SEL-T401L Ultra-High-Speed Line Relay

Dependable Time-Domain Line Protection With a Traveling-Wave Fault Locator and an Ultra-High-Resolution Transient Recorder

Major Features and Benefits

The SEL-T401L is a high-performance, easy-to-use line protective relay in a 3U package. Built on the field experience of the SEL-T400L, the SEL-T401L delivers unprecedented operating times and also includes the complete suite of protection functions that you expect in a line protection system. Suitable for a wide range of applications, the SEL-T401L offers an opportunity to reset the complexity of line protection applications with simple protection philosophies and a reduced setting count.

- **Time-Domain Line Protection.** Protect transmission lines with ultra-high-speed elements and schemes based on the field-proven SEL time-domain technology of traveling waves and incremental quantities. Clear close-in high-current faults in 2 ms with the underreaching incremental-quantity distance protection element (TD21) without relying on a protection channel. Dependably protect the entire line with permissive overreaching transfer trip logic over a standard digital or analog protection channel with traveling-wave (TW32) and incremental-quantity (TD32) directional elements operating as fast as 0.1 ms and 1.5 ms, respectively. Achieve both extraordinary speed and sensitivity with the traveling-wave differential protection scheme (TW87) over a direct fiber-optic channel with end-to-end operating times of 1 to 5 ms, depending on the line length.
- **Dependable Protection.** Complement and back up the traveling-wave and incremental-quantity protection elements and schemes with distance elements, dependable and sensitive directional elements, overcurrent elements, switch-onto-fault logic, permissive and blocking pilot logic, open-breaker echo logic, and weak-infeed logic. Provide remote backup and coordinate with adjacent relays by using step distance protection, definite- and inverse-time overcurrent elements, and definite-time over- and undervoltage elements.
- **Advanced Distance Elements.** Apply five zones of distance protection for direct tripping, in the pilot protection logic, in the switch-onto-fault logic, and for step distance protection. Satisfy your distance protection philosophy and coordinate with adjacent relays by selecting the operating characteristic as either mho or quadrilateral (on a per-zone basis, independently for the phase and ground distance elements). Use the nondirectional (offset) Zone 5 distance element in the switch-onto-fault logic, for time-coordinated backup protection for local bus faults, and for nondirectional starting of the blocking pilot scheme.
- **Supervisory Elements.** Improve protection performance with open-pole detection, loss-of-potential, load-encroachment, and power-swing blocking logic.

- **Flexible Protection Signaling.** Send and receive permissive and blocking signals, direct trip signals, autoreclose initiate signals, and breaker failure initiate signals over contact I/O and over as many as three fiber-optic protection ports. When using a digital channel for protection signaling, select – on a per-port basis – either SEL MIRRORED BITS® encoding or IEEE C37.94 encoding. To simplify and standardize protection panel wiring and improve signal integrity, use the SEL-2507 High-Speed Remote I/O Module to connect to your analog teleprotection channel interface with a fiber-optic cable.
- **Comprehensive Applications.** Protect two-terminal and multiterminal lines with single- or dual-breaker terminations in single- or three-pole tripping applications. Protect and accurately locate faults on series-compensated lines, overhead and cable lines, as well as hybrid lines with both overhead and cable sections.
- **Trip-Rated Outputs.** Eliminate interposing relays and trip directly with high-speed trip-rated relay outputs to simplify wiring, increase reliability, and improve trip times. Trip one or two breakers directly with as many as six outputs in single-pole or three-pole tripping applications.
- **Accurate Fault Locating.** Locate faults to the nearest tower with the field-proven SEL traveling-wave-based fault-locating technology. Use standard instrument transformers without special wiring requirements. Obtain a reliable fault location with the double-ended traveling-wave-based fault-locating method by using a 64 kbps digital channel with IEEE C37.94 encoding or a direct fiber-optic channel. In applications without a digital protection channel, use the single-ended traveling-wave-based fault-locating method and obtain a short prioritized list of possible fault locations. Ensure dependable fault-locating under a wide range of operating conditions with the double-ended and single-ended impedance-based fault-locating methods.
- **Location-Dependent Autoreclosing Control.** Allow or inhibit autoreclosing based on the accurate real-time fault location. Inhibit reclosing for faults on the cable sections of a hybrid line, near airports, along fire-prone stretches of an overhead line, or in areas where humans or animals are present. Location-dependent autoreclosing control works over a direct fiber-optic channel or a 64 kbps IEEE C37.94-encoded multiplexed channel.
- **Line Monitoring.** Monitor the line for incipient faults, recurring faults, or incipient cable faults. Obtain a location-tabulated event count to detect low-energy activity and faults along the line. Prevent faults by selectively cleaning or replacing insulators, trimming vegetation, improving antigalloping solutions, applying line spacers, or improving lightning protection. Line monitoring works over a direct fiber-optic channel or a 64 kbps IEEE C37.94-encoded multiplexed channel.
- **Ultra-High-Resolution Transient Recording.** Record as many as six currents and six voltages at a 1 MHz sampling rate with 18 bits of resolution. Store no less than 45 s of total recording time before having to retrieve the records. Use a direct fiber-optic channel to record line currents and voltages at the remote line terminal or to deploy a two-chassis recording system with a total of 24 channels. Study switching events and other high-frequency phenomena in a single substation or throughout the system by deploying a multichassis recording system with 100 ns accuracy time synchronization between multiple SEL-T401L relays. Use the low burden, dc-coupled SEL-T401L voltage inputs to connect to high-bandwidth, low-power voltage sensors.
- **Modern Relay for a Modern Power System.** Confidently protect lines near nonstandard generators, such as wind generators or inverter-based sources; in low-inertia systems with HVDC links; and in systems with series compensation. The SEL-T401L traveling-wave and incremental-quantity protection elements and schemes are well suited for modern power systems with such characteristics. The relay also features several enhancements in areas such as sensitive directional elements, memory polarization, and use of sequence components in general to address these emerging power system characteristics.
- **Simplicity.** Achieve the right balance between the need to customize the relay to suit your specific requirements and the benefits of simplicity, workforce efficiency, and avoidance of human errors. The SEL-T401L is as flexible as it needs to be to accommodate a variety of applications, yet it simplifies choices and intentionally limits flexibility in other areas for the benefits of efficiency and avoiding human errors.
- **Hardware, Software, and Protection Diversity.** Apply the SEL-T401L as a redundant relay with other SEL line protective relays without concerns for common-mode failures. The new technology of traveling waves and incremental quantities and changes in other protection elements and schemes make the SEL-T401L hardware, software, and protection philosophy significantly different from other SEL line relays. Gain efficiency by using common SEL configuration and integration tools, yet benefit from a diversity of hardware, software, and protection operating principles.

Functional Overview

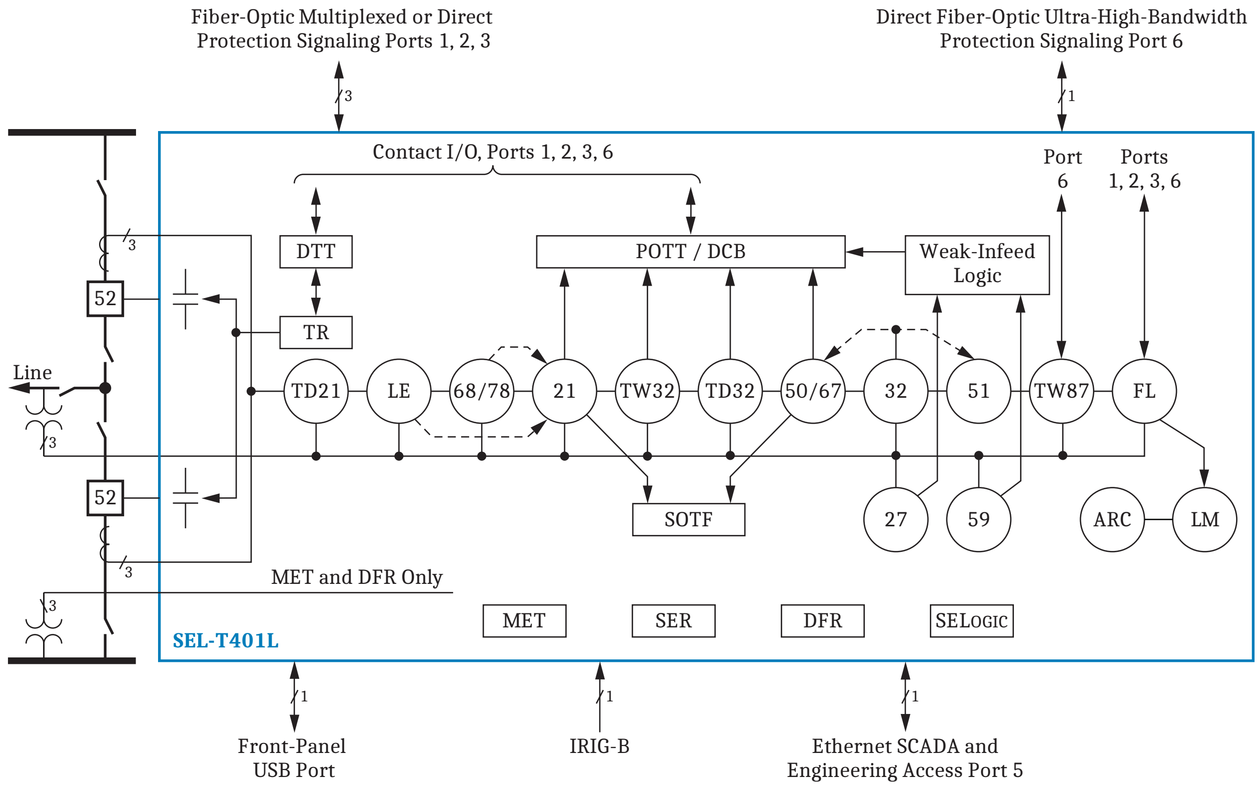

Figure 1 Functional Overview Diagram

ANSI Number or Acronym	Description
21	Phase and Ground Distance
TD21	Incremental-Quantity Phase and Ground Distance
27	Undervoltage (phase, phase-to-phase, and positive-sequence)
32	Directional (phase, zero-sequence, and negative-sequence)
TD32	Incremental-Quantity Directional
TW32	Traveling-Wave Directional
50	Instantaneous Overcurrent (phase, zero-sequence, and negative-sequence)
51	Inverse-Time Overcurrent (phase, zero-sequence, and negative-sequence)
59	Overvoltage (phase, phase-to-phase, positive-sequence, zero-sequence, and negative-sequence)
67	Instantaneous and Definite-Time Directional Overcurrent (phase, zero-sequence, and negative-sequence)
68	Power-Swing Blocking
78	Out-of-Step Tripping
85 RIO	SEL MIRRORED BITS I/O With Selectable SEL MB8 or IEEE C37.94 Encoding
TW87	Traveling-Wave Differential
94	High-Speed Trip-Rated Outputs
POTT	Permissive Overreaching Transfer Trip Logic
CBECHO	Open-Breaker Echo Logic
WI	Weak-Infeed Logic
DCB	Directional Comparison Blocking Logic
SOTF	Switch-Onto-Fault Logic

ANSI Number or Acronym	Description
DTT	Direct Transfer Trip Logic (intertripping)
LOP	Loss-of-Potential Logic
OP	Open-Pole Detection Logic
LE	Load-Encroachment Logic
DFR	Digital Fault Recorder
SER	Sequential Events Recorder
FL	Fault Locator
LM	Line Monitor
SELOGIC	Programmable Logic
MET	Metering
ARC	Adaptive Autoreclose Cancel Logic
HMI	Local Operator Interface
DNP3	Distributed Network Protocol 3.0 (Ethernet)
LB	Local Control Bits (operated through front-panel HMI)
RB	Remote Control Bits (operated through DNP3 and SEL Fast Operate protocols)
FTP	File Transfer Protocol
FTDV	Fast Time-Domain Values
EMI	Electromagnetic Interference Monitoring for Traveling-Wave Functions
TEST	Event Playback and Traveling-Wave Test Mode

Physical Overview

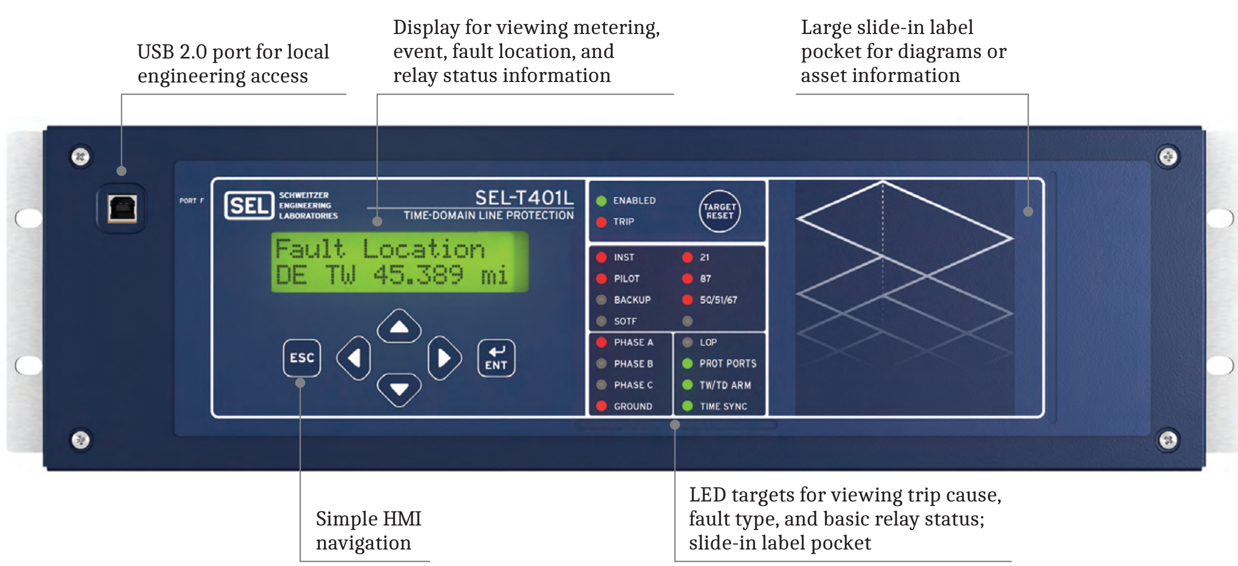

Figure 2 Front-Panel Physical Overview

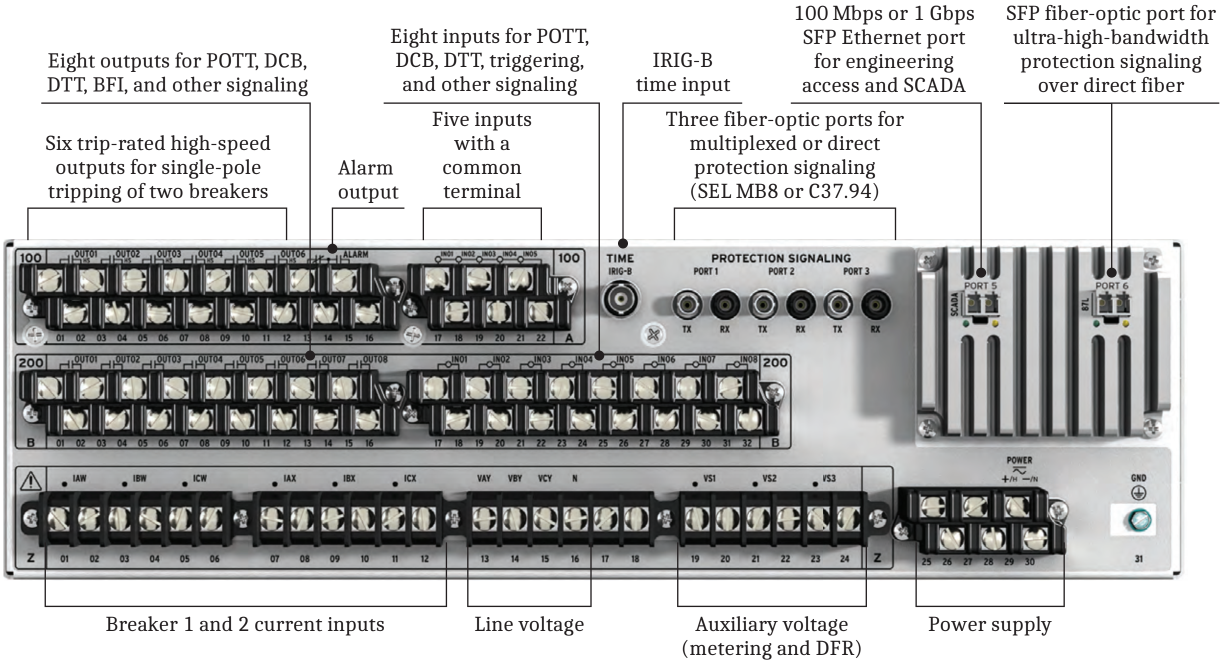

Figure 3 Rear-Panel Physical Overview

Protection

The SEL-T401L includes ultra-high-speed time-domain protection elements and schemes as well as a complete suite of phasor-based protection and supervisory elements. These elements back up the time-domain protection elements and schemes and provide comprehensive primary protection for the line and backup protection for the surrounding power system.

Time-Domain Protection

The SEL-T401L includes the following time-domain protection:

- TD21 underreaching incremental-quantity distance protection element.
- TW87 traveling-wave differential protection scheme.
- Permissive overreaching transfer trip (POTT) scheme with incremental-quantity (TD32) and traveling-wave (TW32) directional elements.

These time-domain elements and schemes use patented SEL technology, first made available in the SEL-T400L.

The TD21 and TD32 elements use incremental quantities – the differences between the instantaneous voltages and currents and their one-cycle-old values. As such, the incremental quantities contain only the fault-induced components of voltages and currents. The relay processes the incremental-quantity calculations and logic at 10 kHz.

The TW32 element and the TW87 scheme respond to traveling waves (TWs). TWs are surges of electricity that propagate along transmission lines at a velocity close to the speed of light. At the relay locations, TWs manifest as sharp changes in the relay input signals with rise times of a few microseconds. The relay processes the TW calculations every microsecond and the associated logic at 10 kHz.

Incremental-Quantity Distance Protection Element (TD21)

The TD21 protection element uses incremental voltages and currents to provide underreaching distance protection without relying on a protection channel. Apply the TD21 element with a reach setting as high as 80 percent of the line length. The TD21 element has a transient overreach below 10 percent and typically operates between 2 and 5 ms, depending on the fault location, system short-circuit level, fault resistance, and point on wave (see *Figure 4*). The TD21 element is suitable for series-compensated lines and you can set it using the line impedance alone, neglecting the in-line and adjacent capacitors. The element is phase-selective and suitable for single-pole tripping applications.

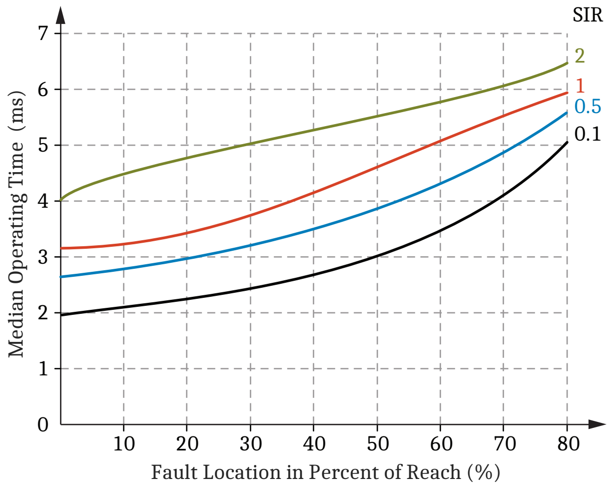

Figure 4 TD21 Element Median Operating Time for Varying Fault Location and Different Source-to-Line Impedance Ratios

To realize the TD21 element, the SEL-T401L calculates an instantaneous voltage change at the intended reach point by using the incremental replica current and the incremental voltage at the relay location and the line RL parameters. Pre-fault voltage is the highest value possible for the change in voltage at the fault point. With reference to *Figure 5*, if the calculated voltage change at the reach point is greater than the pre-fault voltage at the reach point, the fault must be closer than the set reach. If so, the TD21 element operates, provided other security conditions are met.

The TD21 element uses six measurement loops to cover all fault types and applies instantaneous pre-fault voltage at the reach point as a restraint for sensitivity and speed. The element allows independent reach settings for the phase and ground measurement loops.

The TD21 element is dependable for zero-resistance (bolted) faults in relatively strong systems. It operates as fast as 2 ms for close-in faults in strong systems and in a few milliseconds for faults closer to the reach point and in weaker systems. When the source-to-line-impedance ratio (SIR) increases, the effective resistive coverage of the element increases as well, up to a point beyond which the element reach becomes gradually reduced. The element shuts down for SIRs above about 2.5, favoring security over dependability.

Responding to change in voltage rather than voltage, the TD21 element underreaches rather than overreaches during transients caused by capacitively coupled voltage transformers (CCVT).

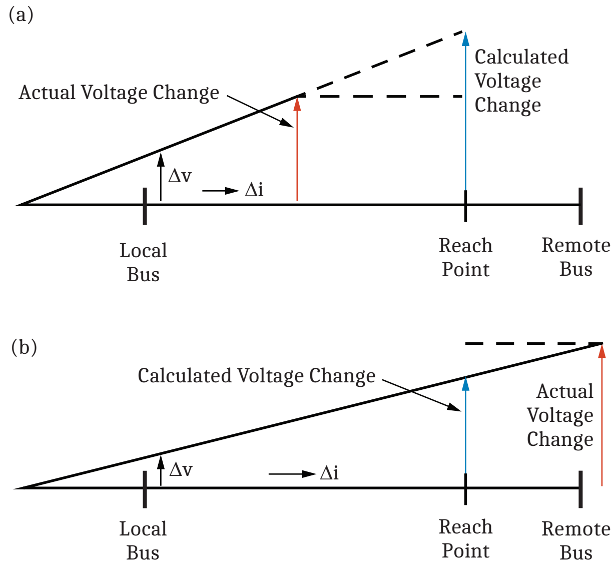

Figure 5 TD21 Element Operating Principle for: (a) In-Zone Faults and (b) Out-of-Zone Faults

Traveling-Wave Differential Protection Scheme (TW87)

The TW87 scheme uses current TWs and a direct fiber-optic channel to detect in-zone faults with end-to-end operating times of 1 to 5 ms, depending on the line length (see *Figure 6*). The TW87 scheme provides internal synchronization of data over the communications channel and is therefore independent from external clocks. The TW87 scheme is well suited for series-compensated lines and can be used for single-pole tripping applications. The TW87 scheme uses traditional CTs and wiring. It uses pre-fault voltage signals for extra security and works well with CCVTs. You can apply the TW87 scheme on two-terminal tapped lines, taking advantage of its built-in location-dependent supervision.

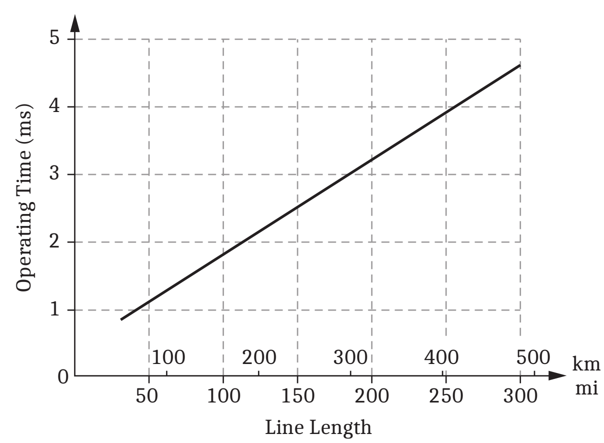

Figure 6 TW87 Scheme Operating Time as a Function of Line Length

The TW87 scheme compares time-aligned current TWs at both ends of the protected line. For an external fault, a TW that has entered one terminal with a given polarity leaves the other terminal with the opposite polarity exactly after the TW line propagation time (see *Figure 7*). To realize the TW87 scheme, the SEL-T401L extracts current TWs from the local and remote currents, identifies the first TWs in the local and remote currents, searches for exiting TWs that arrive at the opposite line terminal after the TW line propagation time, and calculates the operating and restraining signals from the first and exiting TWs.

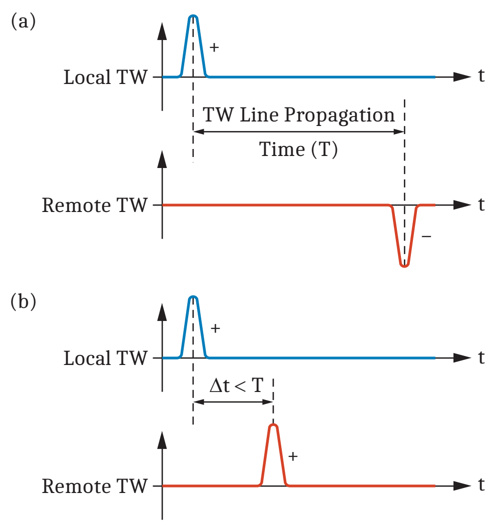

Figure 7 Current TW Timing and Polarities for (a) External Faults and (b) Internal Faults

In addition to the pickup and slope settings customary in any differential protection logic, the TW87 scheme uses the real-time fault location calculated with a double-ended TW-based fault-locating method and other security conditions.

The TW87 scheme logic applies a factory-selected security slope and provides for user-selected phase and ground incremental overcurrent pickup settings. The minimum pickup thresholds apply to the low-frequency incremental current. This overcurrent supervision confirms that the in-zone event is a fault and not a switching event or a nearby lightning strike.

The TW87 scheme uses pre-fault voltage for additional security to verify if the polarity of the current TWs agrees with the polarity of the voltage at the place and time of the fault.

The TW87 scheme is phase-selective and suitable for single-pole tripping applications.

Pilot Protection With Time-Domain Directional Elements

The SEL-T401L provides you with an option to use ultra-high-speed directional elements for permissive keying (TD32 and optionally TW32) and tripping (TD32). The TW32 traveling-wave directional element operates in 0.1 ms, and the TD32 incremental-quantity directional element operates in 1.5 ms, on average. Both directional elements are phase-selective and suitable for single-pole tripping and series-compensated lines. When used with a high-speed digital channel, the POTT scheme operates in 2 to 6 ms, depending on the line length (see *Figure 8*).

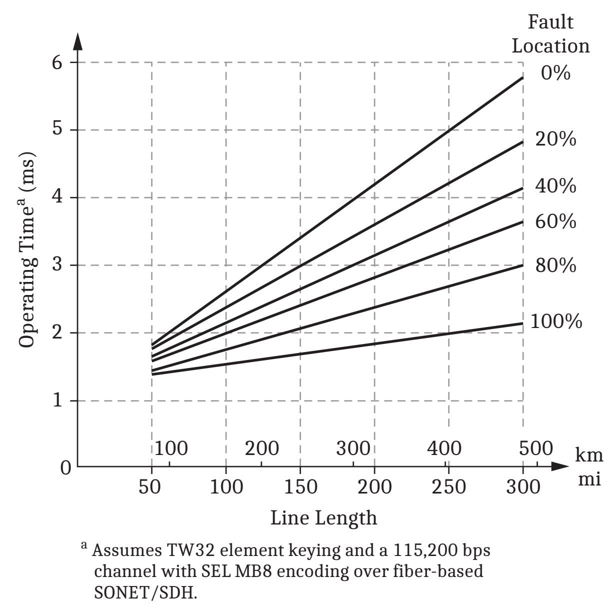

Figure 8 POTT Operating Time as a Function of Fault Location for Different Line Lengths

You can also use the TD32 and TW32 elements in the blocking scheme for acceleration of the blocking signal. These fast directional elements increase the coordination time margin for most external faults.

TD32 Directional Element

To realize the TD32 element, the SEL-T401L calculates a replica current as a voltage drop from the incremental current (Δi) at the relay location across an RL circuit representing one ohm of impedance of the line and the system. As *Figure 9* shows, the incremental replica current is directly proportional to the incremental voltage (Δv) at the relay location. The incremental replica current and the incremental voltage are of opposite polarities for forward faults (*Figure 9(a)*) and of matching polarities for reverse faults (*Figure 9(b)*).

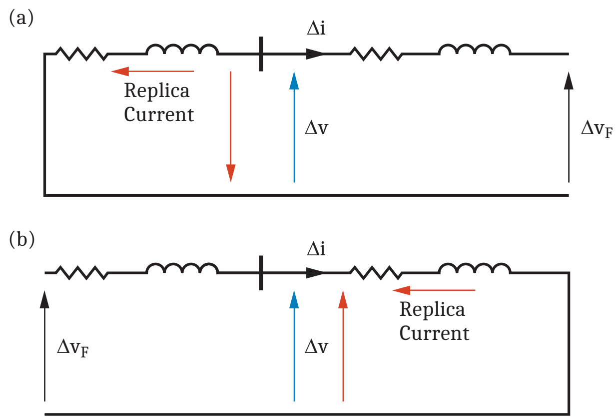

Figure 9 TD32 Element Operating Principle: (a) Forward Faults and (b) Reverse Faults

The TD32 element uses six measurement loops to cover all fault types, calculates and integrates an operating torque, and applies adaptive forward and reverse operating thresholds for optimum sensitivity and speed. The relay calculates these adaptive thresholds by using the present value of the replica current and the impedance threshold settings.

The TD32 element operates dependably and quickly for faults at any point on wave and for resistive faults.

TW32 Directional Element

The TW32 element compares the relative polarity of the current TW with the voltage TW. The two TWs are of opposite polarities for a forward fault and of matching polarities for a reverse fault. To realize the TW32 element, the SEL-T401L integrates a torque calculated from the current and voltage TWs for a few tens of microseconds into the fault (see *Figure 10*). Therefore, the relay responds to the TW activity during the few tens of microseconds following the first TW. Once the TW32 element asserts, the relay logic keeps it asserted for a short period of time. The TW32 element acts as a permissive (POTT) or blocking (DCB) key accelerator in the pilot protection scheme.

When applied with CCVTs, the TW32 element benefits from the stray capacitances across the CCVT tuning reactor and step-down transformer. These capacitances create a path for high-frequency voltage components, allowing some voltage TW signals to appear at the secondary CCVT terminals. The element uses only the polarity and timing of the first voltage TW, and therefore the element is suitable for applications with CCVTs, despite their poor reproduction of the voltage TWs in general.

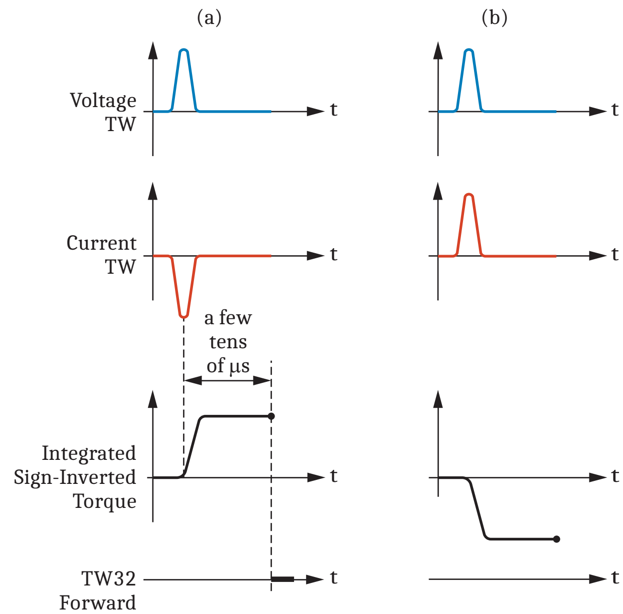

Figure 10 Voltage and Current TWs for (a) Forward Faults and (b) Reverse Faults

Time-Domain Starting Logic

The SEL-T401L combines fault-type identification with nondirectional starting for the time-domain protection elements and schemes. The combined starting and fault-type identification logic is based on incremental voltages in six measurement loops. The logic calculates incremental voltages at a certain electrical distance away from the relay by using the voltages and currents at the relay location and the line RL data (see *Figure 11*). For the incremental-quantity protection elements to start, the change in these calculated incremental voltages must be greater than a factory-selected minimum value. By comparing the voltage changes in all six measurement loops, the logic also identifies the fault type for use in time-domain elements and schemes.

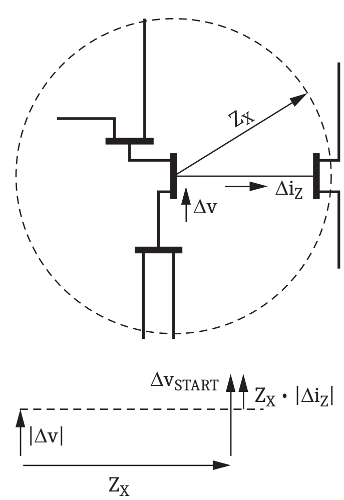

Figure 11 The Principle of Starting and Fault-Type Identification Logic

Time-Domain Overcurrent Supervision

Ultra-high-speed incremental overcurrent elements supervise the TD21 distance element, the TD32 directional element in the POTT scheme, and the TW87 differential scheme. These supervisory incremental overcurrent elements respond to the incremental replica currents and measure the current level in the low-frequency spectrum (below 1 kHz). Their primary purpose is to verify that the event is a fault and not a switching or other low-energy event. The overcurrent supervision allows the TD21 element and the POTT and TW87 schemes to remain secure during switching events that may launch TWs or cause high-frequency incremental quantities.

The SEL-T401L implements the incremental overcurrent elements in the time domain, observing that the incremental replica currents are not affected by the decaying dc component and are at zero before the fault. The relay uses these characteristics of the incremental replica currents to implement the novel overcurrent principle (see *Figure 12*).

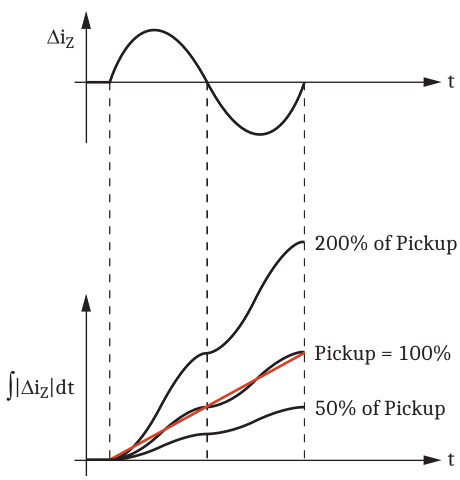

Figure 12 The Incremental Overcurrent Element Principle of Operation

The TD67 and TD50 incremental-quantity elements follow user settings and the relay applies them to supervise the POTT and TW87 schemes, respectively. The TD21 element uses the same overcurrent logic but applies an internal overcurrent threshold that does not require a user setting. The TD67 and TD50 elements are very fast and do not slow down the inherently fast operation of the TD21 element and the POTT and TW87 schemes (see *Figure 13*).

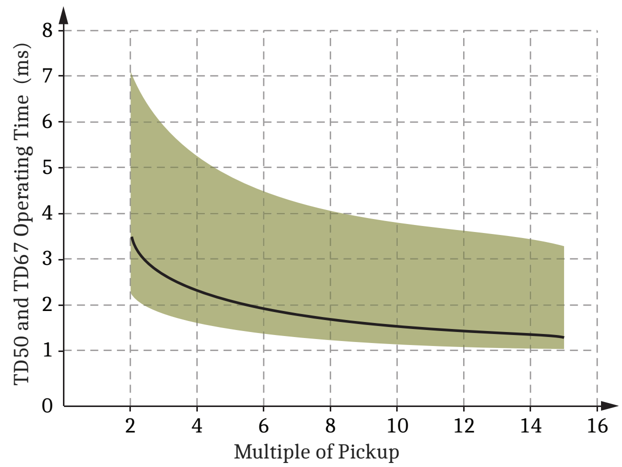

Figure 13 TD50 and TD67 Elements Operating Time as a Function of Multiple of Pickup (Range and Median)

Time-Domain Protection Settings

The time-domain protection elements and schemes of the SEL-T401L are simple to set. The relay requires only a few time-domain protection settings in addition to nameplate data such as CT and PT ratios, line length and impedance, nominal voltage and frequency, and series capacitor reactance. The few time-domain settings that require protection judgment and knowledge are either multiple-choice preferences or simple overcurrent or impedance thresholds. *Table 1* lists the protection settings for the time-domain protection elements and schemes and briefly explains their purpose and recommendations.

Table 1 Settings of the Time-Domain Protection Elements and Schemes (Sheet 1 of 2)

Name	Purpose	Recommendation for Typical Applications
TD21P TD21G	TD21 phase and ground distance reach	Set to 75% to 80% (phase) and 70% to 75% (ground) of the apparent positive-sequence impedance
TD32ZF	TD32 forward impedance threshold	Set to 30% of the net positive-sequence impedance of the strongest local system
TD32ZR	TD32 reverse impedance threshold	Set to 30% of the net positive-sequence impedance of the line
TD67P TD67G	Overcurrent supervision for POTT operation when initiated by the TD32 element (phase and ground)	Set to ride through switching of in-line series capacitors, if present; otherwise, set below the minimum fault current level for line faults

Table 1 Settings of the Time-Domain Protection Elements and Schemes (Sheet 2 of 2)

Name	Purpose	Recommendation for Typical Applications
TWLPT	TW line propagation time	Measure during the SEL-T401L commissioning by using the ultra-high-resolution transient record that captures currents and voltages during line energization
TW87_50P TW87_50G	TW87 scheme overcurrent supervision (phase and ground)	Set below the minimum fault current level for line faults

Security and Dependability of Time-Domain Protection

The TW87 scheme and the TD21, TD32, and TW32 elements prioritize speed and security over dependability.

The SEL-T401L includes arming logic to check for normal line operating conditions before allowing the ultra-high-speed time-domain protection elements and schemes to operate for a fault. The arming logic is fully preconfigured and does not require user customization. If line operating conditions prior to the fault prevent secure application of the ultra-high-speed time-domain protection elements, the arming logic deasserts and blocks the time-domain protection. The protection functions based on phasors are fully operational and the arming logic does not control them.

Sampling at 1 MHz and using TWs for protection, the SEL-T401L monitors electromagnetic interference (EMI) noise in its input currents and voltages. The EMI logic detects, logs, alarms on, and optionally records excessive noise that cannot be correlated with power system events. If the standing EMI can compromise the security of the TW-based protection elements and schemes, the arming logic disarms the TW protection and keeps it blocked until the noise subsides. This unique function provides users with invaluable insight into the overall condition of the substation installation.

Operating extremely fast, in 1 to 2 ms in many cases, for extra security, the SEL-T401L applies redundant measurement in its analog-to-digital converter (ADC) signal processing chain. The relay has one redundant ADC channel for each group of three voltage or current inputs. If the measurements from the redundant channel and the monitored channels disagree, the relay inhibits protection operation instantaneously, as fast as in a few tens of microseconds. This monitoring circuit detects failures in the ADC itself and in the input filtering and signal conditioning circuits of the relay.

Designed for speed and security, the SEL-T401L time-domain elements and schemes are nonetheless highly dependable, but – by nature of their operating principles – they cannot be 100 percent dependable.

Dependability of TWs

Faults occurring when the voltage across the fault path is small, launch only small TWs. Ultimately, faults at voltage zero do not launch any TWs. Terminations with a high surge impedance, such as those with only a power transformer behind the relay, prohibit the relay from measuring TW currents. In applications where the line is terminated with a high surge impedance, configure the HSZ setting to Y to use voltage TWs in the TW-based fault locating methods. In some applications, TWs can be highly distorted because of stray coupling between the primary and secondary circuits. Faults very close to a line terminal launch TWs that reflect frequently, overlap, and cannot be identified by the relay.

Dependability of Incremental Quantities

Evolving faults may create slowly increasing incremental quantities, and these may not develop fast enough to allow the TD21 or TD32 element to operate. The TD21 element is dependable only in strong systems. The relay temporarily inhibits the TD21 and TD32 elements after an event, preventing them from responding to breaker operation but also from responding to a second fault if it occurs soon after the first fault.

Apply traditional protection elements and schemes available in the SEL-T401L for dependable operation in cases where the ultra-high-speed time-domain protection elements are intentionally inhibited for security or may fail to operate because of the natural limitations of their operating principles.

Phasor-Based Protection

The SEL-T401L phasor-based protection elements and schemes respond to the signal spectrum of power sources and not to fault-induced transients. These phasors reflect fault conditions for the duration of the fault and do not expire as with incremental quantities or dissipate as with TWs. Apply these phasor-based protection elements and schemes to back up the time-domain protection, to provide a full range of protection functions for the line, and to provide backup protection for the surrounding power system.

The SEL-T401L design takes a fresh look at the phasor-based protection elements and schemes. The elements are simple to test and use, do not depend on one another, use simple polarizing methods, and require only a few settings. None of the phasor-based elements are dependent on or benefit from the operation of any of the time-domain elements. The time-domain and phasor-based elements are entirely independent for the purposes of simplicity, ease of testing, ease of application, and reliability.

Distance Elements

The SEL-T401L provides you with a total of five phase and ground distance zones for direct tripping, step distance, and switch-onto-fault (SOTF) applications and the POTT and DCB schemes. Zones 1 through 4 are directional; each has an individual direction setting (forward or reverse). Zone 5 is nondirectional (offset) with individual reach settings for the forward and reverse directions. You can configure the phase and ground distance elements of each zone as either a mho characteristic or a quadrilateral characteristic. For example, you can set the Zone 1 phase element as a mho characteristic (*Figure 14*) and the Zone 1 ground element as a quadrilateral characteristic (*Figure 15*).

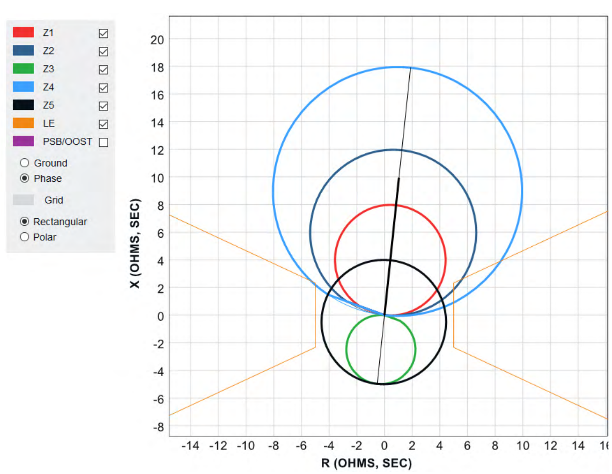

Figure 14 Mho Phase Distance Elements Characteristics

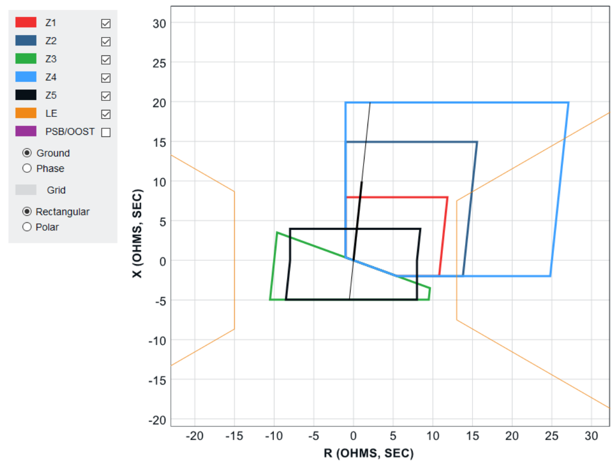

Figure 15 Quadrilateral Ground Distance Elements Characteristics

The SEL-T401L distance elements are self-contained. To apply them, you need to configure only the basic relay settings such as CT and PT ratios, line impedances, nominal voltage and frequency, as well as the open-pole logic. The distance elements are not dependent on any other protection elements. The loss-of-potential logic blocks the distance elements while you can configure the SEL-T401L to block the distance elements on a per-zone basis with the load-encroachment logic and the power-swing blocking logic.

The SEL-T401L distance elements are designed for simplicity and performance. To simplify training, testing, and application, the mho and quadrilateral elements are identical in all but the reach-limiting aspect. When a given element is set as mho, a mho comparator is used as the reach-limiting condition; when the element is set as quadrilateral, the reactance and resistive blinder comparators are used as the reach-limiting conditions. All other distance element design aspects are common to the mho and quadrilateral characteristics.

The following are highlights of this unified SEL-T401L distance element design:

➤ Zones 1 through 4 are directional and can be independently set to reach in either a forward or reverse direction. The zone direction setting applies to both the phase and ground distance elements of that zone.

➤ Zone 5 is nondirectional (offset) with separate forward and reverse reach settings, independently settable for the phase and ground distance elements.

➤ You can set the phase and ground distance elements of each zone as either a mho characteristic or a quadrilateral characteristic.

- ➤ Each ground zone uses its own zero-sequence compensation (ZSC) factor. You can set the ZSC factors individually for each zone based on short-circuit studies or let the relay select the ZSC factors according to the line-impedance values.
- ➤ All zones and all elements use the angle of the positive-sequence line impedance as the distance maximum torque angle (MTA).
- ➤ All zones use a built-in directional element with the memorized positive-sequence voltage as the polarizing signal, loop current as the operating signal, and 70 degrees as the directional maximum torque angle. This directional supervision does not depend on sequence currents and is therefore reliable during open-pole and other unbalanced system conditions.
- ➤ All zones use a built-in overcurrent supervision condition with thresholds individually settable for the phase and ground distance elements of each zone. The overcurrent supervision applies to the phase-to-phase current of the phase distance elements, and it applies to the phase current and zero-sequence current of the ground distance elements.
- ➤ All zones use an optimized faulted-loop selection logic for reach accuracy and selectivity of single-pole tripping and targeting.
- ➤ All zones, phase and ground separately, use torque-control equations that you can program in SELOGIC equations.

Figure 16 and *Figure 17* show the mho and quadrilateral characteristics, respectively, with the associated settings for the Zone 2 ground distance element, used here as an example.

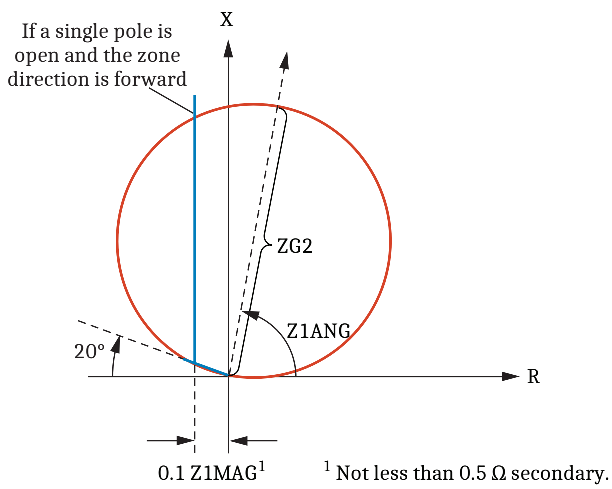

Figure 16 Mho Zone 2 Ground Distance Elements Characteristics, Settings, and Conventions

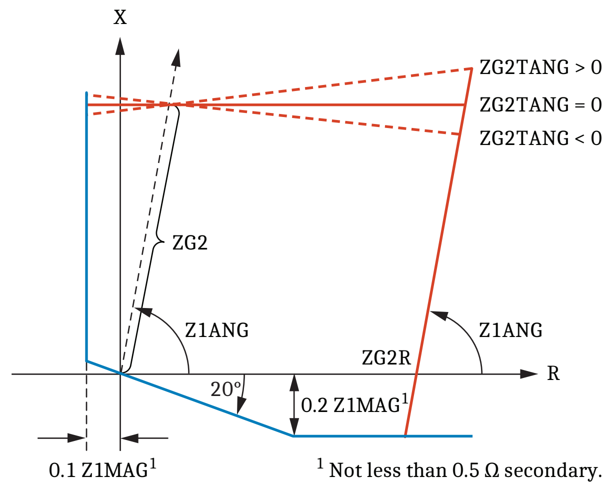

Figure 17 Quadrilateral Zone 2 Ground Distance Elements Characteristics, Settings, and Conventions

Referring to *Figure 16* and *Figure 17*, the ZG2 setting defines the element reach. The reach impedance angle is the same as the Z1ANG setting. The directional element maximum torque angle is 70 degrees. The memorized positive-sequence voltage polarizes the mho characteristic. The reactance line of the quadrilateral characteristic is parallel to the resistive axis (a constant reactance line), but you can use the ZG2TANG angle setting to tilt it up (for better dependability of overreaching zones) or down (for better security of the underreaching Zone 1). The resistive blinder line of the quadrilateral characteristic is parallel to the maximum torque angle line defined by the Z1ANG line setting. The ZG2R setting controls the position of the resistive blinder. Both the reactance and the blinder comparators are polarized with the loop current. This polarizing method makes them reliable during open-pole and other unbalanced system conditions.

Zone 1 Highlights and Applications

The SEL-T401L optimizes Zone 1 for underreaching direct tripping applications. The following are highlights of the Zone 1 distance element:

- ➤ Filtering and logic are optimized for both speed and reach accuracy. Zone 1 has a transient overreach better than 2 percent for magnetic VTs and 8 percent for CCVTs. See *Figure 18* for Zone 1 operating times.
- ➤ CCVT transient security logic allows Zone 1 to avoid overreaching, including in systems with high SIR values. The CCVT logic is always operational and does not engage if the transients are not threatening security. You do not need to evaluate your CCVT and SIR, nor do you need to decide whether to enable the CCVT logic.

- The quadrilateral characteristic uses additional polarization with the sequence current to avoid overreaching on resistive faults with heavy line load. The ground element uses the sequence current (the sum of the negative- and zero-sequence currents) to obtain the second reactance line in addition to the reactance line obtained through polarizing with the loop current. The sequence-current-polarized line tilts up and down to reduce the infeed and outfeed effects. The Zone 1 quadrilateral logic uses an AND combination of the loop-polarized and sequence-current-polarized reactance conditions to prevent overreaching. The resulting characteristic tilts down when needed to avoid overreaching, but for security, it will not tilt up beyond the static loop current-polarized reactance line (see *Figure 19*). The relay applies this enhanced reactance polarization to both the phase and ground distance elements of Zone 1 and to Zone 2 if used in the PILOT logic.
- The Zone 1 and Zone 2 logic, when used in the PILOT logic, boost the sequence-current-polarizing signal with a small fraction of the positive-sequence voltage for additional security in cases where the sequence currents are not reliable or are small. This voltage boost bends the reactance line slightly downward in a mho-like fashion for additional security.

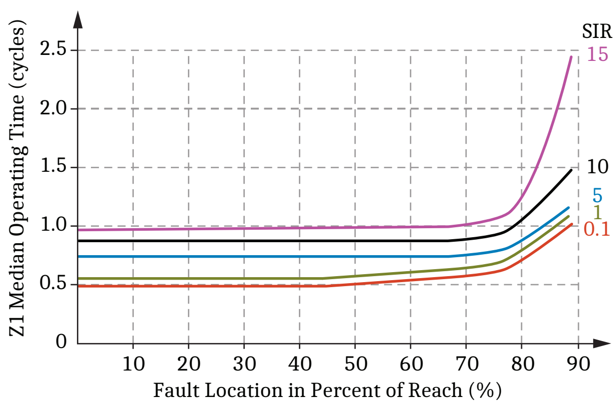

Figure 18 Zone 1 Phase and Ground Distance Elements Operating Times for a Ratio Voltage (Magnetic PT or CCVT With Equivalent Transient Response)

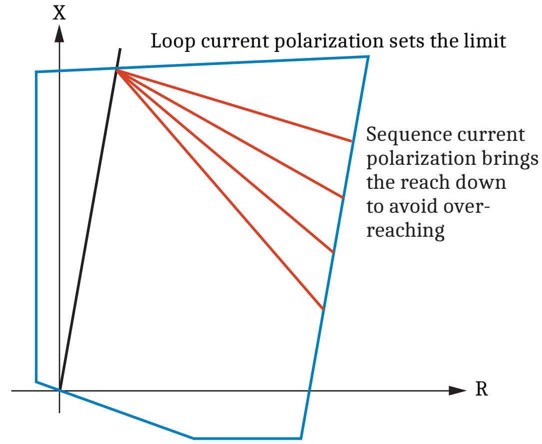

Figure 19 Enhanced Reactance Polarization (Zone 1 and Zone 2 if Used in the PILOT Scheme)

Zones 2 Through 4 Highlights

Zones 2 through 4 are not intended for underreaching applications. They do not apply all the extra filtering and security logic of Zone 1. Therefore, Zones 2 through 4 operate faster than Zone 1, especially for faults toward the end of the zone (see *Figure 20*). When used in a pilot protection scheme, the quadrilateral Zone 2 element polarizes its reactance comparator similarly to Zone 1 for better coordination with the reverse zone applied at the opposite line terminal.

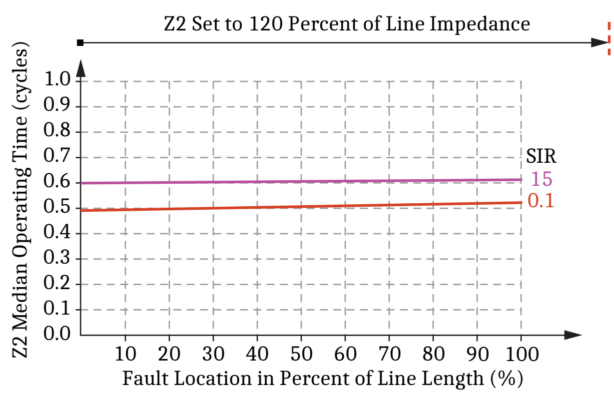

Figure 20 Zones 2 Through 4 Phase and Ground Distance Elements Operating Times

Zone 5 Highlights and Applications

The Zone 5 distance element provides dependable operation independent of voltage polarization. Zone 5 is an offset element, and it extends in both forward and reverse directions. Separate settings define the forward and reverse Zone 5 reach (see *Figure 21*). The element is operational regardless of whether the memory polarizing logic locks onto the voltage and frequency. The zero-impedance point is inside the operating characteristic, guaranteeing dependable and fast operation for close-in faults, even if the voltage is zero.

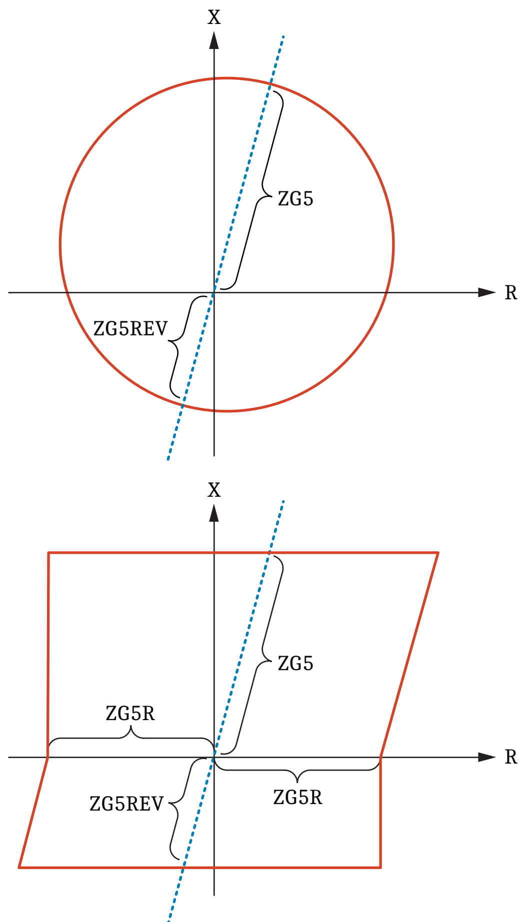

Figure 21 Zone 5 Mho and Quadrilateral Distance Elements Characteristics, Settings, and Conventions

Use the nondirectional (offset) Zone 5 distance elements in these applications:

- SOTF logic to avoid high overcurrent settings especially for long lines drawing large charging currents or tapped lines drawing high cold-load-pickup currents
- Time-coordinated backup protection for local bus faults
- Nondirectional blocking (starting) in a directional comparison blocking scheme
- Dependable fault protection during power-swing conditions

Polarizing Logic

The SEL-T401L includes an enhanced polarizing logic for the distance elements and the phase directional overcurrent elements. The relay uses the well-established method of polarizing the mho and directional comparators of the distance elements with the memorized positive-sequence voltage, but it optimizes the memory control logic for better performance during frequency excursions and in systems with low-inertia sources.

Step Distance Applications

The SEL-T401L uses integrating timers in the step distance, definite-time overcurrent, overvoltage, and undervoltage applications. These timers prevent accidental timer reset for reasons such as a marginal operation, a switching event, or a change in fault attributes over time. Apply common phase and ground distance timers to reliably time out for evolving faults.

Directional Elements

The SEL-T401L includes three phasor-based directional elements:

- Negative-sequence directional (32Q)
- Zero-sequence directional (32G)
- Phase-directional (32P)

Use the 32Q and 32G elements to detect fault direction for unbalanced faults in the PILOT protection scheme and to directionalize instantaneous, definite-time, and inverse-time overcurrent elements. Use the 32P element to back up phase distance elements during three-phase balanced faults and to back up phase and ground distance elements during open-pole conditions when the open-pole logic blocks the 32Q and 32G elements. All three directional elements operate independently from each other.

The 32Q and 32G elements operate based on the apparent impedance principle. The 32Q element responds to the apparent negative-sequence impedance and the 32G element responds to the apparent zero-sequence impedance (see *Figure 22*).

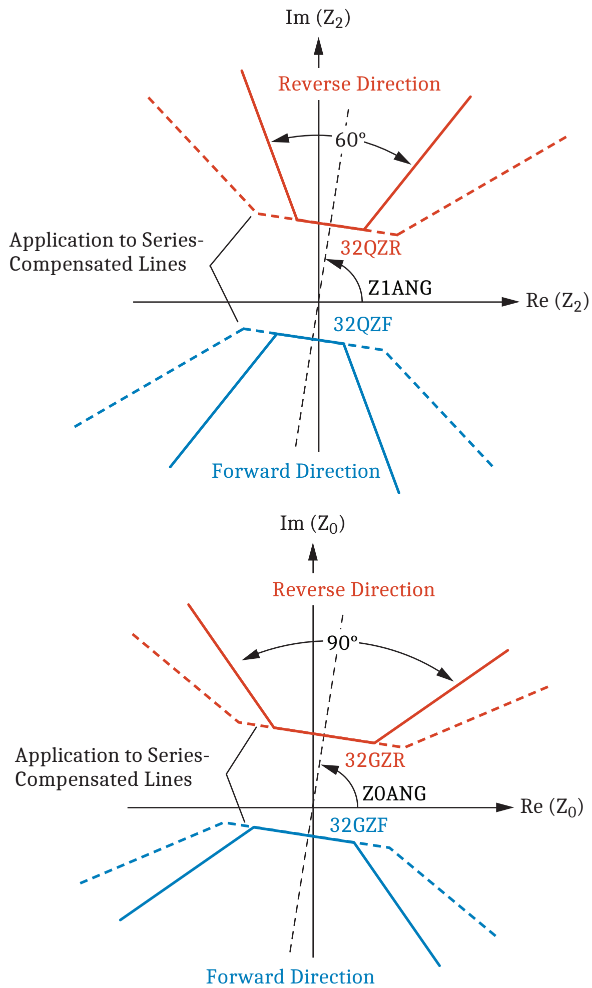

Figure 22 Directional Element Operating Characteristics for (a) 32Q and (b) 32G

The following are highlights of the 32Q and 32G directional elements logic:

- The elements require only three settings each: the forward and reverse impedance thresholds and the minimum operating current for forward assertion.
- The elements use narrow forward and reverse operating characteristics to enhance security for cases of low or spurious sequence voltages and currents without sacrificing dependability because of the high homogeneity of the negative- and zero-sequence networks.
- The 32Q element uses the maximum torque angle equal to the angle of the positive-sequence line impedance, and the 32G element uses the maximum torque angle equal to the angle of the zero-sequence line impedance.
- The elements incorporate a built-in validation logic to ensure the sequence voltages and currents are fault-induced and not caused by CT errors, CT saturation, and similar conditions. The validation logic does not require any user settings.
- The elements allow operation with a zero polarizing voltage if one of the impedance threshold settings effectively requires it, but only if the current level is high enough to rule out current unbalance caused by an open-pole condition in the vicinity of the protected line.
- The element design favors security and sensitivity. The elements operate very fast under high-current fault conditions (4 to 8 ms), but they apply an intentional time delay in the range of 1 cycle if the sequence voltages and currents are small and suspicious, such as those caused by a breaker-pole scatter during switching operations.
- The elements include a built-in current reversal logic for extra security.
- The relay blocks these elements during open-pole and loss-of-potential conditions.

The following are highlights of the 32P directional element logic:

- The element polarizing signal is the memorized positive-sequence voltage (the same signal that polarizes distance elements). The element operating signal is the phase current.
- The element provides the maximum torque angle and the limit angle settings for the forward characteristic (see *Figure 23*). The reverse characteristic uses the same maximum torque angle and the limit angle of the forward characteristic, increased by a small margin for coordination.
- The element provides the minimum operating current settings, set separately for the forward and reverse outputs.
- The loss-of-potential logic blocks the 32P element. The open-pole logic supervises the 32P element on a per-phase basis.

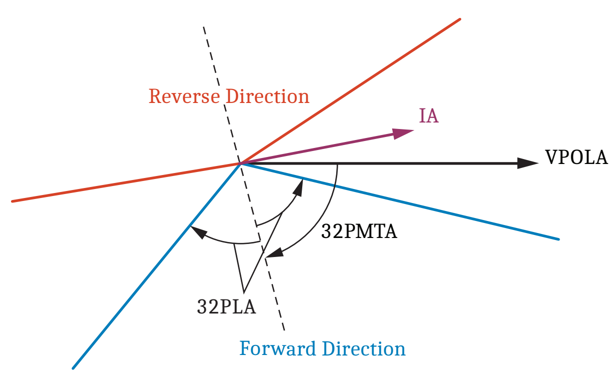

Figure 23 Operating Characteristic of the 32P Directional Element

The 32Q, 32G, and 32P directional elements work independently and do not control any other protection element or scheme in a hardwired way.

Pilot Protection

The SEL-T401L provides you with preconfigured POTT and DCB schemes. An intertripping (tripping remote breakers for line faults) direct transfer trip (DTT) scheme is also available. In addition, you can use SELOGIC equations and programmable I/O to implement breaker failure DTT logic and other types of pilot protection schemes such as the directional unblocking scheme. When programming blocking schemes, you have an option to use the ultra-high-speed TD32 element for fast directional blocking, as well as the nondirectional (offset) Zone 5 distance element for nondirectional blocking (starting).

The following are highlights of the pilot protection logic:

- You can select a set of forward-looking overreaching elements to detect line faults, including TW32, TD32, 67Q, 67G, and 67P, as well as distance elements. Expect permissive keying from the TD32 element in 1.5 to 2 ms, from the 67Q and 67G elements in 4 to 8 ms for high-current faults and in about 1 to 3 cycles for high-resistance faults, and from the Zone 2 overreaching distance element in 8 to 12 ms.
- Distance Zone 2 is a default forward-looking zone. You can select either Zone/Level 3, 4, or 5 as a reverse-looking distance zone and a directional overcurrent level.
- Built-in current reversal logic uses reverse elements that match your selection of the forward-looking elements for proper coordination.
- You can use a single permissive bit, such as in power line carrier (PLC) applications. Or, for enhanced selectivity of single-pole tripping, especially during cross-country faults, you can use three phase-segregated permissive bits in digital channel applications.
- You can connect permissive and blocking pilot signals via various relay I/O means: contact I/O, SEL MIRRORED BITS I/O, IEEE C37.94-encoded I/O, direct fiber I/O, and any combination of these.
- You can apply the POTT and DCB schemes to multiterminal lines with any number of terminals (use SELOGIC equations to AND permissive trip signals and OR blocking signals from all remote relays).
- Weak-infeed logic, built into the POTT scheme, initiates permissive echo keying upon abnormal voltage conditions and simultaneous absence of a reverse fault. The abnormal voltage check provides security and includes a phase undervoltage condition and a sequence overvoltage condition.
- Open-breaker echo logic, built into the POTT scheme, allows dependable operation when one or more line terminals of a multiterminal line are open or out of service. The open-breaker echo logic includes a lockout logic to prevent unwanted latching of the logic when two or more terminals have the open-breaker echo logic enabled.

Switch-Onto-Fault Protection

Apply SOTF protection to clear pre-existing faults or faults following line energization. The following are highlights of the SOTF logic:

- Configure the relay to receive a signal that indicates a breaker has been commanded to close, or let the SOTF logic self-initiate based on the breaker position signals (52a).
- You can use the nondirectional (offset) Zone 5 distance element, either mho or quadrilateral, to detect bolted close-in three-phase faults without relying on the polarizing signal. Using an offset distance element in the SOTF logic in addition to overcurrent elements, you can better protect long lines that are drawing large capacitive current and lines with tapped loads drawing cold-load-pickup currents during line energization.
- You can shut down (reset) the SOTF logic during line energization to improve security as soon as the voltage stabilizes, indicating a healthy line, and the distance polarizing logic reports that it has established a proper polarizing signal for the distance elements. With the voltage reset enabled, you can use a universal and generous SOTF window timer setting, knowing the SOTF logic will reset quickly, regardless of the timer, if there is no fault on the line as soon as the distance elements become properly polarized.

Load Encroachment

Prevent unwanted tripping from distance and overcurrent elements under high load conditions by using the load-encroachment characteristic (see *Figure 24*).

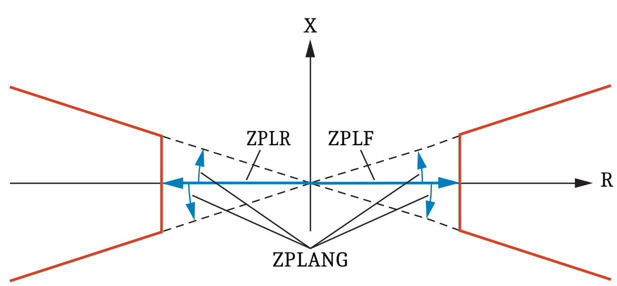

Figure 24 Load-Encroachment Characteristic (Phase Element Settings Shown)

The following are highlights of the load-encroachment logic:

- ➤ The relay implements the load-encroachment logic on a per-loop basis with separate settings for the phase and ground loops. This implementation allows proper blocking of distance elements for heavy load conditions combined with unbalanced conditions caused by a distant external fault or an open-pole condition during single-pole tripping on adjacent lines. Use separate load-encroachment settings for the ground loops to account for the increase in transferred per-phase power during single-pole tripping and reclosing.
- ➤ The logic uses separate load-in and load-out impedance settings, but it uses a common angle setting for both the import and export directions with the leading or lagging power factor.
- ➤ A vertical resistive blinder provides better coordination with both the mho and quadrilateral distance elements. You can set the load angle setting to 90 degrees, effectively using the load-encroachment logic as a straight vertical blinder.
- ➤ The logic includes a load-encroachment blocking setting for the distance elements (see *Figure 25*). You can decide on a per-zone basis which distance zones you want blocked under the load-encroachment condition. Use SELOGIC equations and torque-control inputs to supervise the overcurrent elements for heavy load conditions.
- ➤ The loss-of-potential logic inhibits the load-encroachment logic. The open-pole logic inhibits the load-encroachment logic in loops affected by the open-pole condition.

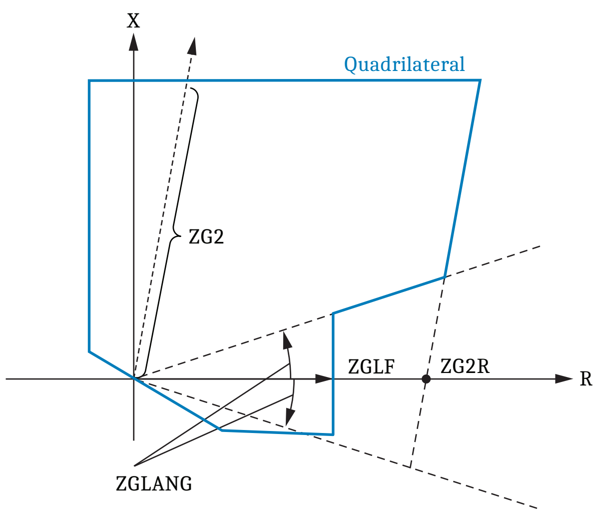

Figure 25 Effect of Load-Encroachment Blocking on Distance Characteristics (Quadrilateral Elements Shown)

Power-Swing Blocking and Out-of-Step Tripping

The SEL-T401L provides a settings-free power-swing blocking (PSB) and out-of-step tripping (OOST) logic based on the impedance-rate-of-change operating principle. The following are highlights of the power-swing blocking logic:

- ➤ The relay implements the power-swing blocking logic on a per-loop basis. It monitors each loop separately to provide reliable power-swing blocking in healthy loops while detecting faults and selectively unblocking the faulted loops.
- ➤ The logic continuously measures and responds to the rate-of-change-of-impedance (dZ/dt) on a per-loop basis.
- ➤ The logic monitors dZ/dt as a vector, and before declaring a swing, it confirms the impedance locus is moving at a speed consistent with a power swing and in a consistent direction. The principle of operation is insensitive to the direction of the traversing impedance (horizontal, vertical, or diagonal).
- ➤ The logic selectively unblocks a loop in which the impedance moves in an inconsistent direction or at a rate inconsistent with a power swing (too fast, too slow, or does not move at all).
- ➤ The logic selectively unblocks a loop in which the apparent impedance is located near the line impedance and does not move fast enough to be considered a swing (such as during a bolted fault). The logic derives an unblocking timer value based on the dZ/dt signal prior to entering the line impedance region.
- ➤ The logic works reliably, providing good balance between security and dependability, regardless of swing frequency and switching events or faults before and during power swings. The logic unblocks a faulted loop while maintaining a blocking signal in healthy loops (see *Figure 26*).
- ➤ The logic does not require any settings and operates when the apparent impedance approaches any of the distance zones configured to be secure during power swings. For testing purposes, you can view the supervisory power-swing phase and ground impedance zones in ACSELERATOR QuickSet® SEL-5030 Software.
- ➤ The OOST logic follows the trip-on-the-way-out principle for security. It operates only when an unstable power swing has already passed through the protected line and the system has slipped a pole. The logic provides delayed tripping to avoid overvoltage conditions across the circuit breaker.

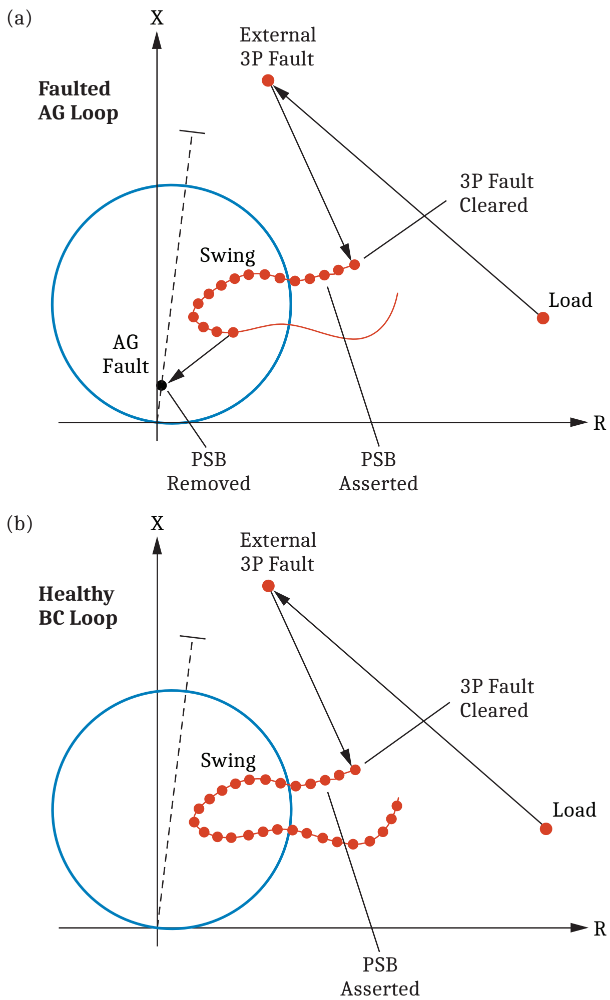

Figure 26 PSB Logic Sequence: Load, External Three-Phase Fault, Power Swing, Internal Phase A-to-Ground Fault in (a) a Faulted AG Loop and (b) a Healthy BC Loop

Overcurrent Elements

Apply as many as five levels of phase, negative-sequence, and zero-sequence overcurrent elements to accomplish high-set overcurrent protection, time-coordinated backup and breaker-pole discrepancy protection, and any auxiliary application you may need to program by using SELOGIC equations. Directionalize these elements on a per-level basis with the 32Q, 32G, and 32P directional elements or any combination of these by using SELOGIC equations. For example, use the 32Q element to directionalize the 50G element to accomplish negative-sequence-polarized ground-overcurrent protection. Benefit from dependable integrating timers in definite-time overcurrent applications.

When the short-circuit current level margins allow, use high-set phase overcurrent elements and obtain very fast trip times for close-in faults without relying on voltage (see *Figure 27*). These elements operate in half a cycle for a multiple of pickup above 2 and have a transient accuracy better than 10 percent.

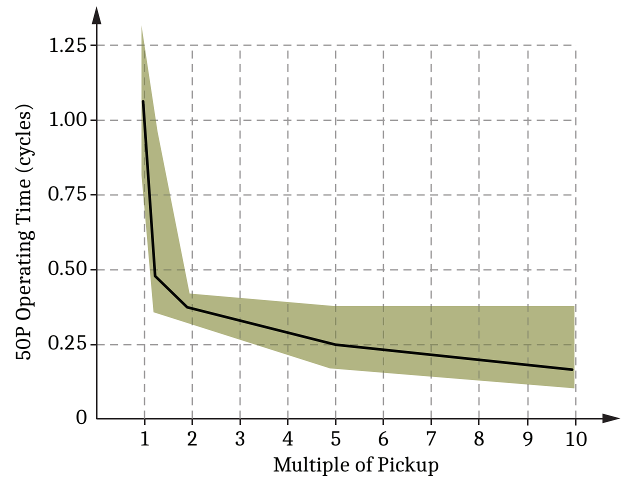

Figure 27 50P Element Operating Time as a Function of Multiple of Pickup (Range and Median)

Apply as many as three levels of phase, negative-sequence, and zero-sequence inverse-time overcurrent elements for time-coordinated protection with standard ANSI and IEC curves. These elements provide you with the flexibility to select all the customary parameters, including torque control, curve type, and a reset that emulates electromechanical-disk relays.

Voltage Elements

The SEL-T401L includes definite-time undervoltage elements that respond to the following:

- Phase voltages (27P)
- Phase-to-phase voltages (27PP)
- Positive-sequence voltage (27PS)

Enable and configure as many as two levels of undervoltage protection for each of these operating quantities. Program a blocking condition if needed (torque control) and use integrating timers for dependable operation.

The relay includes definite-time overvoltage elements that respond to the following:

- Phase voltages (59P)
- Phase-to-phase voltages (59PP)
- Zero-sequence voltage (59G)
- Negative-sequence voltage (59Q)
- Positive-sequence voltage (59PS)

Enable and configure as many as two levels of overvoltage protection for each of these operating quantities. Program a blocking condition if needed (torque control) and use integrating timers for dependable operation.

Programmable Logic

The SEL-T401L allows you to customize applications through SELOGIC equations. All customizable scheme and element inputs, such as trip condition, fault locator trigger, transient recorder trigger, torque-control inputs, or bits driving binary outputs, are available as dedicated SELOGIC equations. In addition, the relay allows 64 generic SELOGIC equations. Each dedicated or generic equation uses the following operations: AND, OR, NOT, rising edge, and falling edge. The equations allow as many as 15 input parameters, permit as many as 14 nested parentheses, and let you enter a comment, all within the limit of 511 characters per equation.

The SEL-T401L includes 16 programmable timers with individually programmable pickup and dropout times and 0.1 ms timing resolution. The relay also includes 16 nonvolatile reset-dominant latches. The timer and latch inputs are themselves SELOGIC equations.

SELOGIC equations run every 0.1 ms at a rate that matches the processing interval of the time-domain protection elements and schemes.

Loss-of-Potential Logic

Based on incremental quantities and TWs, the SEL-T401L time-domain protection elements and schemes are inherently secure when loss-of-potential conditions develop. However, a settings-free loss-of-potential logic blocks the voltage-dependent time-domain elements to prevent misoperation on switching events or faults following a loss of potential. The relay blocks selected voltage-dependent fundamental-frequency protection elements, including distance and directional elements. Use the blocking input (torque control) if you want to block the voltage elements during a loss-of-potential condition. You can also use torque control to decide how the directionalized overcurrent elements should respond (block or default to forward) when the loss-of-potential condition shuts down the directional elements.

Trip Logic

The SEL-T401L preconfigured yet customizable trip logic allows you to easily configure the relay for single-pole and three-pole tripping applications and provides enough flexibility to accommodate different protection philosophies. The SEL-T401L trip logic conveniently routes protection elements and schemes intended for tripping to the contact outputs. The logic allows for three-pole and single-pole tripping, responds to faults during the open-pole condition following a single-pole trip, and maximizes selectivity of single-pole tripping during evolving and intercircuit faults. The trip logic also initiates the fault locator and transient recorder and provides seal-in for the trip outputs by using a timer, the fault current level, or the 52a breaker position.

Protection Signaling Options

Typical SEL-T401L applications exchange some or all of the following protection signals between the SEL-T401L and other relays:

- Permissive trip (PT)
- Direct trip (DT) for line faults (intertripping)
- Breaker failure initiate (BFI)
- Autoreclose initiate (ARI)
- Digital fault recording (DFR) cross-trigger
- Fault locator (FL) cross-trigger
- Direct trip for breaker failure (BFT)

The permissive and direct trip bits may be phase-segregated, depending on your preferences and the capability of the available teleprotection channel.

The SEL-T401L offers the following signaling options:

- Contact inputs (13 total, including those for breaker position) and outputs (14 total, including those for tripping the line circuit breaker or breakers and alarming for relay problems).
- MIRRORED BITS inputs and outputs on three independent fiber-optic protection signaling ports, Ports 1, 2, and 3 (8 programmable outputs and 8 inputs per port). You can independently configure each port for SEL MB8 encoding (19.2 to 115.2 kbps) or IEEE C37.94 encoding (64 kbps).
- MIRRORED BITS inputs and outputs on the direct fiber-optic protection signaling port, Port 6 (14 programmable outputs and 14 inputs).

You can use each of the above signaling means concurrently and independently. *Figure 28*, *Figure 29*, and *Figure 30* show three typical examples.

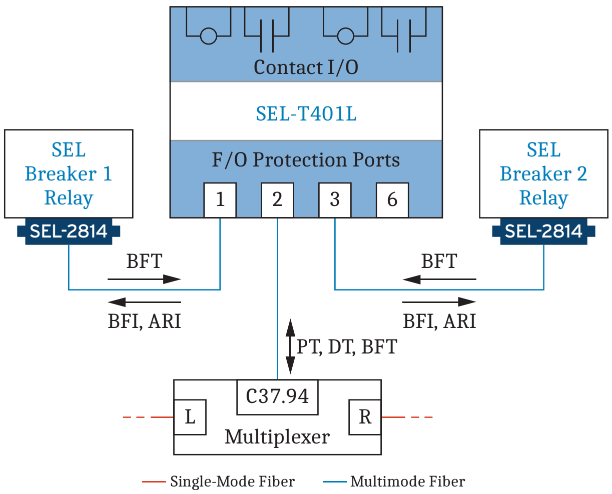

Figure 28 Preferred Application With an IEEE C37.94-Compliant Multiplexer and Standalone SEL Breaker Relays

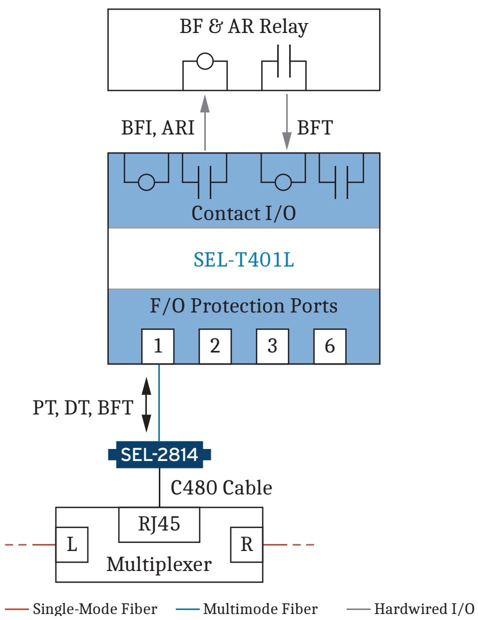

Figure 29 Application With a Multiplexer Not Compliant With IEEE C37.94 and a Hardwired Standalone Breaker Failure and Autoreclosing Relay

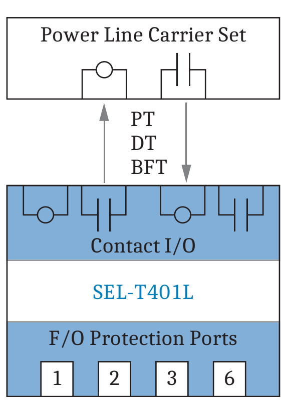

Figure 30 Application With a Hardwired Power Line Carrier Set

Digital channels allow additional applications beyond sending and receiving protection bits, as follows:

- Ports 1, 2, and 3 with IEEE C37.94 encoding allow double-ended TW-based fault locating (TWFL).
- Ports 1, 2, and 3 with IEEE C37.94 encoding allow the application of the adaptive autoreclose cancel logic on hybrid lines to permit single-pole tripping and automatic reclosing for faults on overhead line sections yet force three-pole tripping and inhibit reclosing for faults on cable sections of a hybrid line.
- Ports 1, 2, and 3 with IEEE C37.94 encoding allow line monitoring to detect, tabulate, and alarm on line events, including permanent faults, incipient faults, incipient faults in cables, and so on.
- Port 6 allows the TW87 scheme, double-ended fault locating with both TW-based and impedance-based methods, adaptive autoreclose cancel logic, line monitoring, precise time synchronization between relays, and remote metering and transient recording.

You can share the three protection signaling ports (Ports 1, 2, and 3) between one or more remote SEL-T401L relays and local relays. For example, you can use Ports 1 and 2 to send permissive and direct tripping signals to two remote SEL-T401L relays in a three-terminal application, and you can use Port 3 to send breaker failure initiate and autoreclose initiate signals to the local device that provides breaker failure protection and autoreclosing (see *Figure 31*). Further, you can receive a breaker failure trip signal from the local relay on Port 3 and send the signal on Ports 1 and 2 to the remote SEL-T401L relays. When using Port 1, 2, or 3 to signal local relays or to connect to a multiplexer that is not compliant with IEEE C37.94, apply the SEL-2814 Fiber-Optic Transceiver With Hardware Flow Control.

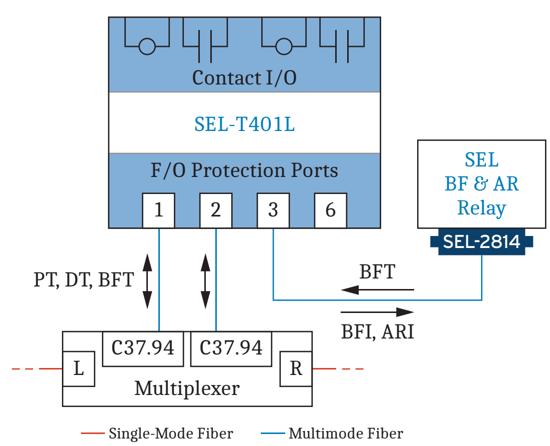

Figure 31 Three-Terminal Application With IEEE C37.94-Compliant Multiplexer and Standalone Breaker Failure and Autoreclosing Relay

When using an analog teleprotection channel, such as when interfacing with power line carrier equipment, you can use the SEL-T401L contact I/O (see *Figure 30*) or apply the SEL-2507 (see *Figure 32*). The SEL-2507 application has the benefit of using a fiber-optic cable for the distance between the SEL-T401L panel and the communications panel or communications building, while minimizing the copper wiring (only needed between the power line carrier set and the SEL-2507).

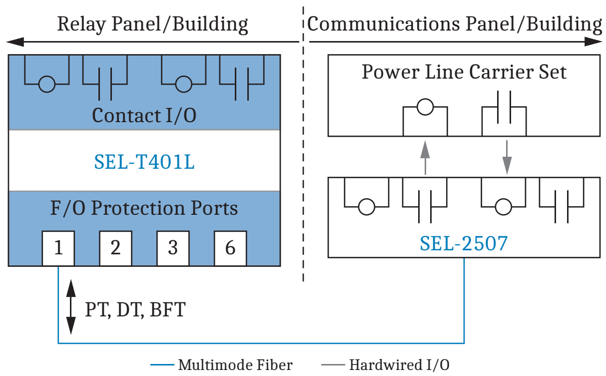

Figure 32 Using the SEL-2507 to Connect With a Power Line Carrier Set

When using Port 6, order the small form-factor pluggable (SFP) transceivers separately to meet your fiber-optic cable length and losses budget. The maximum reach of SEL-supplied SFP transceivers, without optical signal amplification, is 200 km (124 mi), not counting losses in fiber, splices, and connections. See *Specifications* on page 33 for a complete list of SFP transceivers. The communications link on Port 6 is private, secure, and requires a dedicated pair of single-mode fibers. You can also apply the SEL-T401L over shared fiber by using wavelength division multiplexing (WDM), industry-standard Optical Transport Networks (OTN), and dense wavelength division multiplexing (DWDM) systems.

Use SELOGIC equations to map the inputs and outputs to the SEL-T401L elements and schemes and to develop redundant channel applications such as to send and receive permissive, blocking, and direct tripping signals simultaneously via a power line carrier set and via an IEEE C37.94-compliant multiplexer (see *Figure 33*).

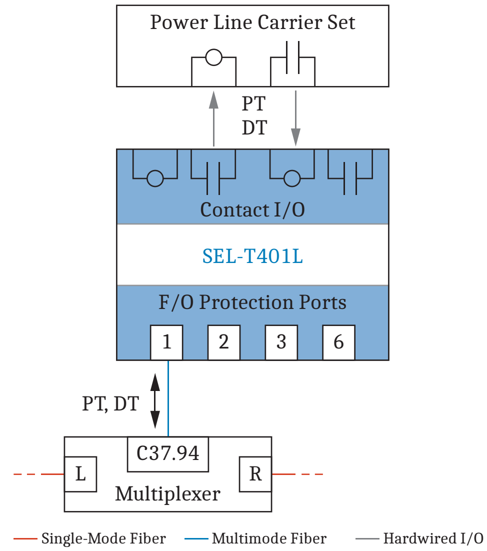

Figure 33 Using a Hardwired Power Line Carrier Set and Multiplexed Port 1 Channel as Redundant Protection Channels

Figure 34 shows yet another example of using an IEEE C37.94-compliant multiplexer and the direct fiber-optic channel on Port 6 for redundancy and to allow the TW87 scheme and other functions.

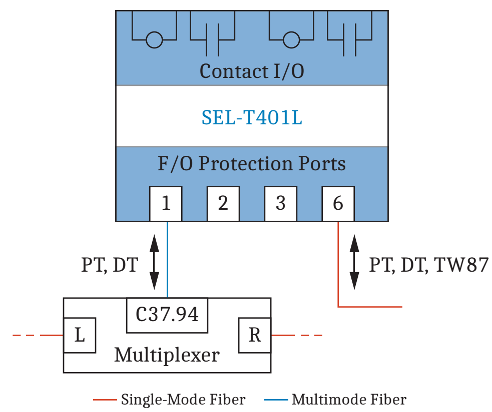

Figure 34 Using Multiplexed Port 1 Channel and Direct Fiber-Optic Channel on Port 6 as Redundant Protection Channels

Fault Locating

Reduce the time and effort to find faults when dispatching line crews based on the SEL-T401L fault-location information. The TWFL technology used in the SEL-T401L has a field-proven accuracy of about one tower span (±300 m or ±1,000 ft), regardless of the line length. The relay incorporates a single-ended TWFL method, which works on local TWs and analyzes the first TW as well as several successive TW reflections. The relay also incorporates a double-ended TWFL method, which uses only the first TWs at both line terminals but requires communications and time synchronization between the two relays.

Trigger the fault locator from the internal trip signal or from the redundant protection system by using a contact input or a MIRRORED BITS input. Obtain the fault-locating result in seconds via DNP3, by using SEL ASCII commands, from the relay front-panel display, or as a part of the IEEE COMTRADE record.

Deploy the double-ended TWFL method by using a 64 kbps IEEE C37.94-encoded channel and an IRIG-B-connected high-accuracy clock at both line terminals, and benefit from the reliability and accuracy of the double-ended method. Alternatively, use the direct fiber-optic channel between the two relays and eliminate the need for external clocks to perform fault locating.

Resort to the single-ended TWFL method if your channel is temporarily down or not available at all, such as in standalone single-ended fault-locating applications or when using the relay with an analog protection channel. The single-ended method is accurate with a good track record in the field, but it cannot narrow down the fault location to a single place on the line with 100 percent certainty. Instead, it provides you with a short, prioritized list of as many as four possible fault locations to be inspected. Avoid patrolling a long stretch of line to find the fault, and instead inspect just one to four locations along the line, each just a few tower spans long.

If the TW signals are small, heavily distorted, or otherwise unusable, the SEL-T401L provides you with the best-available results from the impedance-based double-ended (if the Port 6 channel is available) or single-ended fault-locating method. For each fault-locating trigger, the relay provides results from all four fault-locating methods, as well as TW arrival time stamps and pre-fault and fault voltage and current phasors. You can obtain these data via DNP3 or by parsing the IEEE COMTRADE header file. You can use these data in any custom fault-locating application that you have implemented in the SCADA/HMI software.

To calculate the distance to the fault, the TWFL methods use time stamps of TWs obtained from standard protection CTs or PTs. The relay allows you to compensate the fault locator for the length of the secondary wires. The TWFL methods work with 1 MHz samples and interpolate the time-stamp data between the samples to obtain high-accuracy time stamps with a resolution and accuracy of a small fraction of a microsecond.

The SEL-T401L fault-locating accuracy, including tolerances in the current, voltage, and time input circuitries, is on the order of ±10 m (±33 ft). Application errors such as line data inaccuracy, line sag, or an error in the external clock may increase the total fault-locating error in any given application. SEL field experience with the TWFL technology proves typical accuracy of about ±300 m (±1,000 ft).

Double-Ended TWFL Method

The double-ended TWFL method uses the time difference between the first TWs recorded at both the line terminals to calculate the fault location (see *Figure 35*):

$$M = \frac{L}{2}\left(1 + \frac{t_S - t_R}{T}\right)$$

where:

M	is the distance to the fault from Terminal S in line length units,
t_S and t_R	are time stamps of the first TWs at Terminals S and R, respectively, and
L and T	are user settings specifying the line length and the TW propagation time for the entire line length.

The double-ended algorithm requires a communications channel to exchange the fault-locating data, and it requires the time stamps from both ends of the line to be aligned to the same time reference. You can use a 64 kbps IEEE C37.94-encoded channel with clocks connected via IRIG-B inputs, or you can use the direct fiber-optic channel for both data communications and time alignment.

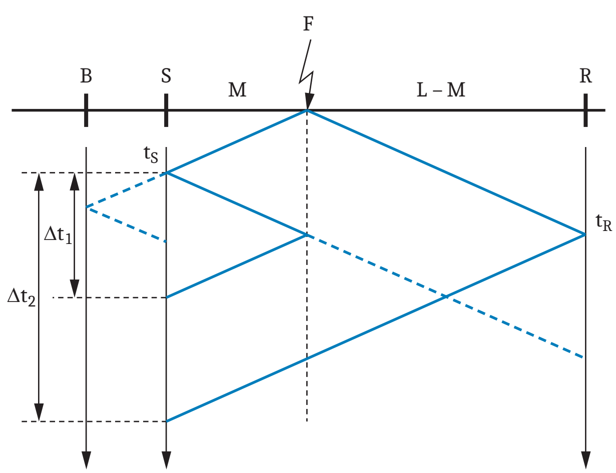

Figure 35 Bewley Diagram Illustrating TWFL Principles

Single-Ended TWFL Method

The single-ended TWFL method uses the time difference between the first TW and the first reflection from the fault to calculate the fault location (see *Figure 35*):

$$M = \frac{L}{2}\left(\frac{\Delta t_1}{T}\right)$$

The single-ended method does not need remote data, and therefore it works without communications and is not affected by the timing errors between the two terminals of the line. However, it depends on reliable identification of the first reflection from the fault among many other TWs that may arrive at the local relay terminal, especially from discontinuities behind the relay (Bus B in *Figure 35*). The SEL-T401L design uses several approaches to identify possible reflections from the fault. For example, the relay uses the output from the impedance-based fault-locating method to narrow the search for the true fault location and the first TW reflection associated with the fault. The relay also finds fault reflections by simultaneously identifying the first reflection from the fault (Δt_1 in *Figure 35*) and the first reflection from the remote bus (Δt_2) and observing that $\Delta t_1 + \Delta t_2 = 2T$.

Fault Locating on Hybrid Lines

Use the double-ended TW-based method to locate faults on hybrid lines comprising both overhead and cable sections. The SEL-T401L double-ended TWFL method corrects for the nonhomogeneity of the propagation velocity in the overhead sections and cable sections (see *Figure 36*).

To use the fault locator on hybrid lines, enter the total line length (L) and the total TW line propagation time (T) as settings and provide the breakdown of these values for each of as many as five sections of the line. Use the ultra-high-resolution recording capability of the SEL-T401L to measure these propagation times during the line energization test. Expect TWFL accuracy on the order of ±300 m (±1,000 ft) for faults on overhead sections and ±150 m (±500 ft) for faults on cable sections.

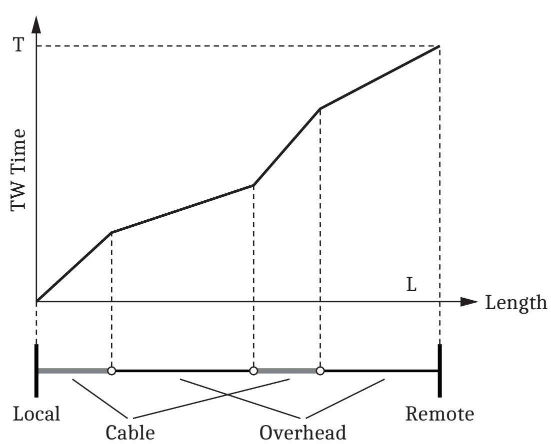

Figure 36 Double-Ended TW-Based Fault Locator Corrects for Differences in TW Propagation Velocities Between Overhead and Cable Sections

Autoreclosing on Hybrid Lines

The SEL-T401L allows you to apply autoreclosing and single-pole tripping on hybrid lines without installing any equipment at the transition points between the line sections and deploying communications channels to these transition points. Using the double-ended TW-based method, the adaptive autoreclose cancel (ARC) logic asserts a control bit based on the fault location obtained at the line terminals. Apply the ARC logic and allow single-pole tripping and reclosing for faults on overhead sections. Trip three poles and inhibit autoreclosing for faults on cable sections. To use the ARC logic, configure the fault locator for your hybrid line, set your autoreclose blocking locations (see *Figure 37*), and configure the logic output bit to control tripping and autoreclosing accordingly. For faults on cable sections, convert single-pole trips to three-pole trips and cancel autoreclosing; for faults on overhead sections, allow single-pole tripping and autoreclosing.

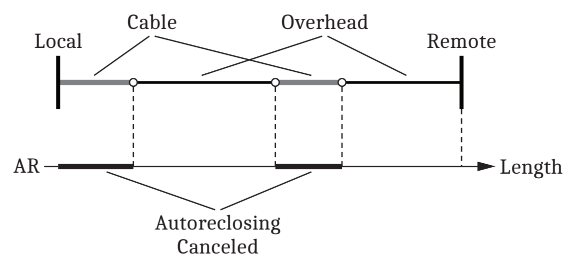

Figure 37 Adaptive Autoreclose Cancel Logic Allows Single-Pole Tripping and Autoreclosing for Hybrid Lines

The ARC logic requires double-ended TWFL, and therefore it works with either a 64 kbps IEEE C37.94-encoded channel and a high-accuracy clock at both terminals of the line or with the direct fiber-optic channel on Port 6. The location-dependent control bit is available in less than 10 ms following the fault-locating trigger. You can set the control bit default value to always allow or always cancel reclosing when the fault location is not available for any reason, such as the loss of a channel or time reference.

Line Monitoring

Identify trouble spots along the line and prevent faults through a condition-based line maintenance program based on the SEL-T401L line monitoring function. The line monitor logic triggers on TWs launched by fault precursors, locates these events with high accuracy by using the double-ended TWFL method (an IEEE C37.94 channel or direct fiber-optic channel is required), tabulates these events for locations along the line, and alarms if the event count exceeds a user-settable threshold. Monitor the line for dirty or cracked insulators, encroaching vegetation, marginal clearances, marginal lightning protection, incipient cable faults, conductor galloping resulting from insufficient damping or faulty spacers, ice unloading, and similar conditions. Reset the event counters for the problem locations after performing adequate maintenance and addressing the underlying problem.

Configure as many as two blocking regions to prevent false alarms for routine switching operations of tapped loads or in-line series capacitors. Monitor the daily event counts at the tap or series capacitor locations, and alarm on unexpected switching patterns.

Applications

The SEL-T401L allows a range of applications including the number of breakers and CTs, series-compensation, number of terminals, unmeasured taps, hybrid lines comprising overhead and cable sections, single-pole and three-pole tripping, and the type of protection channel available. Below are several application examples.

Example 1. Two-terminal dual-breaker line application with IEEE C37.94 multiplexers

- ➤ Connect and monitor both breaker currents individually.
- ➤ Trip both breakers with high-speed trip-rated outputs (single-pole or three-pole).
- ➤ Connect to an IEEE C37.94-compliant multiplexer directly via a fiber-optic cable to apply pilot protection and direct transfer tripping.
- ➤ Connect both relays to high-accuracy clocks and use the double-ended TW-based method and the line monitor.

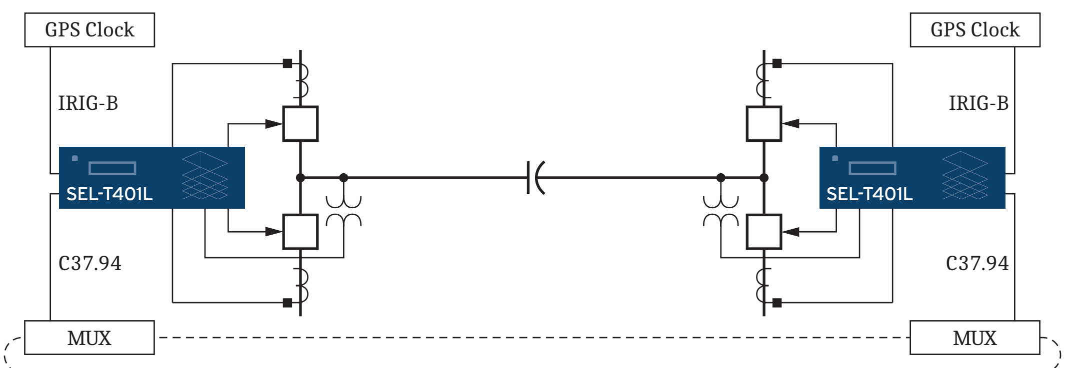

Figure 38 Two-Terminal Dual-Breaker Line With an IEEE C37.94-Encoded Protection Channel

Example 2. Two-terminal dual-breaker line application with switchable reactors and a generic multiplexer

- ➤ Connect the reactor current to remove the reactors from the line protection zone (not required if reactors are not switched or you do not use the TD21 or TD32 element).
- ➤ Parallel the breaker CTs if you used one relay input to wire the reactor current.
- ➤ Trip both breakers with high-speed trip-rated outputs (single-pole or three-pole).
- ➤ Connect to a multiplexer via a fiber-optic cable and the SEL-2814 media converter to apply pilot protection and direct transfer tripping.
- ➤ Use the single-ended TW-based method with impedance backup.

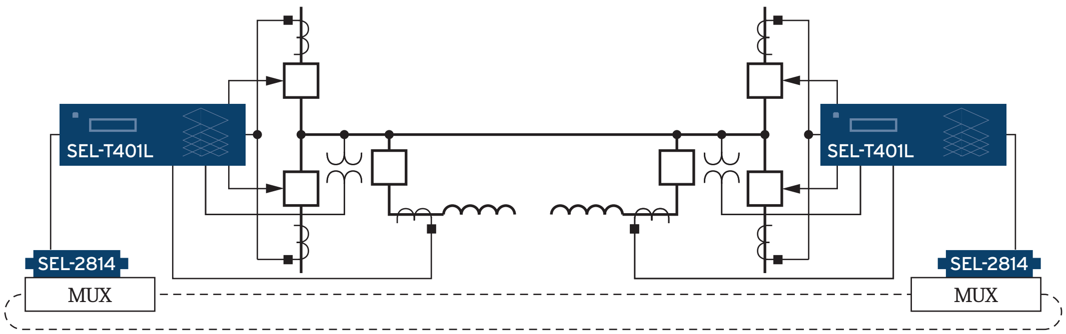

Figure 39 Two-Terminal Line With Switchable In-Line Reactors and an SEL MB8-Encoded Protection Channel

Example 3. Retrofit application with paralleled CTs, lockout relays, and a power line carrier set

- ➤ Connect the breaker currents individually or use the paralleled CT input if this is more convenient.
- ➤ Trip both breakers with high-speed trip-rated outputs or trip the interposing/lockout relays if this is more convenient.
- ➤ Connect to a power line carrier set via contact I/O or via the SEL-2507 over a fiber-optic cable.
- ➤ Use the single-ended TW-based method with impedance backup.

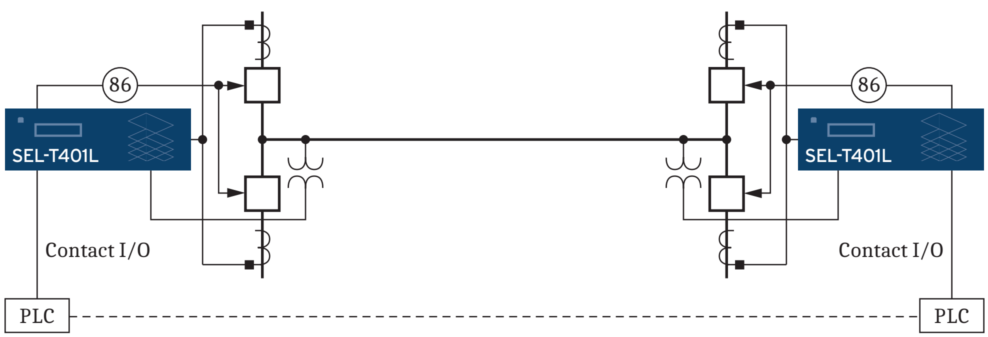

Figure 40 Two-Terminal Dual-Breaker Line Retrofit Application With a Power Line Carrier Set

Example 4. Two-terminal dual-breaker application with redundant protection channels

- ➤ Connect and monitor both breaker currents individually.
- ➤ Trip both breakers with high-speed trip-rated outputs (single-pole or three-pole).
- ➤ Connect to an IEEE C37.94-compliant multiplexer via a fiber-optic cable to apply pilot protection and direct transfer tripping.
- ➤ Connect to the direct fiber-optic channel to apply the TW87 scheme and double-ended fault-locating methods and line monitor without relying on clocks; provide redundancy for the pilot and direct tripping signals.

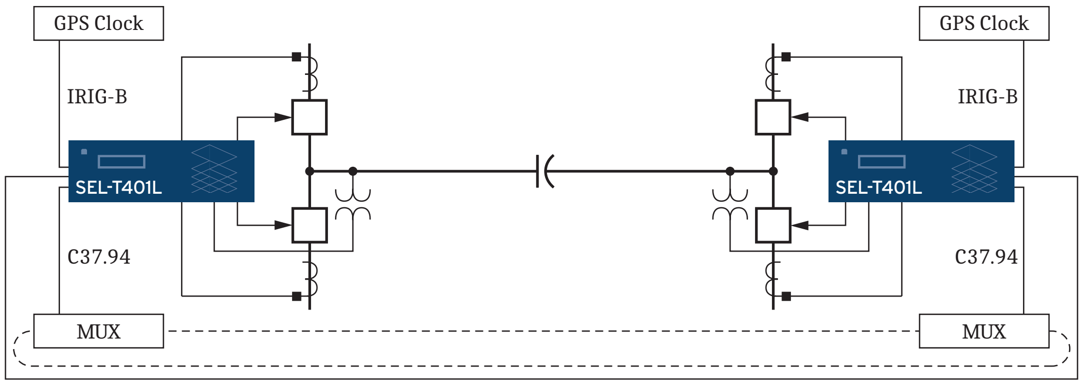

Figure 41 Two-Terminal Dual-Breaker Line With Redundant IEEE C37.94-Encoded and Direct Fiber-Optic Protection Channels

Example 5. Four-terminal application with IEEE C37.94 multiplexers

- ➤ Use three ports on each relay to connect to three remote SEL-T401L relays over an IEEE C37.94-compliant multiplexer.
- ➤ Use open-breaker echo logic to ensure dependable POTT protection for an open breaker or during an out-of-service condition at one or more line terminals.
- ➤ Use the SCADA/HMI software and obtain TW time stamps from all the relays by using DNP3, identify the faulted line segment, and calculate the fault location.

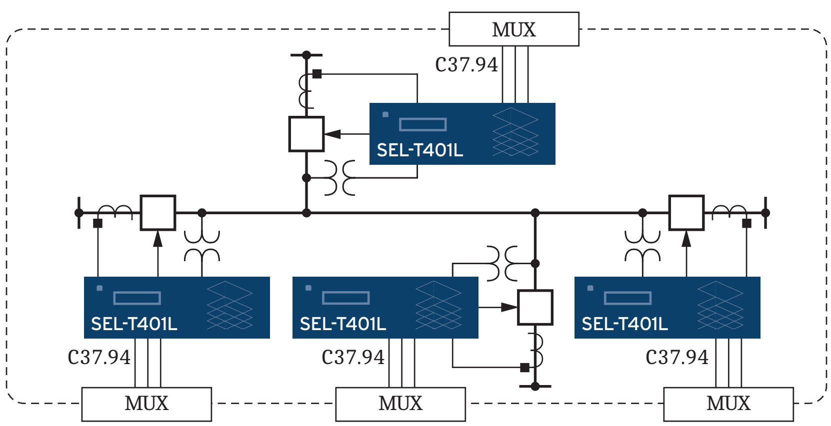

Figure 42 Four-Terminal Line With an IEEE C37.94-Encoded Protection Channel

Example 6. Two-terminal tapped line application with the TW87 scheme

- Apply the TW87 scheme and coordinate with unmeasured taps with built-in location-dependent blocking.
- Set the distance and overcurrent elements to coordinate with unmeasured taps.
- Apply the POTT scheme with impedance elements coordinated not to reach beyond the tapped transformers.
- Use the double-ended TW-based method and line monitor without relying on clocks.

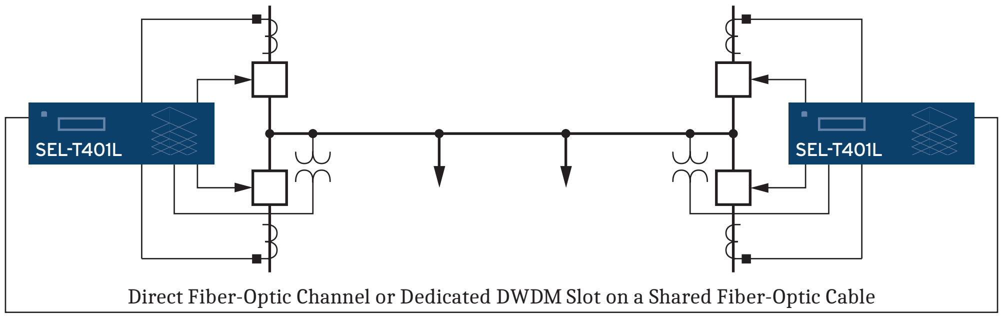

Figure 43 Two-Terminal Line With Two Unmeasured Taps and a Direct Fiber-Optic Protection Channel

Example 7. Hybrid line application

- Connect both relays to high-accuracy clocks and use the double-ended TW-based method and the line monitor over the IEEE C37.94-encoded channel (apply the direct fiber-optic channel and eliminate the need for clocks).
- Locate faults accurately by using the nonhomogeneous line correction in the double-ended TW-based method.
- Detect and locate incipient cable faults with the line monitor.
- Use the adaptive autoreclose cancel logic to apply single-pole tripping and reclosing for faults on overhead sections.

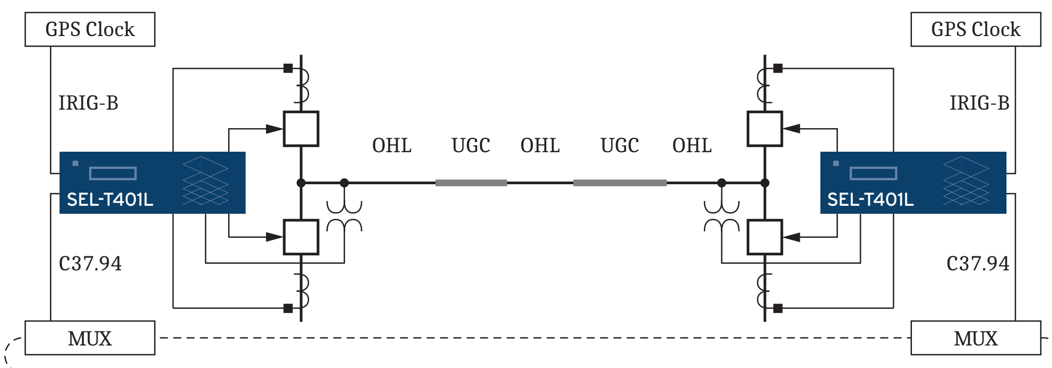

Figure 44 Hybrid Line With an IEEE C37.94-Encoded Protection Channel

Metering, Transient Recording, and Timekeeping

The SEL-T401L provides high-accuracy metering and high-resolution transient recording. These functions help you commission the relay, understand its operation, and gain better insights into the power system, especially high-frequency transients.

Metering

The SEL-T401L measures fundamental-frequency phasors (magnitude and angle) for all input voltages and currents. Phase quantities, as well as symmetrical components and frequency, are available. Current metering is available for each of the two CT inputs separately, as well as for the combined line current. When the direct fiber-optic channel is available, the SEL-T401L also provides metering for the remote-end line currents and voltages.

During commissioning and troubleshooting, access the metering data on the front-panel HMI and the commissioning laptop connected to the relay (use an SEL ASCII command or the SEL Fast Meter protocol). Use DNP3 over Ethernet to integrate the metering data into your SCADA/HMI system.

Transient Recording

The SEL-T401L provides transient recording at a 1 MHz sampling rate, storage for no less than 45 s of total recording time (as many as 40 transient records with a duration of 1.2 s), IEEE C37.111-2013 COMTRADE file format, and a user-configurable trigger. Back-to-back triggering allows you to capture as much as 3.6 s recording time, such as in three 1.2 s long records or eighteen 0.2 s long records. Analyze high-frequency power system events, including lightning strikes, breaker restrikes, and breaker transient recovery voltages with the exceptional 1 MHz, 18-bit recording capability of the SEL-T401L. Use the SEL-5601-2 SYNCHROWAVE® Event Software or any IEEE COMTRADE-compatible program for post-event analysis.

The 1 MHz IEEE COMTRADE record (MHR record) contains voltages and currents sampled at 1 MHz with 18 bits of resolution, relay settings, fault location, and event summary data. The 10 kHz IEEE COMTRADE record (TDR record) contains currents and voltages sampled at 10 kHz with an effective resolution of 20 bits, selected protection operating quantities, Relay Word bits, relay settings, fault location, and event summary data. When the direct fiber-optic channel is available, the MHR and TDR records contain remote-end line currents and voltages. The samples in the transient records are time-stamped with a resolution of 1 µs and an accuracy of 100 ns when the relay is connected to a high-accuracy clock.

Use File Transfer Protocol (FTP) over the Ethernet port for fast download of these large transient records.

Sequential Events Recording

Monitor relay operation and relay input changes with the Sequential Events Recorder (SER). Configure the SER by selecting Relay Word bits to be recorded and time-stamped. The SER inherently records selected device events such as power-up and settings changes. When configuring the SER, you can select rules to address chattering bits. The SER record stores the latest 10,000 entries in nonvolatile memory. The SER time-stamps the events with a resolution of 100 µs and an accuracy of 100 ns when the relay is connected to a high-accuracy clock. The relay makes the SER record available as an ASCII file. Use DNP3 over Ethernet to provide a continuous real-time reporting of binary state changes to your SCADA/HMI system.

Event Summary

Each time the SEL-T401L creates a transient record, it also generates a corresponding event summary. The event summary contains relay identification, time and date of trigger, event type, and for faults: fault location, and pre-fault and fault voltage and current phasors. The header file of the IEEE COMTRADE record includes the event summary. Use an SEL command to print the event summary for a selected transient record.

Fast Time-Domain Values

Fast Time-Domain Values (FTDV) is a novel SEL protocol that streams time-stamped instantaneous voltages and currents obtained with a resolution of 1 µs over Ethernet for remote monitoring and research applications. These applications run continuously in real time on high-performance computing platforms and provide capabilities such as continuous monitoring, recording, signal feature extraction, and visualization. Contact SEL to obtain detailed format descriptions and tools to experiment with this advanced SEL-T401L functionality.

High-Accuracy Timekeeping

To keep track of absolute time, the SEL-T401L accepts a high-accuracy, demodulated, IEEE C37.118-compliant IRIG-B external timing signal from a high-accuracy clock, such as an SEL-2488 Satellite-Synchronized Network Clock, or a terrestrial time distribution system, such as an SEL ICON. The relay keeps internal time locked to the time input with an accuracy of 100 ns. The relay works in UTC time.

The external clock is primarily used for precise time-stamping of relay records. The SEL-T401L protection functions do not depend on the external time input. When two SEL-T401L relays are connected using the direct fiber-optic channel, they synchronize to one another, enabling the TW87 protection scheme and double-ended fault locating to function independently from the external clocks. When using an IEEE C37.94-encoded channel for double-ended TWFL, adaptive auto-reclose cancel logic, or line monitoring, the SEL-T401L uses the external clock for TW time-stamping.

User Interfaces, Network Connections, and SCADA

Front-Panel Display and Targets

The LCD and associated navigation pushbuttons form the HMI, which allows direct access to metering, event summary data, and relay identification and status information, as well as the local control bits. The LCD shows default display messages that provide basic information related to the relay identification, metering, display points, and date and time. These screens advance every 2 s. Multicolor LEDs provide visual indication of relay status, protection element and scheme targets, and fault-type identification (see *Figure 45*). The targets are predefined and cannot be configured. You can print and insert your own target labels to account for the local operator language and to align with your company standards.

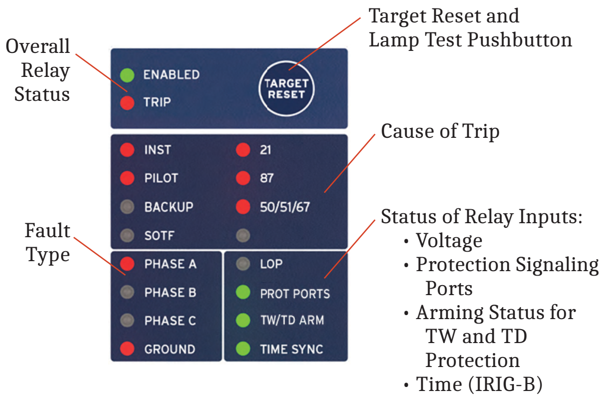

Figure 45 SEL-T401L Targets

Soft Pushbuttons

The SEL-T401L includes 32 local control switches that an operator can set or reset through the front-panel HMI by using the navigation pushbuttons and the LCD. These switches reside in relay firmware and their outputs are stored in nonvolatile memory and referred to as local control bits. Use these local control bits in SELOGIC equations to modify your application for testing purposes, to accommodate temporary power system configurations, and to accommodate seasonal settings changes. When engineering the relay application, you can name each used local control bit for the convenience of the operator. The operator can conveniently access the local control bits through the HMI by pressing the **ENT** pushbutton for 3 s from any LCD screen, view the name and status of each local control bit, and change the bit state. When a bit is set, the operator can reset it. When the bit is reset, the operator can set it. One of the default display messages reminds the operator about how to access local control bits.

Software Configuration and Engineering Tool

QuickSet is the SEL-T401L engineering tool, but you can perform many tasks by using a generic terminal emulator, an FTP client, or an ASCII text editor. Use QuickSet to perform the following:

- ➤ Develop SEL-T401L settings offline, and then connect to your devices to transfer settings and monitor device performance during commissioning.
- ➤ Compare, convert, merge, and amend multiple SEL-T401L settings files to help reduce the overall life-cycle costs of the device.
- ➤ Convert IEEE COMTRADE files into SEL playback files for event playback, upload and manage the event playback test files in the SEL-T401L memory, and execute the event playback tests in the relay.
- ➤ Access SEL-T401L data locally (front-panel Port F) or remotely (Ethernet Port 5) from the convenience of your PC.
- ➤ Design and organize the SEL-T401L settings with the Device Manager, helping your protection and control department to organize all their relevant device information in a central database with a history of the changes.

Use SEL Compass® to keep your software, drivers, and SEL documentation up to date.

Local Engineering Access

Use the front-panel USB 2.0 Port F for occasional engineering access, including relay configuration and upgrading firmware. The SEL-T401L communicates by using SEL ASCII commands and the Fast Meter protocol on Port F to allow QuickSet and terminal emulator tools. You can use Port F for data collection, but to minimize the transfer time, consider using Ethernet Port 5 instead for retrieving large IEEE COMTRADE files.

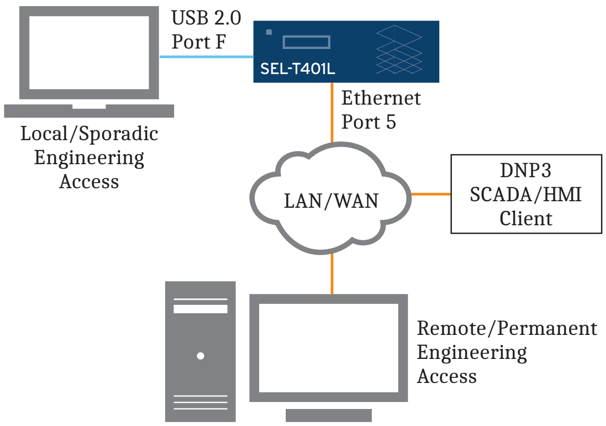

Figure 46 SEL-T401L Engineering and SCADA/HMI Connections

SCADA/HMI Integration and Permanent Engineering Access

Use the rear-panel fiber-optic Ethernet Port 5 for SCADA/HMI applications, including retrieving metering and data reporting with DNP3 and SEL Fast Meter, SEL Fast SER, and SEL Fast Operate protocols, as well as event-driven and ad-hoc file retrieval with FTP. Also, use Port 5 for permanent and remote engineering access. The SEL-T401L allows you to use SEL ASCII commands over Telnet on Port 5 to permit QuickSet and terminal emulator tools. FTP allows you to browse the relay file directories with Windows Explorer or any FTP client. You can conveniently view and copy files between the relay and the computer. You may also remotely upgrade relay firmware by using FTP on Port 5. For excellent data integrity, Port 5 works with fiber-based transceivers only. Order a 100 Mbps or a 1 Gbps Port 5 SFP transceiver to match your Ethernet switch and LAN/WAN needs and capabilities.

The SEL-T401L includes DNP3 Level 2 outstation protocol over Ethernet. Use a DNP3-compliant SCADA system to access metering data, Relay Word bit status, diagnostics, and fault summary information. The relay allows six DNP3 sessions, each with custom data mapping, analog deadbands, and other typical characteristics. Use the built-in test feature to force selected data points during commissioning. *Table 2* summarizes the SEL-T401L DNP3 capabilities.

For security, the SEL-T401L does not allow the DNP3 master to directly control any relay outputs. The DNP3 binary output control points are internal to the relay for event acknowledgment and data housekeeping, including resetting relay targets, resetting DNP3 event data, and loading the next new event via DNP3.

You can operate 32 remote control switches (bits) and use them in SELOGIC equations to allow SCADA/HMI to modify the relay logic. For example, you can temporarily force three-pole tripping in single-pole tripping applications, accommodate temporary power system configurations, and accommodate seasonal settings changes, by disabling one level of an element and enabling a different level to effectively change a setting.

Table 2 Summary of the SEL-T401L DNP3 Capabilities

Feature	Application
Event data	Report data: either unsolicited or when requested
Deadbands	Apply analog deadbands independently for each DNP session on a per-point basis
Sequence-of-events data	Log binary input state changes with time stamps of occurrence
Custom mapping	Select data for each session
Control	Change the state of the remote control bits
Acknowledgment and reset	Reset front-panel targets; reset DNP event summary data and load event summary information
Time synchronization	Set the relay time from the master or request time synchronization from the master
Object 0 device attributes	Provide device attributes (Device ID, number of binary and analog points, manufacturer information, etc.) for the active session
TEST DB2 command	Test the DNP3 protocol interface by forcing analog and binary points

Cybersecurity

The SEL-T401L provides four levels of access for various functions, including viewing status, diagnostics, and changing settings. The relay accepts strong passwords with as many as 12 printable characters. You can limit the access level for remote access over Ethernet, and doing so, intentionally limit the type of engineering tasks that can be performed remotely. The SEL-T401L is compatible with SEL cybersecurity products such as the SEL-3620 Ethernet Security Gateway.

Built-In Testing and Commissioning Tools

Simplify SEL-T401L commissioning, troubleshooting, and approval testing with built-in testing and commissioning functions. Test and troubleshoot digital teleprotection channels with the SEL-standard loopback mode. Apply the TW test mode to test and commission the TW87 scheme and TW32 directional element with high-frequency signal components, without the need to simultaneously inject the fundamental-frequency currents and voltages. Test protection and fault-locating functions without the need for a physical test set by using the built-in event playback function and transient records from the field or simulated with electromagnetic transient programs. Force DNP3 data points to test and commission the SCADA/HMI connection to the relay.

Loopback Test Mode for Digital Protection Channels

Use the port loopback test mode to simplify testing and speed up troubleshooting of the digital teleprotection channels or connections to local relays. The loopback test mode allows the relay to receive its own packets while either permitting the payload bits to be received as sent or forcing the received bits to the fail-safe value of logical 0. Put the SEL-T401L port connecting the channel you want to test into a loopback test mode. Loop the transmit path back to the receive path at various points in the communications chain to pinpoint problems related to data clocking, data corruption, noise, or misconnections between relays. Use the port communications report to obtain the present channel status and the historical data collected during normal operation and while in loopback test mode. The loopback feature is available for Ports 1 through 3. You can test Port 6 without the loopback mode.

Traveling-Wave Test Mode

Use the TW test mode to simplify testing and commissioning of the TW87 scheme, the TW32 element, and the TWFL methods. While the SEL-T401L is in the TW test mode, use a high-fidelity test source, such as the SEL-T4287 Traveling-Wave Test System, to inject TW test signals, without the need to simultaneously inject fundamental-frequency voltages and currents into the relay. While operating in the TW test mode, the TW87 scheme logic suspends security conditions that require fundamental-frequency voltages and currents, allowing the TW87 scheme to operate on the high-frequency signals alone. Prevent an unintentional or malicious initiation of the TW test mode to in-service relays by monitoring the Alarm output on the tested relay and requiring that your testing and commissioning personnel use the relay front panel to acknowledge the TW test mode initiation sent over the engineering access port. The TW test mode expires after 30 minutes if the relay is left in the TW test mode unintentionally.

As an alternative to the TW test mode, use the SEL-T4287 in parallel with a conventional test set capable of injecting low-frequency signals and having the two test sets cross-trigger each other.

Event Playback

Use event playback to test protection and fault-locating functions with a transient file uploaded to the relay without the need for physical signal injection. In playback mode, the relay substitutes the voltage and current samples from the analog-to-digital converter with values uploaded to the relay memory prior to the playback test. As test cases, use historical field records or simulate transient events with any standard electromagnetic transient program (see *Figure 47*).

Use the Playback File Conversion Utility in QuickSet to convert an IEEE COMTRADE file to the SEL playback file format. Use the Event Playback Test Dashboard in QuickSet to upload and manage playback test files in the relay memory and to execute event playback tests. Provide 50 ms or more of pre-event steady-state data in your test file and allow the relay to loop one power cycle from the pre-event data for 1 s to simulate the pre-event steady state.

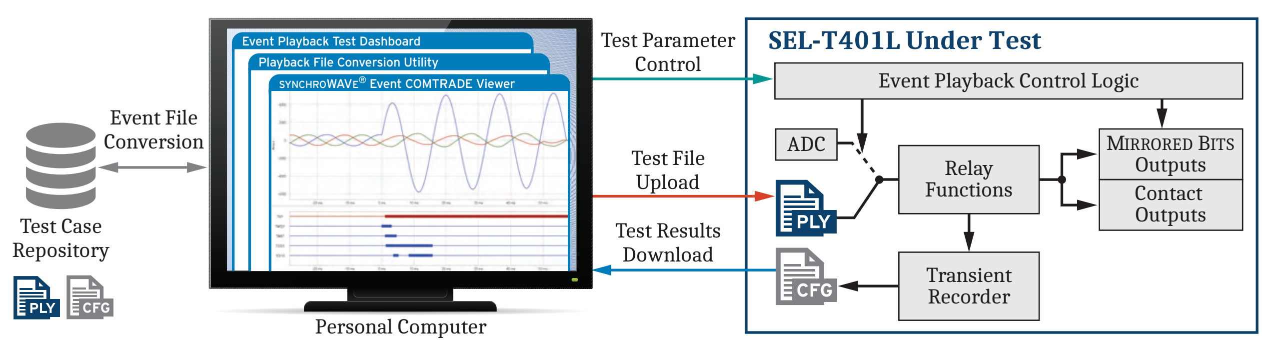

Figure 47 SEL-T401L Event Playback Overview

DNP3 Data Forcing

Simplify and speed up testing and commissioning of the substation automation system, including network configuration and data mapping, with the **TEST DB2** command. This feature provides you with a method to override digital and analog DNP3 inputs for testing DNP3 functionality. The command overrides values in the DNP3 communications interface only. The true values that the relay uses for protection and control are not changed. For security, when the **TEST DB2** command forces the DNP3 inputs to test values, it also asserts a Relay Word bit to indicate that the DNP3 test mode is active.

Front- and Rear-Panel Diagrams

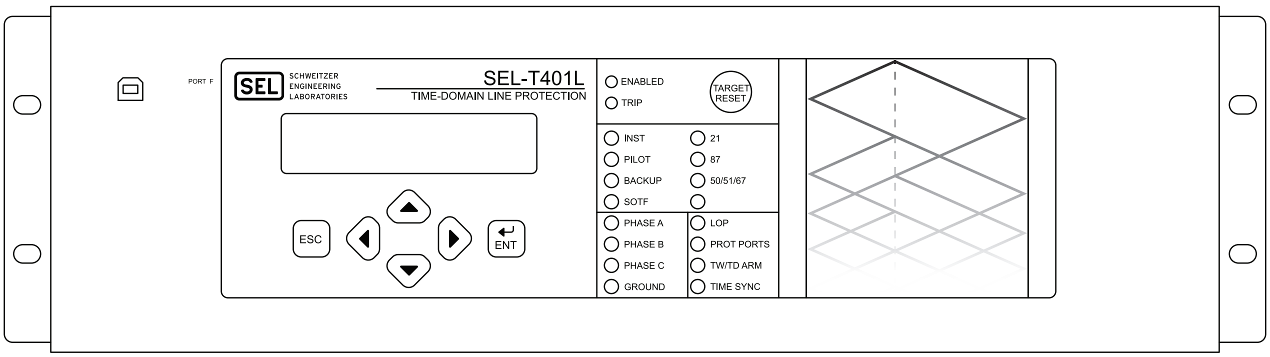

Figure 48 SEL-T401L Front-Panel View

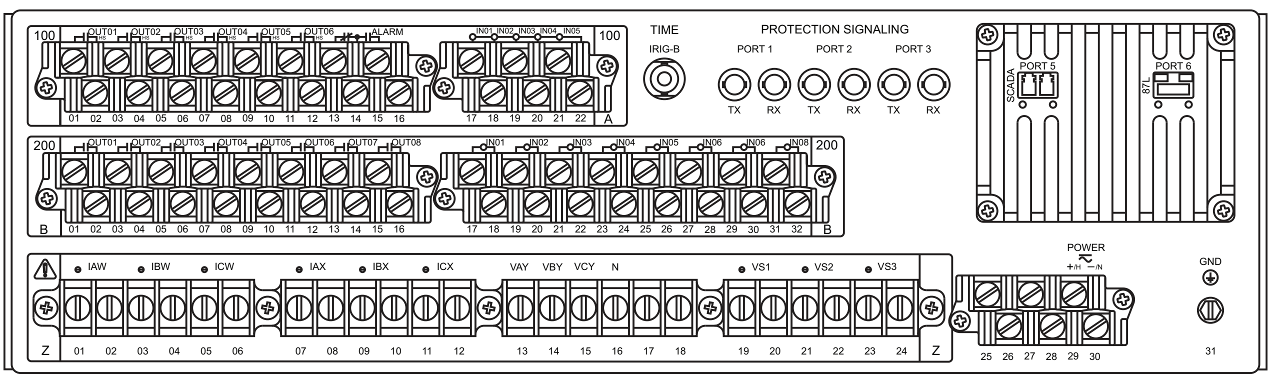

Figure 49 SEL-T401L Rear-Panel View

Dimensions

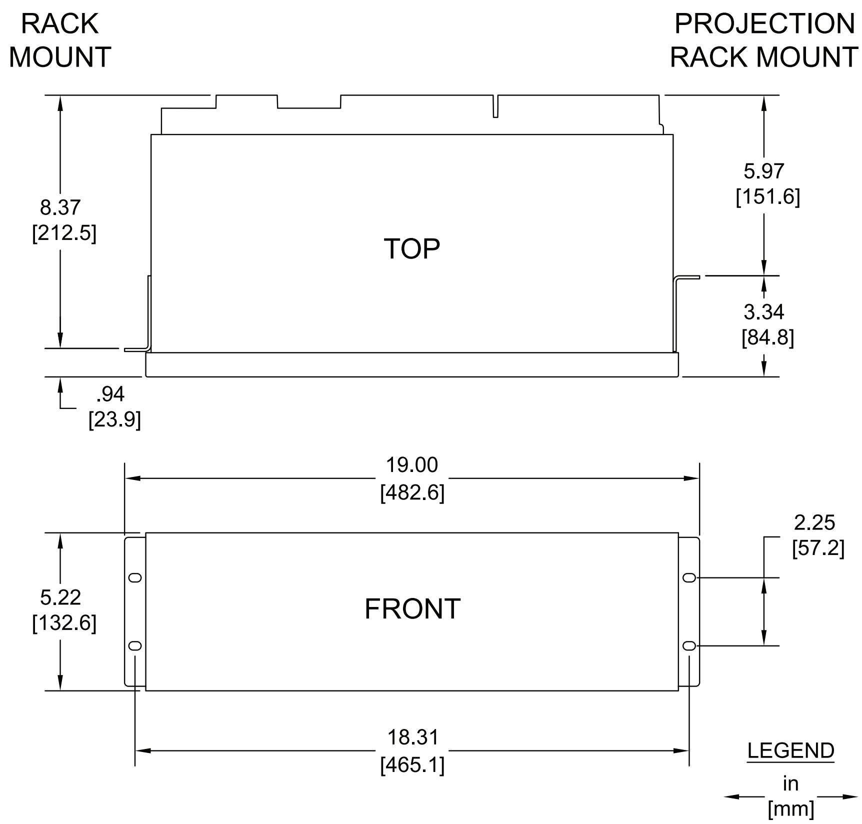

Figure 50 SEL-T401L Rack-Mount Chassis Dimensions

Specifications

Compliance

Designed and manufactured under an ISO 9001 certified quality management system

FCC Compliance Statement

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

UKCA Mark

RCM Mark

General

AC Analog Inputs

Sampling Rate:	1 MHz
A/D Resolution:	18 bits

AC Current Inputs

Rated Input Current:	1 A Model: 1 A 5 A Model: 5 A
Continuous Thermal Rating:	1 A Model: 3 A 5 A Model: 15 A
A/D Measurement Limit:	1 A Model: 50 A peak (17.67 Arms fully offset ac current) 5 A Model: 250 A peak (88.4 Arms fully offset ac current)
One-Second Thermal Withstand:	1 A Model: 100 Arms 5 A Model: 500 Arms
Burden:	1 A Model: <0.1 VA at 1 A, 60 Hz 5 A Model: <0.5 VA at 5 A, 60 Hz

AC Voltage Inputs

Connection:	Three-phase four-wire wye with a common neutral, dc coupled (Voltage Input VY, protection, recording, and metering) Three-phase six-wire individually isolated, dc coupled (Voltage Input VS, recording, and metering)
Rated Voltage Range:	57.7–144.3 V LN (100–250 V LL)
Continuous Thermal Rating:	175 Vrms LN
A/D Measurement Limit:	280 V peak LN

Ten-Second Thermal Withstand: 350 Vrms LN

Burden: <0.1 VA at 120 V LN

Power Supply

High-Voltage Range (125–250 Vdc)

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

Control Power Interruption Ride-Through: 46 ms @ 125 Vdc,
250 ms @ 250 Vdc
per IEC 60255-26:2013

Burden: <35 W, <90 VA

Medium-Voltage Range (48–125 Vdc)

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

Control Power Interruption Ride-Through: 14 ms @ 48 Vdc,
160 ms @ 125 Vdc
per IEC 60255-26:2013

Burden: <35 W, <90 VA

Contact Outputs

Update Rate: 10 kHz

Mechanical Endurance: 10,000 operations

Fast Hybrid (High-Speed, High-Current Interrupting) Form A

Rated Voltage: 48–250 Vdc

Operational Voltage Range: 0–300 Vdc

Operating Time: Pickup time ≤10 µs (resistive load)
Dropout ≤8 ms (resistive load)

Make[1, 2] (Short Duration Contact Current): 30 Adc
2,000 operations

Limiting Making Capacity[2]: 1,000 W at 250 Vdc (L/R = 40 ms)

Short-Time Thermal Withstand: 50 Adc for 1 s

Continuous Contact Current: 6 Adc at 70°C (158°F)
4 Adc at 85°C (185°F)

Contact Protection: MOV protection across open contacts
300 Vdc continuous voltage

Maximum Leakage Current: <100 µA at 300 Vdc

Limiting Breaking Capacity/Electrical Endurance[1, 2]: 10,000 operations
4 operations in 1 s, followed by 2 min idle

[1] According to IEEE C37.90-2005.
[2] According to IEC 60255-27:2013.

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

Standard Form A

Rated Voltage: 48–250 Vdc

Operational Voltage Range: 0–300 Vdc

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

Make[1, 2] (Short Duration Contact Current): 30 Adc
1,000 operations at 250 Vdc
2,000 operations at 125 Vdc

Limiting Making Capacity[2]: 1,000 W at 250 Vdc (L/R = 40 ms)

Short-Time Thermal Withstand: 50 Adc for 1 s

Continuous Contact Current: 6 Adc at 70°C (158°F)
4 Adc at 85°C (185°F)

Contact Protection: MOV protection across open contacts
300 Vdc continuous voltage

Limiting Breaking Capacity/Electrical Endurance[1, 2]: 10,000 operations
10 operations in 4 s, followed by 2 min idle

[1] According to IEEE C37.90-2005.
[2] According to IEC 60255-27:2013.

Rated Voltage	Resistive Break	Inductive Break
48 Vdc	0.63 Adc	0.63 Adc (L/R = 40 ms)
125 Vdc	0.30 Adc	0.30 Adc (L/R = 40 ms)
250 Vdc	0.20 Adc	0.20 Adc (L/R = 40 ms)

Alarm Output (Form C)

Rated Voltage: 48–250 Vdc

Operational Voltage Range: 0–300 Vdc

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

Short-Time Thermal Withstand: 50 Adc for 1 s

Continuous Contact Current: 6 Adc at 70°C (158°F)
4 Adc at 85°C (185°F)

Contact Protection: MOV protection across open contacts
300 Vdc continuous voltage

Limiting Breaking Capacity/Electrical Endurance[1, 2]: 10,000 operations
10 operations in 4 s, followed by 2 min idle

[1] According to IEEE C37.90-2005.
[2] According to IEC 60255-27:2013.

Rated Voltage	Resistive Break	Inductive Break
48 Vdc	0.63 Adc	0.63 Adc (L/R = 40 ms)
125 Vdc	0.30 Adc	0.30 Adc (L/R = 40 ms)
250 Vdc	0.20 Adc	0.20 Adc (L/R = 40 ms)

Contact Inputs

Optoisolated (Bipolar Operation)

Connection: Terminal Block 100: 5 inputs with a shared common terminal
Terminal Block 200: 8 fully isolated inputs

Sampling Rate: 10 kHz

Input Voltage Options:

Rated Voltage	Maximum Voltage	Pickup Voltage	Dropout Voltage
48 Vdc	60 Vdc	38 Vdc	28 Vdc
110 Vdc	132 Vdc	88 Vdc	66 Vdc
125 Vdc	150 Vdc	100 Vdc	75 Vdc
220 Vdc	264 Vdc	176 Vdc	132 Vdc
250 Vdc	300 Vdc	200 Vdc	150 Vdc

Current Draw: ≤5 mA at rated voltage
≥1 mA required for assertion (220, 250 Vdc option)
≥2 mA required for assertion (48, 110, 125 Vdc option)

Communications Ports

Fiber-Optic Protection Signaling Ports 1, 2, and 3

Applications: Relay-to-relay signaling, POTT, DCB, DTT, double-ended traveling-wave fault locating[1], adaptive autoreclose cancel logic[1], and line monitoring[1]

[1] IEEE C37.94 encoding, 30 ms maximum channel latency

Data Rate: 19,200 to 115,200 bps (SEL MIRRORED BITS encoding)
64 kbps (IEEE C37.94 encoding)

Connector Type: ST

Fiber Type: Multimode

Wavelength: 820 nm

Fiber Size: 62.5/125 µm

Minimum Receiver Sensitivity: –24 dBm

Transmitter Power: –18.5 dBm (minimum)
–10.5 dBm (maximum)

Maximum Distance: 2 km (for typical continuous fiber-optic cable)

Data Integrity Protection: Meets IEC 60834-1 transmission time, bit error rate security, and bit error rate dependability recommendations for direct tripping and teleprotection applications over digital channels

Fiber-Optic Protection Signaling Port 6 (Transceivers Ordered Separately)

Applications: POTT, DCB, and DTT for two-terminal applications, traveling-wave differential protection scheme[1], double-ended fault locating, adaptive autoreclose cancel logic, line monitoring, and remote line-end recording and metering

Data Rate: 1 Gbps

Connector Type: LC

Wavelength: 850–1,550 nm, depending on transceiver

Distance of Direct Connection: 0.3–200.0 km, depending on transceiver

[1] One-way channel delay less than 4 ms and less than the TW line propagation time plus 2 ms.

USB Front-Panel Port F

Connector Type: Type B

USB Type: 2.0

Fiber-Optic Ethernet Port 5

Applications: Remote engineering access and permanent connection to SCADA or HMI client

Installed SFP Transceiver: 2 km, 1,310 nm, multimode

Connector Type: LC

Port 5- and Port 6-Compliant SFP Transceivers

2 km, 1,310 nm, multimode (Port 5 only)
0.3/0.55 km, 850 nm, multimode
10 km, 1,310 nm, single-mode
20 km, 1,310 nm, single-mode
30 km, 1,310 nm, single-mode
40 km, 1,310 nm, single-mode
50 km, 1,550 nm, single-mode
80 km, 1,550 nm, single-mode
160 km, 1,550 nm, single-mode
200 km, 1,550 nm, single-mode

Time Input

IRIG-B Input

Applications: Precise time synchronization for digital fault recording, sequential events recording, double-ended traveling-wave fault locating, adaptive autoreclose cancel logic, and line monitoring when using an IEEE C37.94 channel

Format: Demodulated IRIG-B

Rated I/O Voltage: 5 Vdc

Operating Voltage Range: 0–8 Vdc

Input Impedance: ≥1 kΩ

Time Accuracy: 100 ns when connected to a high-accuracy clock

Holdover Accuracy: <1 µs for 15 s

Clock Drift When Free Running: <5 min per year typical

Installation

According to IEC 60255-27:2013

Operating Temperature

Relay: –40° to +85°C (–40° to +185°F)

Note: LCD contrast impaired for temperatures below –20°C (–4°F) and above +70°C (+158°F).

SFP Transceivers: –40° to +70°C (–40° to +158°F)

Humidity: 5% to 95% without condensation

Altitude: <2000 m

Overvoltage Category: Category III

Insulation Class: I

Pollution Degree: 2

Size and Weight

Size: 3U 19-in horizontal rack-mount

Weight: 7.54 kg (16.63 lb) (maximum)

Terminal Connections and Wire Sizes

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 (221°F). Ring terminals are recommended.

Wire Sizes
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 in the same cable connected to the device, unless otherwise required by local or national wiring regulations.

Connection Type	Minimum Wire Size	Maximum 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)
Power, Contact I/O	18 AWG (0.8 mm^2)	10 AWG (5.3 mm^2)

Type Tests

Electromagnetic Compatibility (EMC)

Emissions: IEC 60255-26:2013, Section 7.1
Class A
47 CFR Part 15B
Class A
Canada ICES-001 (A) / NMB-001 (A)

Electromagnetic Compatibility Immunity

Conducted RFI Immunity: IEC 60255-26:2013, Section 7.2.8
10 Vrms

Radiated RFI Immunity: IEC 60255-26:2013, Section 7.2.4
10 V/m (modulated)
IEEE C37.90.2-2004
20 V/m (modulated, >35 V/m peak)

Electrostatic Discharge Immunity: IEC 60255-26:2013, Section 7.2.3
IEEE C37.90.3-2001
2, 4, 6, and 8 kV contact discharge
2, 4, 8, and 15 kV air discharge

Electrical Fast Transient Burst Immunity: IEC 60255-26:2013, Section 7.2.5
Zone A
4 kV, 5 kHz repetition rate on power supply I/O, signal data, and control lines
2 kV, 5 kHz repetition rate on communications ports (IRIG-B)

Power Frequency Immunity: IEC 60255-26:2013, Section 7.2.9
Zone A

Power Frequency Magnetic Field Immunity: IEC 60255-26:2013, Section 7.2.10
Level 5
1,000 A/m for 3 s
100 A/m for 60 s

Pulse Magnetic Field Immunity: IEC 61000-4-9:2001
Level 5
1,000 A/m

Damped Oscillatory Magnetic Field: IEC 61000-4-10:2001
Level 5
100 A/m at 100 kHz and 1 MHz

Power Supply Immunity: IEC 60255-26:2013, Section 7.2.11, 7.2.12, and 7.2.13
IEC 60255-27:2013, Section 5.1.3, 10.6.6

Surge Immunity: IEC 60255-26:2013, Section 7.2.7
Zone A
Line-to-line: 0.5, 1.0, 2.0 kV
Line-to-earth: 0.5, 1.0, 2.0, 4.0 kV

Surge Withstand Capability Immunity and Damped Oscillatory Wave Immunity: IEC 60255-26:2013, Section 7.2.6
2.5 kV peak common mode
1.0 kV peak differential mode
1 MHz damped oscillatory
IEEE C37.90.1-2012
2.5 kV oscillatory
4.0 kV fast transient
2.5 kV, 1 MHz damped oscillatory

Environmental

Cold, Operational: IEC 60255-27:2013, Section 10.6.1.2
Test Ad: 16 hours at –40°C

Dry Heat, Operational: IEC 60255-27:2013, Section 10.6.1.1
Test Bd: 16 hours at +85°C

Damp Heat, Cyclic: IEC 60255-27:2013, Section 10.6.1.6
Test Db: +25° to +55°C, 6 cycles (12 + 12-hour cycle), 95% RH

Damp Heat, Steady State: IEC 60255-27:2013, Section 10.6.1.5
Test Cab: 93% RH, +40°C, 10 days

Object Penetration: IEC 60255-27:2013, Section 10.6.2.6
Protection Class: IP30

Vibration Resistance: IEC 60255-27:2013, Section 10.6.2.1
Class 2 Endurance, Class 2 Response

Shock Resistance: IEC 60255-27:2013, Section 10.6.2.2, 10.6.2.3
Class 1 Shock Withstand, Class 1 Bump Withstand, Class 2 Shock Response

Seismic: IEC 60255-27:2013, Section 10.6.2.4
Class 2 Quake Response

Safety

Dielectric Strength: IEC 60255-27:2013, Section 10.6.4.3
IEEE C37.90-2005, Section 8
2.5 kVrms: analog inputs, contact inputs, contact outputs, and IRIG-B input
3.6 kVdc: power supply

Impulse: IEC 60255-27:2013, Section 10.6.4.2
IEEE C37.90-2005, Impulse section
5.0 kV: analog inputs, digital inputs, digital outputs, power supply, and IRIG-B input

Product Safety Requirements: IEC 60255-27:2013

Laser Safety: 21 CFR 1040.10
IEC 60825-1:2014
Class 1

Reporting Functions

Fault Locator

Methods: Double-ended and single-ended traveling-wave; double-ended and single-ended impedance

Communications Port for Double-Ended Methods: User-selectable, Port 1, 2, 3, or 6

Time Synchronization Requirements: None for single-ended methods or when using Port 6
High-accuracy IRIG-B when using Port 1, 2, or 3

Data Presentation: Summary report, transient record (IEEE COMTRADE[1] header file), front-panel HMI, SCADA protocols

[1] IEEE Std C37.111-2013 (IEC 60255-24:2013), *Measuring Relays and Protection Equipment – Part 24: Common Format for Transient Data Exchange (COMTRADE) for Power Systems*

Double-Ended Traveling-Wave-Based Method

Channel Requirements: Direct fiber-optic on Port 6 or IEEE C37.94 channel on user-selectable Port 1, 2, or 3 with a high-accuracy clock at both line terminals and channel latency less than 30 ms

Device Accuracy[1]: 20 m (90th percentile error)
10 m (median error)

[1] Device accuracy tested with a current or voltage step

Application Accuracy: 300 m typical

Sensitivity

Current TWs: Greater than 2% of peak nominal current

Voltage TWs: Greater than 1% of peak nominal voltage

Number of Nonhomogeneous Line Sections: Up to 5

CT or PT Cable Length Compensation: 0.000 to 10.000 µs

Single-Ended Traveling-Wave-Based Method

Device Accuracy[1]:	20 m (90th percentile error) 10 m (median error)

[1] Device accuracy tested with a current or voltage step

Application Accuracy:	300 m typical
Sensitivity	
Current TWs:	Greater than 2% of peak nominal current
Voltage TWs:	Greater than 1% of peak nominal voltage
Number of Ranked Fault Location Alternatives Reported:	Up to 4
CT or PT Cable Length Compensation:	Not required

Double-Ended Impedance-Based Method

Channel Requirements:	Direct fiber-optic on Port 6
Method:	Negative-sequence line voltage profile (unbalanced faults) or positive-sequence line voltage profile (three-phase faults)

Single-Ended Impedance-Based Method

Method:	Apparent impedance polarized with negative-sequence current (unbalanced faults) or positive-sequence current (three-phase faults)

Transient Recording

Recording Rates:	1 MHz concurrently with 10 kHz
Maximum Duration:	3.6 s total in back-to-back recording
Output Format:	Binary 32-bit IEEE COMTRADE

Record Storage (Summary, History, Transient Records)

Total Storage:	No less than 45 s of total recording time 40 records at LER = 1.2 s 225 records at LER = 0.2 s

Sequential Events Recorder

Storage	10,000 entries
Number of Configurable Points:	200
Burst Mode:	1,000 entries
Resolution	100 µs

Protection Specifications

Processing Intervals

TW Calculations:	1 µs
Incremental-Quantity Calculations:	100 µs
Fundamental Frequency Protection Calculations:	500 µs
SELOGIC Processing:	100 µs
Protection Logic Processing:	100 µs

Protection Element Steady-State Accuracy

Pickup Accuracy for Phase Current Elements:	±(1% of setting or 1% of nominal, whichever is greater)
Pickup Accuracy for Sequence Current Elements:	±(2% of the highest phase current or 1% of nominal, whichever is greater)
Pickup Accuracy for Phase Voltage Elements:	±(0.25% of setting or 0.1 V sec, whichever is greater)
Pickup Accuracy for Sequence Voltage Elements:	±(0.5% of highest phase voltage or 0.2 V sec, whichever is greater)
Angle Accuracy for Directional Elements:	±1 degree
Pickup Accuracy for Impedance Elements:	±1.5% of impedance setting or 0.05 Ω, whichever is greater
Definite-Time Protection Timers Accuracy:	±(1 ms or 0.1% of the setting, whichever is greater)

System Configuration

Nominal System Frequency:	50 Hz or 60 Hz
Frequency Tracking Range:	±10 Hz from nominal
Maximum Frequency Slew Rate:	±10 Hz/s
System Phase Rotation:	ABC or ACB
Current Transformer Ratio:	1 to 50,000 in steps of 1
Line Current Source:	IW, IX, or COMB (combined)
Secondary Cable Delay Compensation:	0.000 to 10.000 µs in steps of 0.001 µs
Potential Transformer Ratio:	1.00 to 10,000.00 in steps of 0.01
Nominal Voltage (LL):	100 to 250 V secondary in steps of 1 V

Line Configuration

Positive-Sequence Line Impedance Magnitude:	1 A Model: 0.25 to 1,275.00 Ω secondary in steps of 0.01 Ω 5 A Model: 0.05 to 255.00 Ω secondary in steps of 0.01 Ω
Positive-Sequence Line Impedance Angle:	30.00° to 90.00° in steps of 0.01°
Zero-Sequence Line Impedance Magnitude:	1 A Model: 0.25 to 1,275.00 Ω secondary in steps of 0.01 Ω 5 A Model: 0.05 to 255.00 Ω secondary in steps of 0.01 Ω
Zero-Sequence Line Impedance Angle:	30.00° to 90.00° in steps of 0.01°
Line Length:	0.01 to 500.00 in steps of 0.01
Line Length Unit:	km or mi
TW Line Propagation Time:	10.00 to 1,700.00 µs in steps of 0.01 µs
In-Line Series Capacitance:	1 A Model: 0.00 to 1,275.00 Ω secondary in steps of 0.01 Ω 5 A Model: 0.00 to 255.00 Ω secondary in steps of 0.01 Ω
External Series Compensation:	Y or N

Traveling-Wave Differential Scheme (TW87)

Channel Requirements:	Direct fiber-optic channel One-way channel delay less than 4 ms and less than the TW line propagation time plus 2 ms
External Clock Requirements:	None
Voltage Requirements:	TW87 requires pre-fault voltage to operate
TW87 Overcurrent Supervision:	1 A Model: 0.05 to 2.00 A secondary in steps of 0.01 A 5 A Model: 0.25 to 10.00 A secondary in steps of 0.01 A
Blocking Fault Location:	OFF, 0.00 to line length (mi/km) in steps of 0.01
Blocking Fault Location Radius:	0.00 to 10.00 mi/km in steps of 0.01
Number of Blocking Fault Location Zones:	2
Operating Time[1] (in ms):	0.5000 + 0.0087 • line length (km); or 0.500 + 0.014 • line length (mi); see *Figure 6*

[1] Operating time is defined as the length of time from when the first TW arrives at the local terminal to when the element operates.

Incremental-Quantity Distance Element (TD21)

Phase Reach:	OFF, 0.10 to 0.90 of the positive-sequence line impedance, in steps of 0.01 Ω
Ground Reach:	OFF, 0.10 to 0.90 of the positive-sequence line impedance, in steps of 0.01 Ω
Operating Time[1]:	<5 ms typical for bolted faults; <50% of the reach and SIR <1; see *Figure 4*
Transient Overreach:	<10%

[1] Operating time is defined as the length of time from when the first TW arrives at the local terminal to when the element operates.

Distance Elements (21)

Number of Directional Zones:	4
Number of Nondirectional Zones:	1 (Zone 5)
Directionality:	Forward or reverse, selectable per zone, common to phase and ground distance elements of a zone
Operating Characteristic:	Mho or quadrilateral, selectable per zone, separate for phase and ground distance elements of a zone
Impedance Maximum Torque Angle:	Fixed, same as the positive-sequence line impedance angle
Directional Supervision:	Loop current polarized with memorized positive-sequence voltage
Directional Maximum Torque Angle:	70°
Zero-Sequence Compensation Method:	Entered by using settings or calculated based on line impedance data
Zero-Sequence Compensation Factor Magnitude:	0.000 to 10.000 in steps of 0.001
Zero-Sequence Compensation Factor Angle:	–180.00° to 180.00° in steps of 0.01°
Reach Including Zone 5 Reverse Reach and Resistive Reach for Quadrilateral Elements:	1 A Model: 0.25 to 320.00 Ω secondary in steps of 0.01 Ω 5 A Model: 0.05 to 64.00 Ω secondary in steps of 0.01 Ω
Mho Characteristic Polarization:	Memorized positive-sequence voltage
Quadrilateral Reactance Polarization:	Loop current (Zones 2–5), loop current and sequence current (Zone 1 and Zone 2 if used in PILOT protection logic)
Quadrilateral Reactance Tilt Angle:	–25.0° to 25.0° in steps of 0.1°
CCVT Security Logic:	Built-in for Zone 1, no settings
Zone 1 Transient Overreach:	<2% for magnetic VTs <8% for CCVTs
Overcurrent Supervision, Phase Elements	
Operating Current:	Phase-to-phase current
Pickup:	1 A Model: 0.10 to 30.00 A secondary in steps of 0.01 A 5 A Model: 0.50 to 150.00 A secondary in steps of 0.01 A
Overcurrent Supervision, Ground Elements	
Operating Current:	Phase and zero-sequence current
Pickup:	1 A Model: 0.10 to 20.00 A secondary in steps of 0.01 A 5 A Model: 0.50 to 100.00 A secondary in steps of 0.01 A
Torque Control:	Configurable through a SELOGIC equation
Operating Time:	See *Figure 18* and *Figure 20*

Step Distance Timers (21T)

Number of Timers:	15 (ground, phase, and common, for each of 5 zones)
Delay:	0.000 to 10.000 s in steps of 0.001 s
Timer Operation:	Integrating with user-controllable reset type
Reset Type:	Delayed or instantaneous (common to all 21T timers)
Reset Delay:	0.000 to 0.200 s in steps of 0.001 s (common to all 21T timers); the time does not integrate down but holds during the reset delay time

Load Encroachment (LE)

Operation:	Phase-segregated (six-loop measurement with corresponding selective blocking/ unblocking, separate phase and ground settings for systems with single-pole tripping)
Blocking Action:	Selectable on a per-zone basis
Export (Forward) Load Impedance:	1 A Model: 0.25 to 320.00 Ω secondary in steps of 0.01 Ω 5 A Model: 0.05 to 64.00 Ω secondary in steps of 0.01 Ω
Import (Reverse) Load Impedance:	1 A Model: 0.25 to 320.00 Ω secondary in steps of 0.01 Ω 5 A Model: 0.05 to 64.00 Ω secondary in steps of 0.01 Ω
Load Impedance Angle:	5.0° to 90.0° in steps of 0.1° (common to positive and negative power factors)
Pickup Time (Blocking):	<1.25 cycle
Reset Time (Unblocking):	<0.75 cycle, typical

Power-Swing Blocking (68)

Operation:	Phase-segregated (six-loop measurement with corresponding selective blocking/ unblocking; suitable for systems with single-pole tripping)
Operating Principle:	Continuous measurement of the impedance rate-of-change
Blocking Action:	Selectable on a per-zone basis
Unblocking for Faults:	Yes
Settings:	None

Out-of-Step Tripping (78)

Operation:	Trip-on-the-way-out
Operating Principle:	Continuous measurement of the impedance rate-of-change
Tripping Action:	Delayed to avoid breaker overvoltages
Settings:	None

Traveling-Wave Directional Element (TW32)

Application:	Accelerating POTT keying (optional)
Operating Time[1]:	0.1 ms typical

[1] Operating time is defined as the length of time from when the first TW arrives at the local terminal to when the element operates.

Incremental-Quantity Directional Element (TD32)

TD32 Forward Impedance Threshold:	1 A Model: –1,275.00 to –0.05 Ω secondary in steps of 0.01 Ω 5 A Model: –255.00 to –0.01 Ω secondary in steps of 0.01 Ω
TD32 Reverse Impedance Threshold:	1 A Model: 0.05 to 1,275.00 Ω secondary in steps of 0.01 Ω 5 A Model: 0.01 to 255.00 Ω secondary in steps of 0.01 Ω

Operating Time[1]:	<2 ms typical

[1] Operating time is defined as the length of time from when the first TW arrives at the local terminal to when the element operates.

Zero-Sequence Directional Element (32G)

32G Forward Impedance Threshold:	1 A Model: –320.00 to 320.00 Ω secondary in steps of 0.01 Ω 5 A Model: –64.00 to 64.00 Ω secondary in steps of 0.01 Ω
32G Reverse Impedance Threshold:	1 A Model: –320.00 to 320.00 Ω secondary in steps of 0.01 Ω 5 A Model: –64.00 to 64.00 Ω secondary in steps of 0.01 Ω
32G Overcurrent Pickup:	1 A Model: 0.01 to 1.00 A secondary in steps of 0.01 A 5 A Model: 0.05 to 5.00 A secondary in steps of 0.01 A
Maximum Torque Angle:	Fixed, same as the zero-sequence line impedance angle
Comparator Limit Angle:	±45° or ±75° in applications with series compensation
Operating Time:	0.5 cycle, typical

Negative-Sequence Directional Element (32Q)

32Q Forward Impedance Threshold:	1 A Model: –320.00 to 320.00 Ω secondary in steps of 0.01 Ω 5 A Model: –64.00 to 64.00 Ω secondary in steps of 0.01 Ω
32Q Reverse Impedance Threshold:	1 A Model: –320.00 to 320.00 Ω secondary in steps of 0.01 Ω 5 A Model: –64.00 to 64.00 Ω secondary in steps of 0.01 Ω
32Q Overcurrent Pickup:	1 A Model: 0.01 to 1.00 A secondary in steps of 0.01 A 5 A Model: 0.05 to 5.00 A secondary in steps of 0.01 A
Maximum Torque Angle:	Fixed, same as the positive-sequence line impedance angle
Comparator Limit Angle:	±30° or ±60° in applications with series compensation
Operating Time:	0.5 cycle, typical

Phase Directional Element (32P)

32P Maximum Torque Angle:	0.0° to 90.0° in steps of 0.1°
32P Comparator Limit Angle:	20.0° to 90.0° in steps of 0.1°
32P Forward Overcurrent Pickup:	1 A Model: 0.05 to 10.00 A secondary in steps of 0.01 A 5 A Model: 0.25 to 50.00 A secondary in steps of 0.01 A
32P Reverse Overcurrent Pickup:	1 A Model: 0.05 to 10.00 A secondary in steps of 0.01 A 5 A Model: 0.25 to 50.00 A secondary in steps of 0.01 A
Operating Time:	<1.25 cycle

Instantaneous and Definite-Time Zero-Sequence Overcurrent Element (50G/67G)

Number of Elements (Levels):	5
Operating Current:	3I0
Pickup:	1 A Model: 0.05 to 20.00 A secondary in steps of 0.01 A 5 A Model: 0.25 to 100.00 A secondary in steps of 0.01 A
Delay:	0.000 to 10.000 s in steps of 0.001 s
Timer Operation:	Integrating with user-controllable reset type
Reset Type:	Delayed or instantaneous (common to all 50/67 timers)
Reset Delay:	0.000 to 0.200 s in steps of 0.001 s (common to all 50/67 timers); the time does not integrate down but holds during the reset delay time
Directionality:	Selectable forward or reverse, or implemented by using a torque-control SELOGIC equation
Torque Control:	Configurable through a SELOGIC equation
Pickup Time:	<1.25 cycle
Transient Overreach:	<10%

Instantaneous and Definite-Time Negative-Sequence Overcurrent Element (50Q/67Q)

Number of Elements (Levels):	5
Operating Current:	3I2
Pickup:	1 A Model: 0.05 to 20.00 A secondary in steps of 0.01 A 5 A Model: 0.25 to 100.00 A secondary in steps of 0.01 A
Delay:	0.000 to 10.000 s in steps of 0.001 s
Timer Operation:	Integrating with user-controllable reset type
Reset Type:	Delayed or instantaneous (common to all 50/67 timers)
Reset Delay:	0.000 to 0.200 s in steps of 0.001 s (common to all 50/67 timers); the time does not integrate down but holds during the reset delay time
Directionality:	Selectable forward or reverse, or implemented by using a torque-control SELOGIC equation
Torque Control:	Configurable through a SELOGIC equation
Pickup Time:	<1.25 cycle
Transient Overreach:	<10%

Instantaneous and Definite-Time Phase Overcurrent Element (50P/67P)

Number of Elements (Levels):	5
Operation:	Phase-segregated pickup with common torque control and timer
Pickup:	1 A Model: 0.05 to 20.00 A secondary in steps of 0.01 A 5 A Model: 0.25 to 100.00 A secondary in steps of 0.01 A
Delay:	0.000 to 10.000 s in steps of 0.001 s
Timer Operation:	Integrating with user-controllable reset type
Reset Type:	Delayed or instantaneous (common to all 50/67 timers)
Reset Delay:	0.000 to 0.200 s in steps of 0.001 s (common to all 50/67 timers); the time does not integrate down but holds during the reset delay time
Directionality:	Selectable forward or reverse, or implemented by using a torque-control SELOGIC equation
Torque Control:	Configurable through a SELOGIC equation
Pickup Time:	<1.25 cycle; see *Figure 27*
Transient Overreach:	<10%

Inverse-Time Zero-Sequence Overcurrent Element (51G)

Number of Elements (Levels):	3
Operating Current:	3I0
Pickup:	1 A Model: 0.05 to 3.20 A secondary in steps of 0.01 A 5 A Model: 0.25 to 16.00 A secondary in steps of 0.01 A
Hysteresis:	Fixed, 5%
Curve:	ANSI (SEL designed as U1–U5) IEEE (SEL designed as E1–E3) IEC (SEL designed as C1–C5)
Time Dial:	0.10–15.00 for U1–U5 and E1–E3 0.05–1.00 for C1–C5 in steps of 0.01
Minimum Delay:	0.000 to 10.000 s in steps of 0.001 s
Directionality:	Selectable forward or reverse, or implemented by using a torque-control SELOGIC equation
Torque Control:	Configurable through a SELOGIC equation
Emulating EM Reset:	Y, N
Pickup Time:	<1.25 cycle

Inverse-Time Negative-Sequence Overcurrent Element (51Q)

Number of Elements (Levels):	3
Operating Current:	3I2
Pickup:	1 A Model: 0.05 to 3.20 A secondary in steps of 0.01 A 5 A Model: 0.25 to 16.00 A secondary in steps of 0.01 A
Hysteresis:	Fixed, 5%
Curve:	ANSI (SEL designed as U1–U5) IEEE (SEL designed as E1–E3) IEC (SEL designed as C1–C5)
Time Dial:	0.10–15.00 for U1–U5 and E1–E3 0.05–1.00 for C1–C5 in steps of 0.01
Minimum Delay:	0.000 to 10.000 s in steps of 0.001 s
Directionality:	Selectable forward or reverse, or implemented by using a torque-control SELOGIC equation
Torque Control:	Configurable through a SELOGIC equation
Emulating EM Reset:	Y, N
Pickup Time:	<1.25 cycle

Inverse-Time Phase Overcurrent Element (51P)

Number of Elements (Levels):	3
Operation:	Phase-segregated with independent timing per phase
Pickup:	1 A Model: 0.05 to 3.20 A secondary in steps of 0.01 A 5 A Model: 0.25 to 16.00 A secondary in steps of 0.01 A
Hysteresis:	Fixed, 5%
Curve:	ANSI (SEL designed as U1–U5) IEEE (SEL designed as E1–E3) IEC (SEL designed as C1–C5)
Time Dial:	0.10–15.00 for U1–U5 and E1–E3 0.05–1.00 for C1–C5 in steps of 0.01
Minimum Delay:	0.000 to 10.000 s in steps of 0.001 s
Directionality:	Selectable forward or reverse, or implemented by using a torque-control SELOGIC equation
Torque Control:	Configurable through a SELOGIC equation
Emulating EM Reset:	Y, N
Pickup Time:	<1.25 cycle

Instantaneous and Definite-Time Phase Undervoltage Element (27P)

Number of Elements (Levels):	2
Operation:	Phase-segregated pickup with common torque control and timer
Operating Voltage:	Phase-to-neutral
Pickup:	OFF, 2.00 to 175.00 V secondary in steps of 0.01 V
Delay:	0.000 to 10.000 s in steps of 0.001 s
Timer Operation:	Integrating with user-controllable reset type
Reset Type:	Delayed or instantaneous (common to all 27/59 timers)
Reset Delay:	0.000 to 0.200 s in steps of 0.001 s (common to all 27/59 timers); the time does not integrate down but holds during the reset delay time
Torque Control:	Configurable through a SELOGIC equation
Pickup Time:	<1.25 cycle

Instantaneous and Definite-Time Phase-to-Phase Undervoltage Element (27PP)

Number of Elements (Levels):	2
Operation:	Phase-segregated pickup with common torque control and timer
Operating Voltage:	Phase-to-phase
Pickup:	OFF, 2.00 to 300.00 V secondary in steps of 0.01 V
Delay:	0.000 to 10.000 s in steps of 0.001 s
Timer Operation:	Integrating with user-controllable reset type
Reset Type:	Delayed or instantaneous (common to all 27/59 timers)
Reset Delay:	0.000 to 0.200 s in steps of 0.001 s (common to all 27/59 timers); the time does not integrate down but holds during the reset delay time
Torque Control:	Configurable through a SELOGIC equation
Pickup Time:	<1.25 cycle

Instantaneous and Definite-Time Positive-Sequence Undervoltage Element (27PS)

Number of Elements (Levels):	2
Operating Voltage:	Positive-sequence
Pickup:	OFF, 2.00 to 175.00 V secondary in steps of 0.01 V
Delay:	0.000 to 10.000 s in steps of 0.001 s
Timer Operation:	Integrating with user-controllable reset type
Reset Type:	Delayed or instantaneous (common to all 27/59 timers)
Reset Delay:	0.000 to 0.200 s in steps of 0.001 s (common to all 27/59 timers); the time does not integrate down but holds during the reset delay time
Torque Control:	Configurable through a SELOGIC equation
Pickup Time:	<1.25 cycle

Instantaneous and Definite-Time Phase Overvoltage Element (59P)

Number of Elements (Levels): 2

Operation: Phase-segregated pickup with common torque control and timer

Operating Voltage: Phase-to-neutral

Pickup: OFF, 2.00 to 175.00 V secondary in steps of 0.01 V

Delay: 0.000 to 10.000 s in steps of 0.001 s

Timer Operation: Integrating with user-controllable reset type

Reset Type: Delayed or instantaneous (common to all 27/59 timers)

Reset Delay: 0.000 to 0.200 s in steps of 0.001 s (common to all 27/59 timers); the time does not integrate down but holds during the reset delay time

Torque Control: Configurable through a SELOGIC equation

Pickup Time: <1.25 cycle

Instantaneous and Definite-Time Phase Overvoltage Element (59PP)

Number of Elements (Levels): 2

Operation: Phase-segregated pickup with common torque control and timer

Operating Voltage: Phase-to-phase

Pickup: OFF, 2.00 to 300.00 V secondary in steps of 0.01 V

Delay: 0.000 to 10.000 s in steps of 0.001 s

Timer Operation: Integrating with user-controllable reset type

Reset Type: Delayed or instantaneous (common to all 27/59 timers)

Reset Delay: 0.000 to 0.200 s in steps of 0.001 s (common to all 27/59 timers); the time does not integrate down but holds during the reset delay time

Torque Control: Configurable through a SELOGIC equation

Pickup Time: <1.25 cycle

Instantaneous and Definite-Time Positive-Sequence Overvoltage Element (59PS)

Number of Elements (Levels): 2

Operating Voltage: Positive-sequence

Pickup: OFF, 2.00 to 175.00 V secondary in steps of 0.01 V

Delay: 0.000 to 10.000 s in steps of 0.001 s

Timer Operation: Integrating with user-controllable reset type

Reset Type: Delayed or instantaneous (common to all 27/59 timers)

Reset Delay: 0.000 to 0.200 s in steps of 0.001 s (common to all 27/59 timers); the time does not integrate down but holds during the reset delay time

Torque Control: Configurable through a SELOGIC equation

Pickup Time: <1.25 cycle

Instantaneous and Definite-Time Zero-Sequence Overvoltage Element (59G)

Number of Elements (Levels): 2

Operating Voltage: 3V0

Pickup: OFF, 2.00 to 300.00 V secondary in steps of 0.01 V

Delay: 0.000 to 10.000 s in steps of 0.001 s

Timer Operation: Integrating with user-controllable reset type

Reset Type: Delayed or instantaneous (common to all 27/59 timers)

Reset Delay: 0.000 to 0.200 s in steps of 0.001 s (common to all 27/59 timers); the time does not integrate down but holds during the reset delay time

Torque Control: Configurable through a SELOGIC equation

Pickup Time: <1.25 cycle

Instantaneous and Definite-Time Negative-Sequence Overvoltage Element (59Q)

Number of Elements (Levels): 2

Operating Voltage: 3V2

Pickup: OFF, 2.00 to 300.00 V secondary in steps of 0.01 V

Delay: 0.000 to 10.000 s in steps of 0.001 s

Timer Operation: Integrating with user-controllable reset type

Reset Type: Delayed or instantaneous (common to all 27/59 timers)

Reset Delay: 0.000 to 0.200 s in steps of 0.001 s (common to all 27/59 timers); the time does not integrate down but holds during the reset delay time

Torque Control: Configurable through a SELOGIC equation

Pickup Time: <1.25 cycle

Switch-Onto-Fault Logic (SOTF)

Initiation: Breaker close command or auto-initiation by using 52a contacts

Minimum Open-Pole Duration to Arm: 0.000 to 10.000 s in steps of 0.001 s

Permission Window: 0.008 to 10.000 s in steps of 0.001 s

Fault-Detection Condition: Configurable through a SELOGIC equation

Voltage Reset: Positive-sequence voltage

Voltage Reset Threshold: 30 to 160 V secondary in steps of 1 V

Directional Comparison Schemes (POTT and DCB)

Principle of Operation: Selectable as DCB or POTT

Forward Fault Condition: Selectable TD32, TW32, and Zone 2 ZP and ZG, and Level 2 67P, 67G, and 67Q

Reverse Fault Condition: Nonselectable; matches the forward fault condition

Reverse Zone/Level: 3, 4, or 5

TW32-Based POTT Key: Permitted; uses a separate pilot signal

Number of Pilot Signals: One or multiple phase-segregated bits, TW32 element keys separately

Pilot Signal Interfaces: SEL MIRRORED BITS I/O (MB8 or IEEE C37.94 encoding), contact I/O

Pilot Signal Redundancy and Security: Permitted using SELOGIC equations

Number of Line Terminals: Unlimited, subject only to the relay I/O count

Current Reversal Blocking Pickup Delay: 0.0–20.0 ms in steps of 0.1 ms

Current Reversal Blocking Dropout Delay: 0.0–100.0 ms in steps of 0.1 ms

DCB Coordination Timer Pickup Delay: 0.0–1,000.0 ms in steps of 0.1 ms

DCB Received Blocking Signal Extension Time:	0.0–1,000.0 ms in steps of 0.1 ms
DCB Received Blocking Signal Extension Time Multiplier:	1.0–10.0 in steps of 0.1
Weak-Infeed Echo:	Included, request to echo programmable as a SELOGIC equation
Weak-Infeed Voltage Condition:	OFF, Selectable Level 2 27P, 59G, and 59Q
Weak-Infeed Tripping:	Included
Open-Breaker Echo Logic:	Included, open breaker condition programmable as a SELOGIC equation

Direct Transfer Trip (DTT)

Principle of Operation:	Tripping remote breaker(s) upon tripping the local breaker(s)
DTT Supervisory Condition (Sending Relay):	SELOGIC equation
DTT Supervisory Condition (Receiving Relay):	Disturbance detector or 10 ms time delay, whichever asserts first
Number of Pilot Signals:	One or multiple phase-segregated
Pilot Signal Interfaces:	SEL MIRRORED BITS I/O (MB8 or IEEE C37.94 encoding), contact I/O
Pilot Signal Redundancy and Security:	Permitted using SELOGIC equations
Number of Line Terminals:	Unlimited, subject only to the relay I/O count

Trip Logic

Trip Condition:	SELOGIC equation
Trip Signal Seal-In Logic:	Included
Minimum Trip Signal Duration Timer:	100–1000 ms in steps of 1 ms
Number of Breakers:	1 or 2
Trip Mode:	Single-pole or three-pole
Single-Pole Tripping Elements and Schemes:	TW87, TD21, Z1, ZG1T, ZG2T, 67P, 67Q, POTT, DCB, DTT
Single-Pole Trip Conversion to Three-Pole Trip:	SELOGIC equations on a per-breaker basis

SELOGIC Equations, Latches, and Timers

Equations

Number of Equations:	64

Note: Torque-control inputs, output actuation, timers, latches, and other relevant settings have their own separate equations.

Logical Operations:	AND, OR, NOT, rising edge, falling edge
Number of Inputs:	Up to 15
Parentheses:	Up to 14
Length Limit:	511 characters

Latches

Number of Latches:	16
Operation:	Reset-dominant, nonvolatile
Set and Reset Inputs:	Dedicated equations

Timers

Number of Timers:	16
Pickup Time:	0.0 to 60,000.0 ms in steps of 0.1 ms
Dropout Time:	0.0 to 60,000.0 ms in steps of 0.1 ms
Timing Accuracy:	±(0.2 ms or 1% of the setting, whichever is greater)
Inputs:	Dedicated equations

Local Control Bits

Number of Bits:	32
Operation:	Set and reset
Name:	Text string up to 13 characters long
Storage:	Nonvolatile memory
Access:	Front-panel HMI, two-step method with acknowledgment
Access Protection:	SELOGIC equation

Remote Control Bits

Number of Bits:	32
Operation:	Set, clear, and pulse
Storage:	Nonvolatile memory
Access:	DNP3, SEL Fast Operate, SEL ASCII command
Access Protection:	Protocol enable settings; Access Level B or 2 for SEL ASCII command

Monitoring Functions

Open-Pole Logic

Number of Breakers:	1 or 2
Breaker Operation:	Single-pole or three-pole (per breaker)
Principle of Operation:	Current with 52a position (per breaker) or current with voltage supervision
52a Inputs:	Dedicated SELOGIC equations, including contact inputs and MIRRORED BITS inputs
Current Selection:	IW, IX, or COMB (combined)
Undervoltage Pickup:	1 to 200 V secondary in steps of 1 V
Security Dropout Timer:	0.000 to 1.000 s in steps of 0.001 s

Adaptive Autoreclose Control

Operation:	Asserts an autoreclose cancel signal for user-settable line sections based on fault location obtained from the double-ended traveling-wave fault-locating method
Channel Requirements:	Direct fiber-optic on Port 6 or IEEE C37.94 channel on user-selectable Port 1, 2, or 3 with a high-accuracy clock at both line terminals and channel latency less than 30 ms
Number of Autoreclose Blocking Regions:	2
Default Output if Fault Locating Fails:	Cancel or allow reclosing (user-selectable)

Line Monitor

Operation:	Detects, locates, tabulates, and alarms on fault precursors. Provides blocking regions for line taps with load or generation, or in-line series capacitors. Tabulates and alarms for total line events outside the blocking regions and for daily event counts within the blocking regions
Channel Requirements:	Direct fiber-optic on Port 6 or IEEE C37.94 channel on user-selectable Port 1, 2, or 3 with a high-accuracy clock at both line terminals and channel latency less than 30 ms
Triggering Mechanism:	Low-energy events only, faults only, low-energy events and faults (user-selectable)
Sensitivity	
Current TWs:	Greater than 2% of peak nominal current
Voltage TWs:	Greater than 1% of peak nominal voltage
Location Resolution:	0.25 mi or km

Counter Range per Location:	0–255 (counting stops at 255)
Number of Line Monitoring Blocking Regions:	2
Alarm Threshold:	1–200
Data Presentation:	A text file with tabulated event location and count, alarm bits, and alarm locations available over SCADA protocols

Metering Accuracy

All metering specifications apply at 20°C and nominal frequency unless otherwise noted.

Current (Local)

Phase Current Magnitude:	±0.2% plus ±0.001 • Inom (0.05 • Inom – 3 • Inom)
Phase Current Angle:	±1° (0.05 • Inom – 0.2 • Inom) ±0.2° (0.2 • Inom – 3 • Inom)
Sequence Current Magnitude:	±0.3% plus ±0.001• Inom (0.05 • Inom – 3 • Inom)
Sequence Current Angle:	±1.5° (0.05 • Inom – 0.2 • Inom) ±0.3° (0.2 • Inom – 3 • Inom)

Voltage

Phase Voltage Magnitude:	±0.2% (5–175 V_{LN})
Phase Voltage Angle:	±0.2° (5–175 V_{LN})
Sequence Voltage Magnitude:	±0.3% (5–175 V_{LN})
Sequence Voltage Angle:	±0.3° (5–175 V_{LN})

Frequency (Input 5–175 V_{LN}, 40–70 Hz)

Accuracy:	±0.001 Hz

Built-In Testing Functions

Loopback Mode for Protection Signaling Ports 1, 2, and 3

Purpose:	Troubleshoot a teleprotection channel by allowing the relay to receive its own packets while passing the received teleprotection bits to the downstream logic or substituting them with fail-safe values
Initiation:	SEL ASCII command
Annunciation:	Relay Word bit
Security:	Access Level 2 and time-out

Traveling-Wave Test Mode

Purpose:	Test the TW87 scheme by using only high-frequency signals, without the presence of fundamental frequency components in currents or voltages
Initiation:	SEL ASCII command
Annunciation:	Front-panel LED, Relay Word bit, Alarm output
Security:	Access Level 2 and confirmation of the initiating command on the front panel; time-out

Event Playback

Purpose:	Test protection and fault-locating functions by substituting – in real time –samples from the analog-to-digital converter, with values from relay memory (e.g., playing back transient records)
Test File Format:	SEL playback file (.ply)
File Conversion:	Playback File Conversion Utility in QuickSet converts compliant IEEE C37.111 COMTRADE files into the SEL-T401L-compatible SEL playback file
Test Record Sampling Rate:	1 MHz, with the conversion software utility accepting and resampling files recorded or simulated at a fixed sampling rate of 1, 2, 4, 8, or 10 kHz or 1, 2, 3, 4, or 5 MHz
Test File Storage:	As many as five files in addition to storage for relay records
Test Record Duration:	0.1–1.2 s
Pre-Event Steady-State:	Pre-event steady-state emulation by looping the first cycle in the test file for 1 s; requires at least 50 ms of pre-event steady-state data in the input test record
Test Trigger:	Ad hoc or time-based (scheduled and synchronized to absolute time for end-to-end testing)
Front-End Circuitry:	Playback File Conversion Utility optionally models the SEL-T401L analog anti-aliasing filters
Initiation:	SEL ASCII command or Event Playback Test Dashboard in QuickSet
Annunciation:	Front-panel HMI message, Relay Word bit, Alarm output
Security:	Access Level 2 and confirmation of the initiating command on the front panel; time-out

Technical Support

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

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