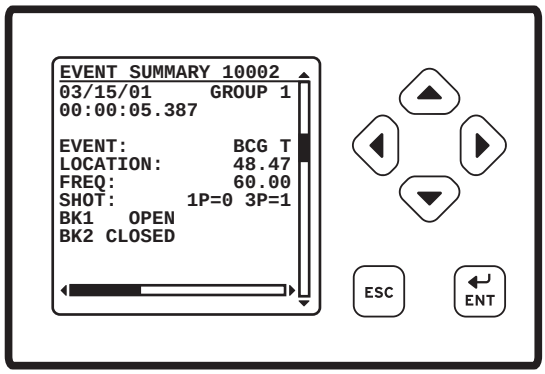


Figure 17 Factory Default Front-Panel Display and Pushbuttons

Status and Trip Target LEDs

The SEL-421 includes programmable status and trip target LEDs, as well as programmable direct-action control pushbuttons on the front panel. These targets are shown in *Figure 15* and *Figure 16* and explained in *Table 5*.

The SEL-421 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-421. Functions are simple to configure using ACSELERATOR QuickSet software. Label sets can be printed from a laser printer using templates supplied with the relay or hand labeled on supplied blank labels.

Table 5 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 trip
TIME	Time-delayed trip
COMM	Communications-assisted trip
SOTF	Switch-onto-fault trip
ZONE 1–4	Trip by Zone 1–4 distance elements
PHASE	
A, B, C	Phases involved in fault
GROUND	Ground involved in fault
50	Instantaneous overcurrent element trip
51	Time-overcurrent element trip
RECLOSER	
79 RESET	Ready for reclose cycle
79 LOCKOUT	Control in lockout state
79 CYCLE[a]	Control in cycle state
25 SYNCH[a]	Voltages within synchronism angle
BKR CLOSE[a]	Breaker close command detected
BKR FAIL[a]	Breaker failure trip
OSB[a]	Out-of-step condition
LOP	Loss-of-potential condition
PMCU OK[a]	Synchrophasor measurement enabled
IRIG LOCKED[a]	IRIG synchronization detected

[a] Only available in 24 LED models

Alarm Points

You can display messages on the SEL-421 front-panel LCD that indicate alarm conditions in the power system. The relay uses alarm points to place these messages on the LCD.

Figure 18 shows a sample alarm points screen. The relay is capable of displaying up to 66 alarm points. The relay automatically displays new alarm points while in manual-scrolling mode and in autoscrolling mode. The alarm points message is user-configurable and can be triggered using inputs, communications, the SEL-2600, or conditional using powerful SELOGIC control equations. The asterisk next to the alarm point indicates an active alarm. Inactive alarms can be cleared using the front-panel navigation pushbuttons.

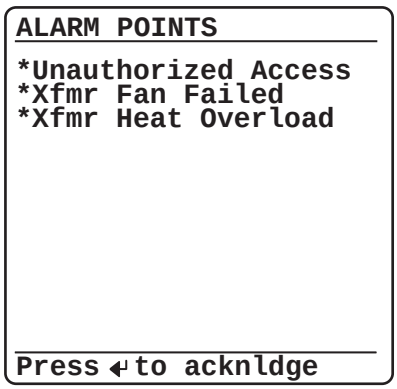


Figure 18 Sample Alarm Points Screen

Advanced Display Points

Create custom screens showing metering values, special text messages, or a mix of analog and status information. *Figure 19* 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 19*. These screens become part of the autoscrolling display when the front panel times out.

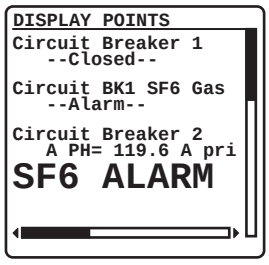


Figure 19 Sample Display Points Screen

Auxiliary Trip/Close Pushbuttons and Indicating LEDs

Optional auxiliary trip and close pushbuttons (see *Figure 20*) 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 24* for a rear-panel view. *Figure 21* 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-421 Relay. The operating voltage ranges of the breaker **CLOSED** and breaker **OPEN** indicating LEDs are also jumper selectable.

Figure 20 Operator Controls (Auxiliary Trip/Close Model)

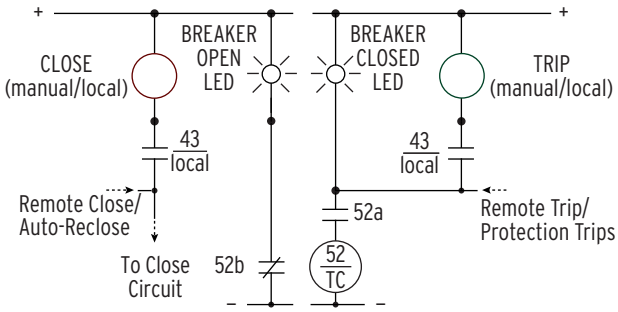


Figure 21 Optional Breaker Trip/Close Control Switches and Indicating Lamps

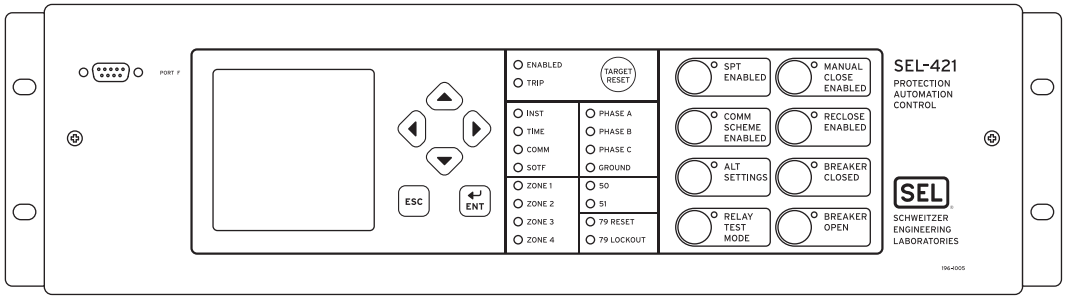
Guideform Specification

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

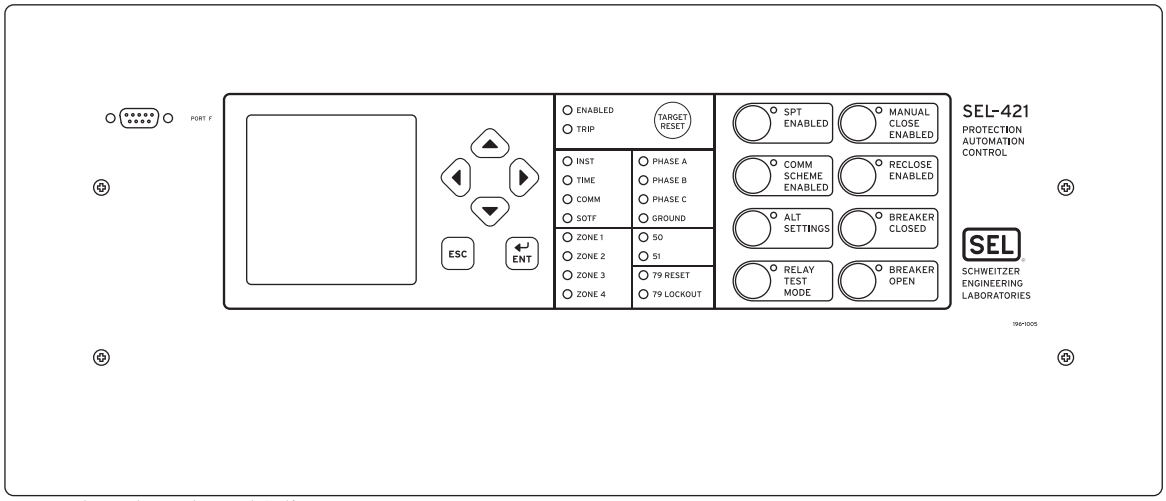
- **Phase Distance Protection.** The relay shall incorporate five zones of mho distance protection for detection of phase faults. Three zones shall be settable for either forward or reverse direction. Positive-sequence memory polarization shall be used to provide stable reach and reliable operation for zero voltage faults.
- **Optional.** High-speed elements shall be included to provide tripping in less than one cycle. Relay shall prevent Zone 1 overreaching or loss of directionality for faults on series-compensated lines.
- **Ground Distance Protection.** The relay shall incorporate five zones of mho and quadrilateral distance protection for detection of faults involving ground. Three zones shall be settable for either forward or reverse direction. Ground elements shall not overreach on multiphase faults and shall not be affected by load flow.
- **Optional.** High-speed elements shall be included to provide tripping in less than one cycle.
- **CCVT Transient Blocking.** The relay shall detect CCVT transients and block the operation of Zone 1 distance elements during the transient time.
- **Out-of-Step Characteristics.** The relay shall detect stable and unstable power swings. User settings shall determine whether the relay trips or blocks tripping.
- **High-Accuracy Timing.** The relay shall time-tag COMTRADE event reports to an absolute accuracy of ± 10 µs. Relays at different system locations shall have the same absolute timing accuracy.
- **Overcurrent Fault Protection.** The relay shall incorporate selectable input overcurrent elements. Torque control capability (internal and external) shall be provided.
- **Combined CT Current.** The relay shall monitor the current from two CTs separately while using the combined current for line protection functions.
- **Voltage Transfer Capability.** The relay shall change protection voltage source upon detection of loss of potential (LOP). Voltage shall be capable of changing to a second source connected to the relay.
- **Breaker Failure Logic.** The relay shall incorporate breaker failure logic for single- and three-pole tripping and reclosing. Retrip and transfer trip initiate contacts shall be provided. Pole discordance logic shall be included. Dropout time of the current detection circuit shall be less than 5/8 cycle, even in cases with residual dc current in the CT secondary.
- **Auto-Reclosing Control.** The relay shall incorporate both single- and three-pole reclosing with four separately-set open time intervals for three-pole and two intervals for single-pole reclosing. Separately-set reset times from reclose cycle and from lockout shall be available. Recloser shall be selectable for one or two breakers.
- **Synchronism Check.** The relay shall include two synchronism check elements with separate maximum angle settings. The synchronism check function shall incorporate slip frequency and close angle settings and allow different sources of synchronizing voltage (VA, VB, VC, VAB, VBC, VCA).
- **Event Reporting and Sequential Events Recorder.** The relay shall automatically record disturbance events of up to 2 seconds at 8 kHz sampling rate and 5 seconds at 1 kHz sampling rate. Events shall be stored in nonvolatile memory. The relay shall also include a Sequential Events Recorder (SER) that stores the latest 1000 entries.
- **Operator Controls.** The relay shall include operator control pushbuttons on the relay front panel. Each pushbutton shall be programmable and accessible in the relay control logic.
- **Independent Trip/Close Pushbuttons.** The relay shall include independently operated breaker trip/close switches and indicating lamps. The switches and breaker status lamps shall be functional regardless of the relay status.
- **Configurable Labels.** The relay shall include configurable labels to customize the targets and operator control pushbuttons.
- **Password Protection.** The relay shall have multilevel passwords to safeguard protection and automation settings.
- **Dual Circuit Breaker Monitor.** The relay shall include a breaker wear monitor function for two circuit breakers with a programmable breaker monitor curve. Electrical and mechanical operating times, with comparison between last and average times, shall be monitored and reported.
- **Dual Substation Battery Monitor.** The relay shall measure and report the substation battery voltages both at steady-state conditions and during trip operations. Two sets of selectable threshold parameters shall be provided for alarm and control purposes at each battery voltage. DC ground detection for two systems shall be included.
- **Fault Locator.** The relay shall include a fault locating algorithm to provide an accurate estimate of fault location without communications channels or special instrument transformers.
- **Digital Relay-to-Relay Communications.** The relay shall have send and receive logic elements, and analog and virtual terminal elements in each of two communications ports for dedicated relay-to-relay communications.

- **Automation.** The relay shall include 32 local control switches, 32 remote control switches, 32 latching switches, and programmable display messages in conjunction with a local display panel in the relay. The relay shall be capable of displaying custom messages. Input signals to the relay shall have settable assertion levels.
- **Relay Logic.** The relay shall include programmable logic functions for a wide range of user-configurable protection, monitoring, and control schemes. Logic shall have the ability to use relay elements, math functions, comparison functions, and Boolean logic functions.
- **IEC 61850 Ethernet Communications.** The relay shall provide IEC 61850-compliant communications. The IEC 61850 capability shall include GOOSE messaging and defined logical node data points.
- **Distributed Network Protocol (DNP).** The relay shall incorporate certified DNP3 Level 2 Slave protocol and Ethernet DNP3 LAN/WAN communications capability.
- **Terminal Connectors.** The relay shall include the ability to remove the screw terminal block connectors from the back of the relay to disconnect I/O, dc battery monitor, and power without removing each wire connection.
- **Communications.** The relay shall include four independent EIA-232 serial ports for external communications.
- **PC Interface.** The relay shall be capable of being set by Windows®-based graphical and ASCII terminal interfaces.
- **IRIG-B Time Input.** The relay shall include an interface port for either a standard or high-accuracy demodulated IRIG-B time synchronization input signal.
- **HMI Display.** The relay shall include custom configurable display information to display status, analog quantities, text, and alarm information.
- **Synchrophasors.** The relay shall include operation as a phasor measurement unit (PMU) following the IEEE C37.118-2005 Standard for Synchrophasors for Power Systems. The relay shall also receive IEEE C37.118-2005 synchrophasor data, time-align, and concentrate the data.
- **Environment.** The relay shall be suitable for continuous operation over a temperature range of –40° to +85°C.
- **Warranty.** The relay shall have a minimum 10-year worldwide warranty.

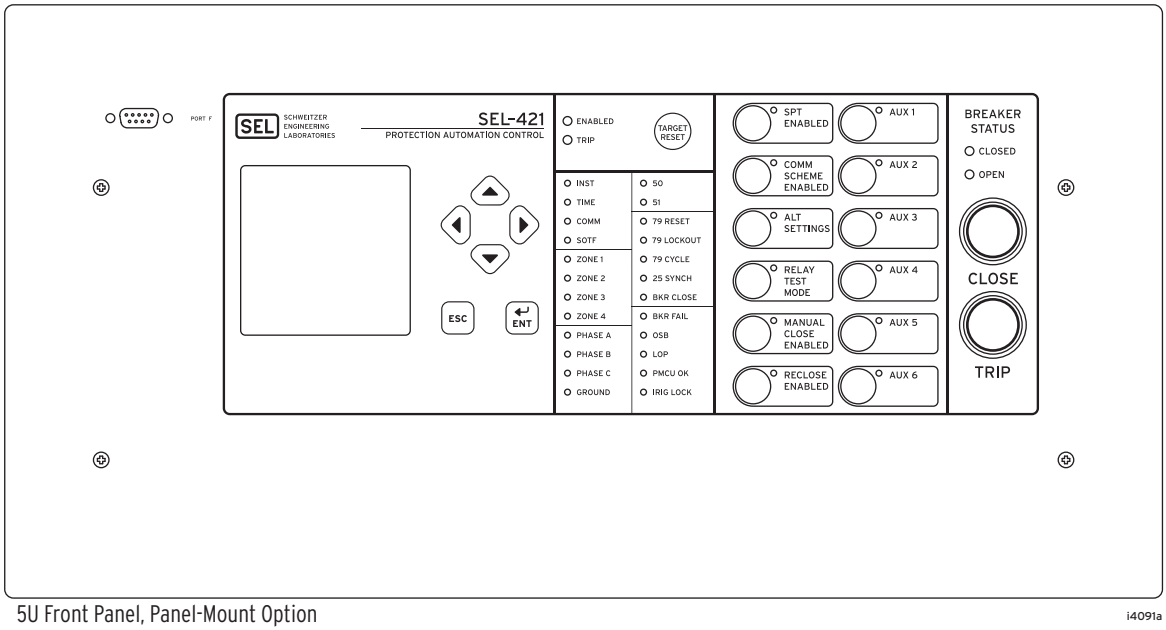
Front- and Rear-Panel Diagrams



3U Front Panel, Rack-Mount Option

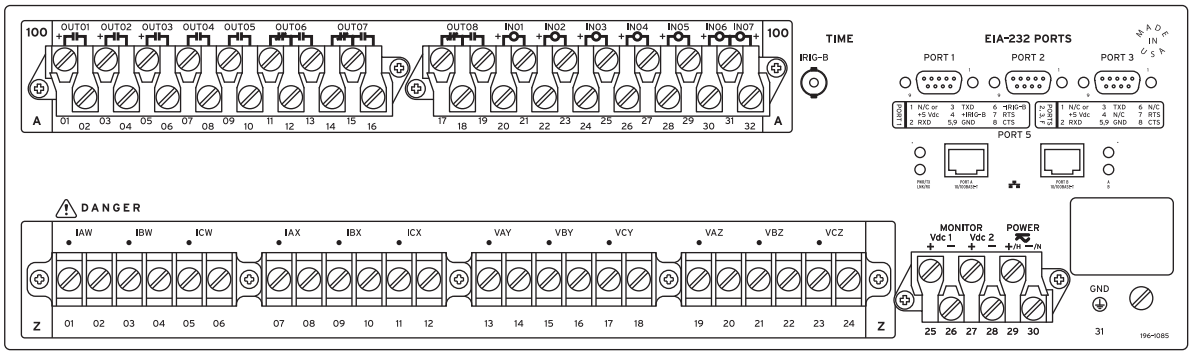


4U Front Panel, Panel-Mount Option



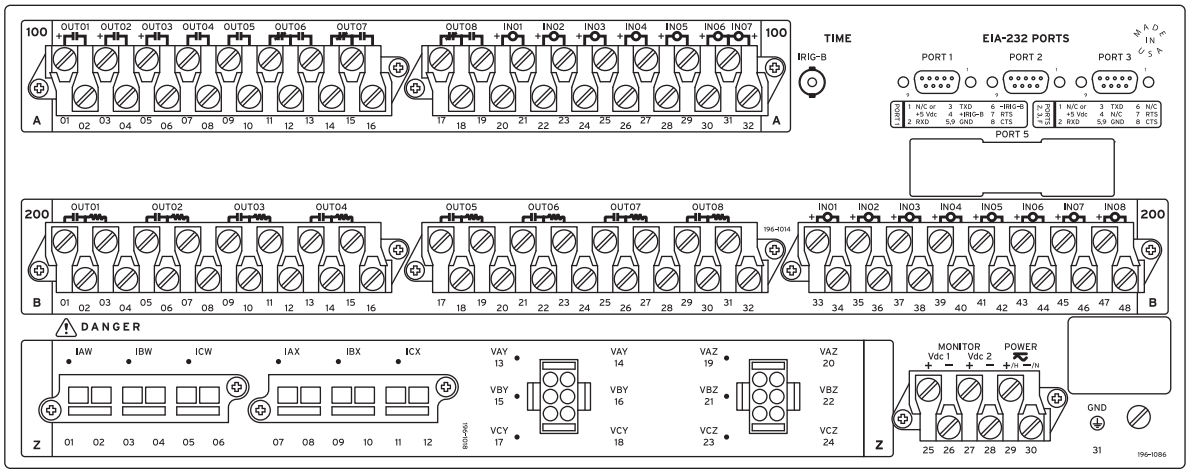
5U Front Panel, Panel-Mount Option

Figure 22 Typical SEL-421 Front-Panel Diagrams



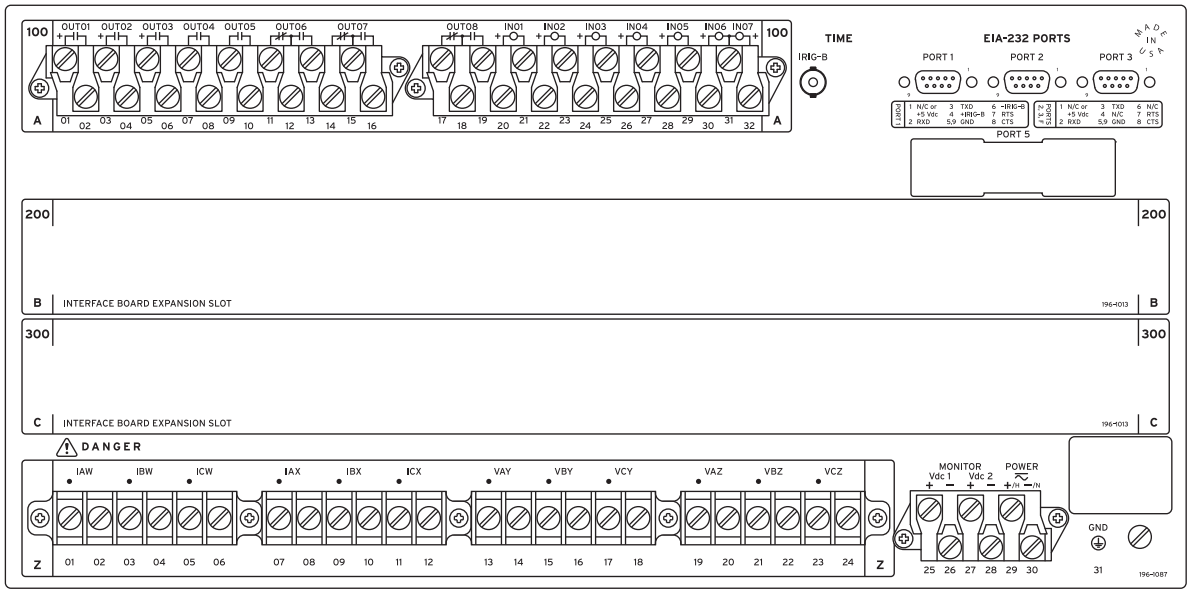
3U Rear Panel, Main Board A

i4148a



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

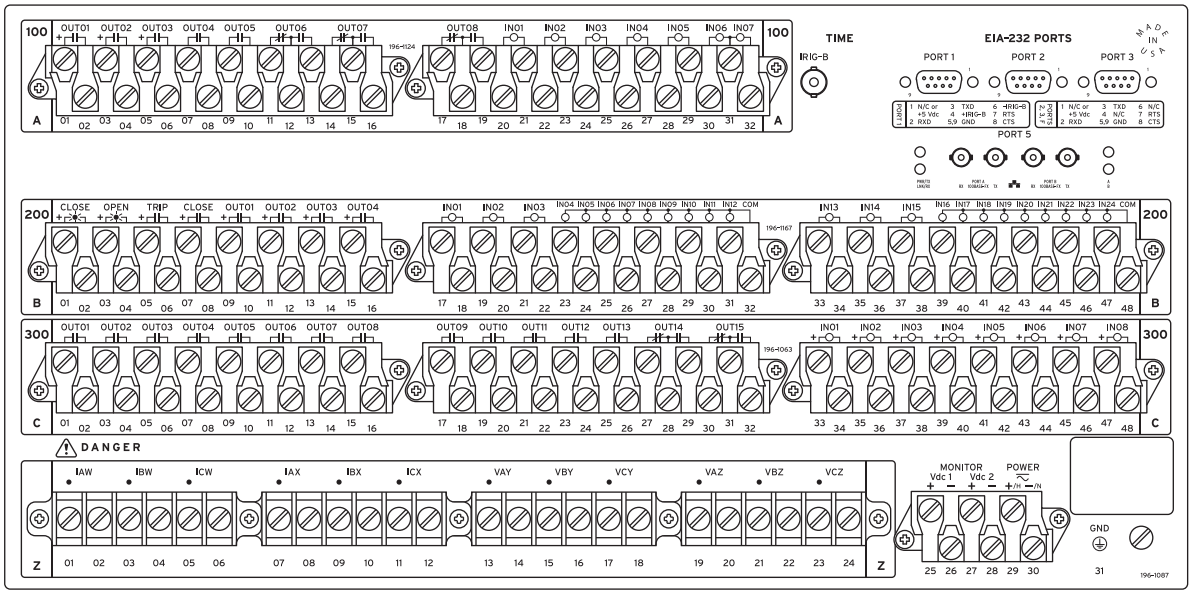
I3375c



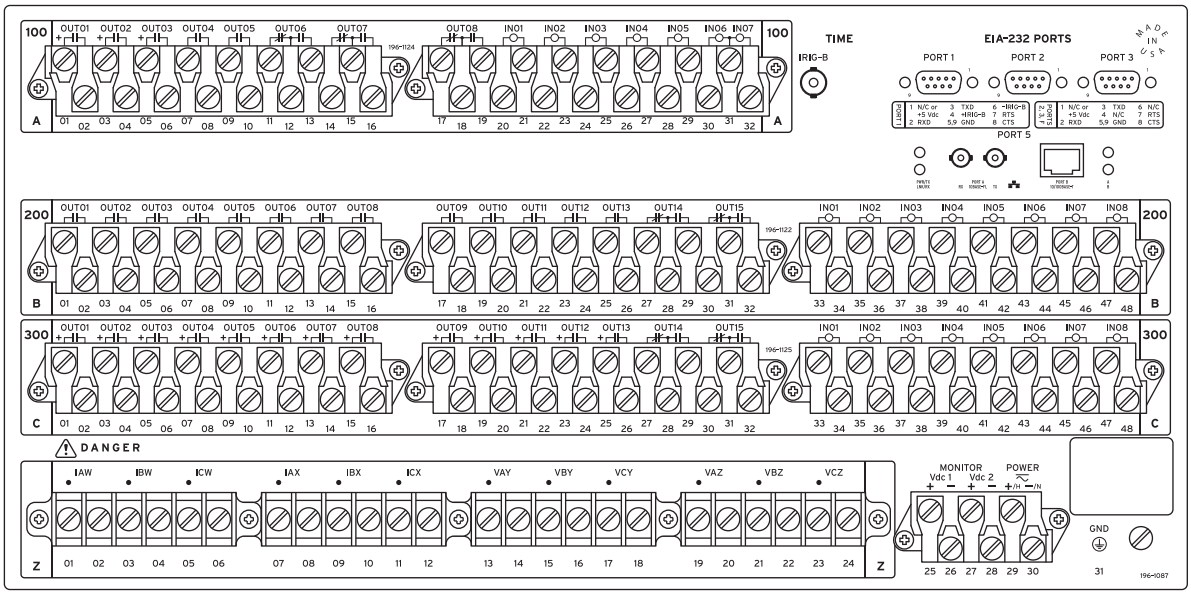
5U Rear Panel, With Space for Additional I/O Boards

i3363c

Figure 23 Typical SEL-421 Rear-Panel Diagrams



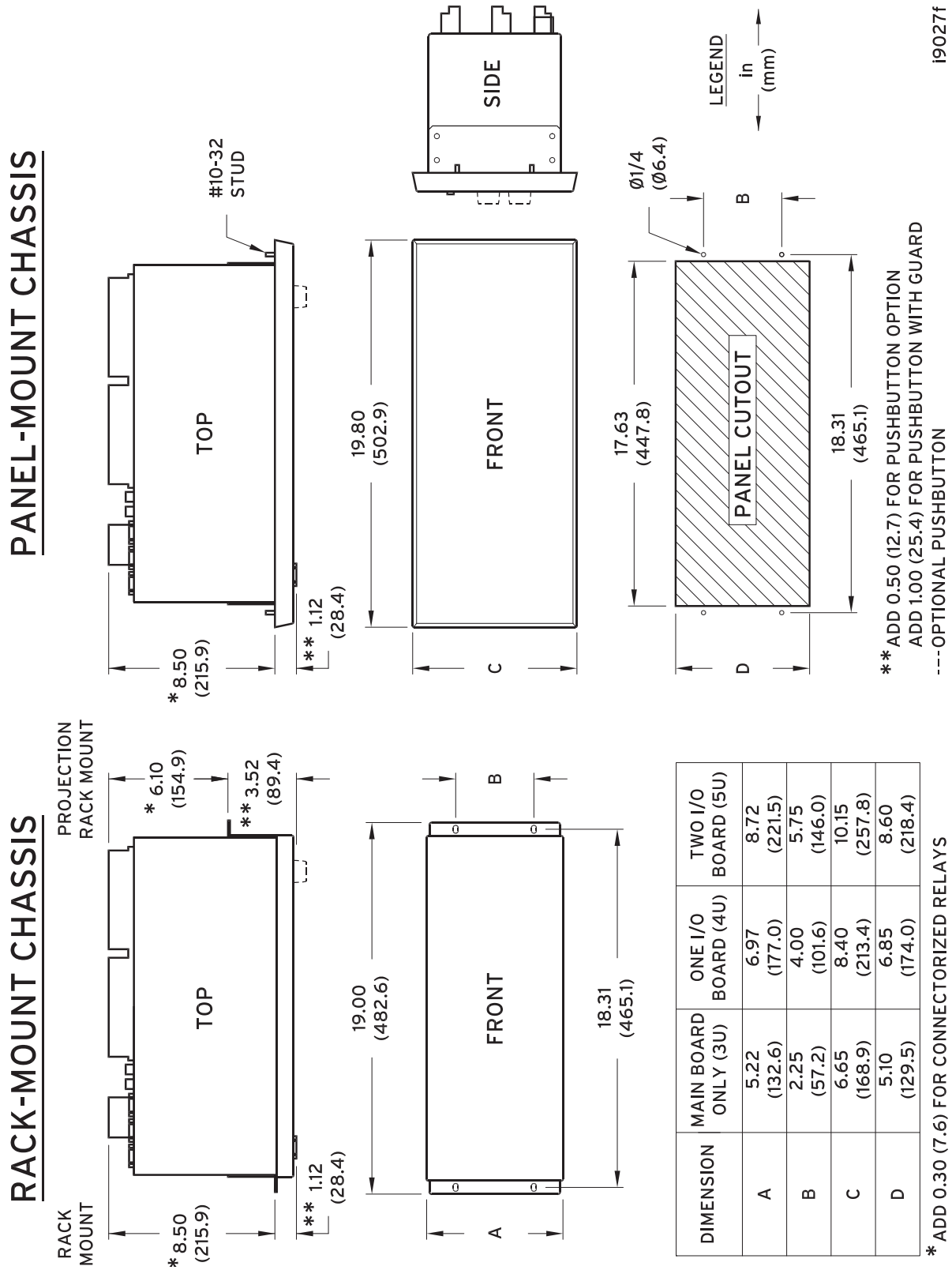
5U Rear Panel, Main Board B, INT3 and INT1 I/O Interface Board



5U Rear Panel, Main Board B, INT2 and INT7 I/O Interface Board

Figure 24 Additional Typical Rear Panel Drawings

Relay Dimensions



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

Figure 25 SEL-421 Dimensions for Rack- and Panel-Mount Models
(Horizontal Mounting Shown; Dimensions Also Apply to Vertical Mounting)

Specifications

Important: Do not use the following specification information to order an SEL-421. Refer to the actual ordering information sheets.

General

AC Current Inputs (Secondary Circuits)

Note: Current transformers are Measurement Category II.

5 A nominal:	15 A continuous, linear to 100 A symmetrical 500 A for 1 second 1250 A for 1 cycle
Burden:	0.27 VA at 5 A 2.51 VA at 15 A
1 A nominal:	3 A continuous, linear to 20 A symmetrical 100 A for 1 second 250 A for 1 cycle
Burden:	0.13 VA at 1 A 1.31 VA at 3 A

AC Voltage Inputs

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

600 Vac for 10 seconds

Burden:	0.03 VA at 67 V 0.06 VA at 120 V 0.8 VA at 300 V

Power Supply

125/250 Vdc or 120/230 Vac

Range:	85–300 Vdc <35 W or 85–264 Vac
Nominal Frequency:	50/60 Hz
Range:	30–120 Hz
Burden:	<120 VA

48/125 Vdc or 120 Vac

Range:	38–140 Vdc <35 W or 85–140 Vac
Nominal Frequency:	50/60 Hz
Range:	30–120 Hz
Burden:	<120 VA

24/48 Vdc

Range:	18–60 Vdc
Burden:	<35 W

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

Break Capacity (10000 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 cycle/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

Note: EA certified relays do not have MOV protected standard output contacts.

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/Dropout Time:	6 ms, resistive load
Update Rate:	1/8 cycle

Break Capacity (10000 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.

Fast Hybrid (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

Break Capacity (10000 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 C37.90-1989.

Auxiliary Trip/Close Pushbuttons (Select Models Only)

Resistive DC or AC Outputs with Arc Suppression Disabled:

Make:	30 A
Carry:	6 A continuous carry
1 s Rating:	50 A
MOV Protection:	250 Vac/330 Vdc/130 J

Breaking Capacity (1000 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

Note: Make per IEEE C37.90-1989.

High Interrupt DC Outputs with Arc Suppression Enabled:

Make:	30 A
Carry:	6 A continuous carry
1 s Rating:	50 A
MOV Protection:	330 Vdc/130 J

Breaking Capacity (10000 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

Note: Make per IEEE C37.90-1989.

Breaker Open/Closed LEDs:

250 Vdc:	on for 150–300 Vdc; 192–288 Vac
125 Vdc:	on for 80–150 Vdc; 96–144 Vac
48 Vdc:	on for 30–60 Vdc;
24 Vdc:	on for 15–30 Vdc

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 (for use with dc signals)

Main Board A:	5 inputs with no shared terminals 2 inputs with shared terminals
INT1, INT5, and INT6 interface boards:	8 inputs with no shared terminals
Range:	15–265 Vdc, independently adjustable
Accuracy:	±5% plus ±3 Vdc
Maximum Voltage:	300 Vdc
Sampling Rate:	1/16 cycle
Typical Burden:	0.24 W at 125 Vdc

Optoisolated (use with ac or dc signals)

Main Board B:	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 board:	6 inputs with no shared terminals 18 inputs with shared terminals (2 groups of 9 inputs with each group sharing one terminal)
Voltage Options:	24 V standard 48, 110, 125, 220, 250 V level sensitive

DC Thresholds
(Dropout thresholds indicate level-sensitive option):

24 Vdc:	Pickup 15.0–30.0 Vdc rms
48 Vdc:	Pickup 38.4–60.0 Vdc; Dropout <28.8 Vdc
110 Vdc:	Pickup 88.0–132.0 Vdc; Dropout <66.0 Vdc
125 Vdc:	Pickup 105–150 Vdc; Dropout <75 Vdc
220 Vdc:	Pickup 176–264 Vdc; Dropout <132 Vdc
250 Vdc:	Pickup 200–300 Vdc; Dropout <150 Vdc

AC Thresholds (Ratings met only when recommended control input settings are used—see *Table 2.2 on page U.2.7* of the User's Guide.):

24 Vac:	Pickup 12.8–30.0 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 150–264 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:	1/16 cycle

Frequency and Rotation

System Frequency:	50/60 Hz
Phase Rotation:	ABC or ACB
Frequency Tracking Range:	40–65 Hz

Communications Ports

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

Communications Card Slot for optional Ethernet Processor

Fiber Optic (Optional)

Ordering Options:

Mode:	Multi	Multi
Wavelength (nm):	820	1300
Source:	LED	LED
Connector type:	ST	ST
Min. TX Pwr. (dBm):	–15.8	–19
Max. TX Pwr. (dBm):	12	–14
RX Sens. (dBm):	–34.4	–32
Sys. Gain (dB):	5	13

Time Inputs

IRIG-B Input–Serial Port 1

Input:	Demodulated IRIG-B
Nominal Voltage:	5 Vdc +10%
Maximum Voltage:	8 Vdc
Input Impedance:	333 ohms
Isolation:	500 Vdc

IRIG-B Input–BNC Connector

Input:	Demodulated IRIG-B
Nominal Voltage:	5 Vdc +10%
Maximum Voltage:	8 Vdc
Input Impedance:	2500 ohms

Operating Temperature

Without Ethernet:	–40° to +85°C (–40° to +185°F)
With Ethernet:	–40° to +75°C (–40° to +167°F)

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

Humidity

5% to 95% without condensation

Weight (Maximum)

3U Rack Unit:	8.0 kg (17.5 lbs)
4U Rack Unit:	9.8 kg (21.5 lbs)
5U Rack Unit:	11.6 kg (25.5 lbs)

Terminal Connections

Rear Screw-Terminal Tightening Torque, #8 Ring Lug

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

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

Wire Sizes and Insulation

Wire sizes for grounding (earthing), current, voltage, and contact connections are dictated by the terminal blocks and expected load currents. You can use the following table as a guide in selecting wire sizes:

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

Use wire with 0.4 mm-thick insulation for high-voltage connections to allow for contact between adjacent wires. If possible, use 0.4 mm insulated wires for all connections.

Routine Dielectric Strength Tests (Performed on Each Manufactured Relay)

AC Current Inputs, optoisolated inputs, and output contacts:	2500 Vac for 10 s
Power Supply:	3100 Vdc for 10 s

Type Tests

Electromagnetic Compatibility Emissions

Emissions:	IEC 60255-25:2000

Electromagnetic Compatibility Immunity

Conducted RF Immunity:	IEC 60255-22-6:2001 Severity Level: 10 Vrms IEC 61000-4-6:2008 Severity Level: 10 Vrms
Electrostatic Discharge Immunity:	IEC 60255-22-2:2008 Severity Level: 2, 4, 6, 8 kV contact; 2, 4, 8, 15 kV air IEC 61000-4-2:2008 Severity Level: 2, 4, 6, 8 kV contact; 2, 4, 8, 15 kV air IEEE C37.90.3-2001 Severity Level: 2, 4, 8 kV contact; 4, 8, 15 kV air
Fast Transient/Burst Immunity:	IEC 60255-22-4:2008 Severity Level: Calss A: 4 kV, 5 kHz; 2 kV, 5 kHz on communication ports IEC 61000-4-4:2011 Severity Level: 4 kV, 5 kHz
Magnetic Field Immunity:	IEC 61000-4-8:2009 Severity Level: 900 A/m for 3 seconds, 100 A/m for 1 minute IEC 61000-4-9:2001 Severity Level: 1000 A/m
Power Supply Immunity:	IEC 60255-11:2008 IEC 61000-4-11:2004 IEC 61000-4-29:2000
Radiated Digital Radio Telephone RF Immunity:	ENV 50204:1995 Severity Level: 10 V/m at 900 MHz and 1.89 GHz
Radiated Radio Frequency Immunity:	IEC 60255-22-3:2007 Severity Level: 10 V/m IEC 61000-4-3:2010 Severity Level: 10 V/m IEEE C37.90.2-2004 Severity Level: 35 V/m
Surge Immunity:	IEC 60255-22-5:2008 Severity Level: 1 kV Line-to-Line, 2 kV Line-to-Earth IEC 61000-4-5:2005 Severity Level: 1 kV Line-to-Line, 2 kV Line-to-Earth
Surge Withstand Capability Immunity:	IEC 60255-22-1:2007 Severity Level: 2.5 kV peak common mode, 1.0 kV peak differential mode IEEE C37.90.1-2002 Severity Level: 2.5 kV oscillatory, 4 kV fast transient waveform

Environmental

Cold:	IEC 60068-2-1:2007 Severity Level: 16 hours at –40°C
Damp Heat, Cyclic:	IEC 60068-2-30:2005 Severity Level: 25°C to 55°C, 6 cycles, Relative Humidity: 95%
Dry Heat:	IEC 60068-2-2:2007 Severity Level: 16 hours at +85°C
Vibration:	IEC 60255-21-1:1988 Severity Level: Class 1 Endurance, Class 2 Response IEC 60255-21-2:1988 Severity Level: Class 1–Shock withstand, Bump, and Class 2–Shock Response IEC 60255-21-3:1993 Severity Level: Class 2 (Quake Response)

Safety

Dielectric Strength:	IEC 60255-5:2000 Severity Level: 2500 Vac on contact inputs, contact outputs, and analog inputs. 3100 Vdc on power supply. Type Tested for 1 minute. IEEE C37.90-2005 Severity Level: 2500 Vac on contact inputs, contact outputs, and analog inputs. 3100 Vdc on power supply. Type Tested for 1 minute.
Impulse:	IEC 60255-5:2000 Severity Level: 0.5 Joule, 5 kV IEEE C37.90-2005 Severity Level: 0.5 Joule, 5 kV

Safety Agency Certifications

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

Certifications

ISO:	Relay is designed and manufactured using ISO 9001:2000 certified quality program.
Product Safety:	IEC 60255-6:1988

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 Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems, IEEE C37.111–1999*

Event Reports

Storage:	35 quarter-second events or 24 half-second events
Maximum Duration:	Record events as long as 5 seconds
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

Processing Specifications

AC Voltage and Current Inputs

8000 samples per second, 3 dB low-pass analog filter cut-off 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

8 times per power system cycle

Synchrophasors

Maximum data rate in messages per second

IEEE C37.118 protocol:	60 (nominal 60 Hz system) 50 (nominal 50 Hz system)
SEL Fast Message protocol:	20 (nominal 60 Hz system) 10 (nominal 50 Hz system)

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

Mho Phase Distance Elements

Zones 1–5 Impedance Reach

Setting Range

5 A Model:	OFF, 0.05 to 64 Ω secondary, 0.01 Ω steps
1 A Model:	OFF, 0.25 to 320 Ω secondary, 0.01 Ω steps

Sensitivity

5 A Model:	0.5 A_{p-p} secondary
1 A Model:	0.1 A_{p-p} secondary (Minimum sensitivity is controlled by the pickup of the supervising phase-to-phase overcurrent elements for each zone.)
Accuracy (Steady State):	±3% of setting at line angle for SIR (source-to-line impedance ratio) < 30 ±5% of setting at line angle for 30 ≤ SIR ≤ 60
Zone 1 Transient Overreach:	<5% of setting plus steady-state accuracy
SEL-421-0 and SEL-421-3 Maximum Operating Time:	0.8 cycle at 70% of reach and SIR = 1
SEL-421-1 and SEL-421-2 Maximum Operating Time:	1.5 cycle at 70% of reach and SIR = 1

Mho Ground Distance Elements

Zones 1–5 Impedance Reach

Mho Element Reach

5 A Model:	OFF, 0.05 to 64 Ω secondary, 0.01 Ω steps
1 A Model:	OFF, 0.25 to 320 Ω secondary, 0.01 Ω steps

Sensitivity

5 A Model:	0.5 A secondary
1 A Model:	0.1 A secondary (Minimum sensitivity is controlled by the pickup of the supervising phase and residual overcurrent elements for each zone.)
Accuracy (Steady State):	±3% of setting at line angle for SIR < 30 ±5% of setting at line angle for 30 ≤ SIR ≤ 60
Zone 1 Transient Overreach:	<5% of setting *plus* steady-state accuracy
SEL-421-0 and SEL-421-3 Maximum Operating Time:	0.8 cycle at 70% of reach and SIR = 1
SEL-421-1 and SEL-421-2 Maximum Operating Time:	1.5 cycle at 70% of reach and SIR = 1

Quadrilateral Ground Distance Elements

Zones 1–5 Impedance Reach

Quadrilateral Reactance Reach

5 A Model:	OFF, 0.05 to 64 Ω secondary, 0.01 Ω steps
1 A Model:	OFF, 0.25 to 320 Ω secondary, 0.01 Ω steps

Quadrilateral Resistance Reach

5 A Model:	OFF, 0.05 to 50 Ω secondary, 0.01 Ω steps
1 A Model:	OFF, 0.25 to 250 Ω secondary, 0.01 Ω steps

Sensitivity

5 A Model:	0.5 A secondary
1 A Model:	0.1 A secondary (Minimum sensitivity is controlled by the pickup of the supervising phase and residual overcurrent elements for each zone.)
Accuracy (Steady State):	±3% of setting at line angle for SIR < 30 ±5% of setting at line angle for 30 ≤ SIR ≤ 60
Transient Overreach:	<5% of setting plus steady-state accuracy

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:	0.000–16000.000 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

US:	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

Ground Directional Elements

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

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

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

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

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

Undervoltage and Overvoltage Elements

Pickup Ranges:	Phase elements: 1–200 V secondary, 1 V steps
Phase-to-Phase Elements:	1.0–300.0 V secondary, 0.1 V steps
Accuracy (Steady State):	±1 V plus ±5% of setting
Transient Overreach:	<5% of pickup

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

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

Monitor Ambient or Other Temperatures

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

Up to 500 m Fiber-Optic Cable to SEL-2600 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°

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°

Out-of-Step Elements

Blinders (R1) Parallel to the Line Angle

5 A Model:	0.05 to 70 Ω secondary –0.05 to –70 Ω secondary
1 A Model:	0.25 to 350 Ω secondary –0.25 to –350 Ω secondary

Blinders (X1) Perpendicular to the Line Angle

5 A Model:	0.05 to 96 Ω secondary –0.05 to –96 Ω secondary
1 A Model:	0.25 to 480 Ω secondary –0.25 to –480 Ω secondary

Accuracy (Steady State)

5 A Model:	±5% of setting plus ±0.01 A for SIR (source to line impedance ratio) < 30 ±10% of setting plus ±0.01 A for 30 ≤ SIR ≤ 60
1 A Model:	±5% of setting plus ±0.05 A for SIR (source to line impedance ratio) < 30 ±10% of setting plus ±0.05 A for 30 ≤ SIR ≤ 60
Transient Overreach:	<5% of setting *plus* steady-state accuracy

Positive-Sequence Overcurrent Supervision

Setting Range

5 A Model:	1.0–100.0 A, 0.01 A steps
1 A Model:	0.2–20.0 A, 0.01 A steps

Accuracy

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

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

Out-of-Step Timers

OSBD, OSTD:	0.500–8000 cycles, 0.125 cycle steps
UBD:	0.500–120 cycles, 0.125 cycle steps
Pole Open Timer:	0.000–60 cycles, 0.125 cycle steps
Recloser:	1–99999 cycles, 1 cycle steps

Switch-Onto-Fault

CLOEND, 52AEND:	OFF, 0.000–16000 cycles, 0.125 cycle steps
SOTFD:	0.50–16000 cycles, 0.125 cycle steps

Synchronism Check Timers

TCLSBK1, TCLSBK2:	1.00–30.00 cycles, 0.25 cycle steps
Zone Time Delay:	0.000–16000 cycles, 0.125 cycle steps

Station DC Battery System Monitor Specifications

Operating Range:	0–350 Vdc
Input Sampling Rate:	2 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 • I_{nom} to 3.0 • 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 • I_{nom} to 3.0 • I_{nom}

Voltages

Phase and Phase-to-Phase Voltage Magnitude:	± 0.1% (33.5–200 V_{L-N})
Phase and Phase-to-Phase Angle:	±0.05° (33.5–200 V_{L-N})
Sequence Voltage Magnitude:	±0.15% (33.5–200 V_{L-N})
Sequence Voltage Angle:	±0.1° (33.5–200 V_{L-N})

Frequency (Input 40–65 Hz)

Accuracy:	±0.01 Hz

Power and Energy

Real Power, P (MW), Three Phase

At 0.1 • I_{nom}

Power factor unity:	±0.4%
Power factor 0.5 lag, 0.5 lead:	±0.7%

At 1.0 • I_{nom}

Power factor unity:	±0.4%
Power factor 0.5 lag, 0.5 lead:	±0.4%

Reactive Power, Q (MVAR), Three Phase

At 0.1 • I_{nom}

Power factor 0.5 lag, 0.5 lead:	±0.5%

At 1.0 • I_{nom}

Power factor 0.5 lag, 0.5 lead:	±0.4%

Energy (MWh), Three Phase

At 0.1 • I_{nom}

Power factor unity:	±0.5%
Power factor 0.5 lag, 0.5 lead:	±0.7%

At 1.0 • I_{nom}

Power factor unity:	±0.4%
Power factor 0.5 lag, 0.5 lead:	±0.4%

Synchrophasors

See *Accuracy on page R.7.9* of the Reference Manual for test exclusions and details.

TVE (total vector error):	£1%
Frequency Range:	±5 Hz of nominal (50 or 60 Hz)
Voltage Range:	30 V–150 V
Current Range:	(0.1–2) • I_{nom} (I_{nom} = 1 A or 5 A)
Phase Angle Range:	–179.99° to 180°

Notes

Notes

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