SEL-400G Advanced Generator Protection System

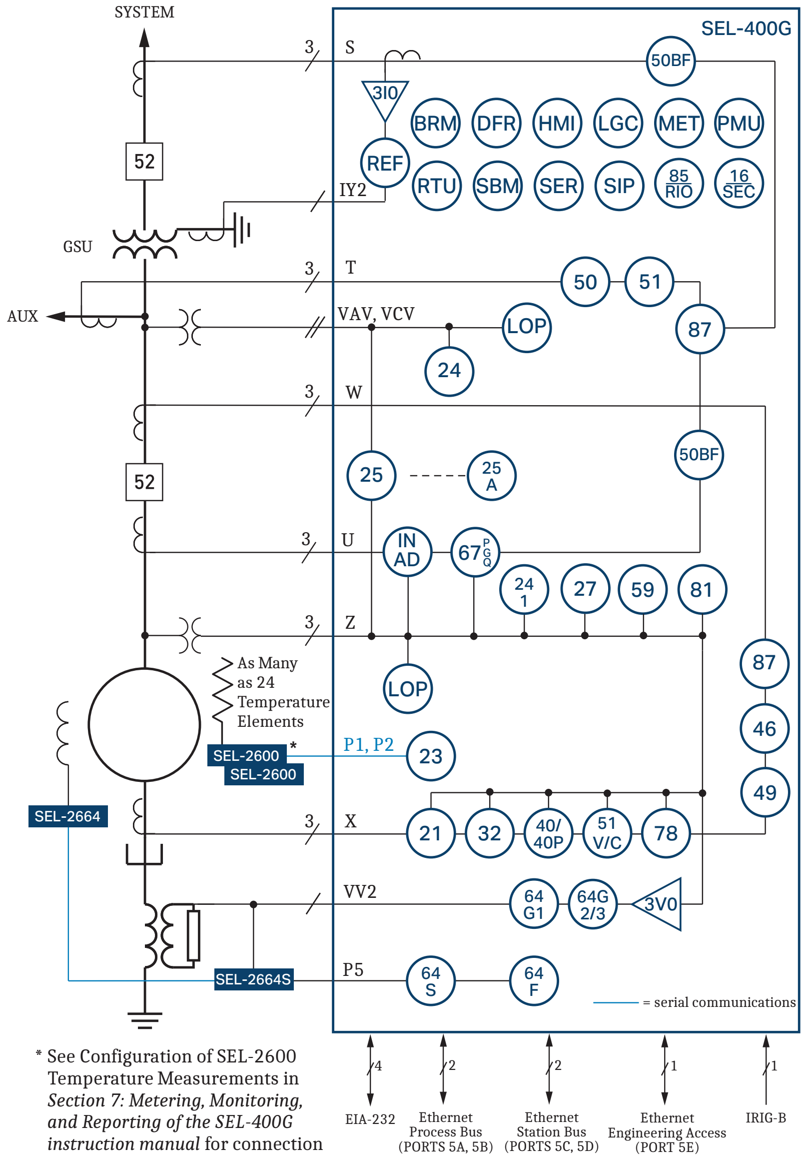
Advanced Generator Protection System

Key Features and Benefits

The SEL-400G Advanced Generator Protection System offers unsurpassed protection, integration, control, and monitoring features for all types of generators including hydro, pumped-storage hydro, large steam turbines, and combustion gas turbines (CGTs).

- ➤ Protect generators and step-up transformers in a single device with two independent universal differential zones.
- ➤ Provide protection during generator startup with two independent frequency zones with frequency tracking from 5 Hz to 120 Hz.
- ➤ Increase machine life with advanced generator monitoring capabilities such as turn-to-turn fault detection to detect faults and abnormal conditions before they cause permanent damage.
- ➤ Reduce complexity for pumped storage generation with internal relay logic that eliminates the need for external switching.
- ➤ Implement comprehensive protection schemes for generator and auxiliary systems with 18 current and 6 voltage inputs.
- ➤ Design, deploy, and commission relay settings with ease using SEL Grid Configurator.

Functional Overview



* See Configuration of SEL-2600 Temperature Measurements in *Section 7: Metering, Monitoring, and Reporting of the SEL-400G instruction manual* for connection details.

ANSI NUMBERS/ACRONYMS AND FUNCTIONS	
21	Phase Distance
23	RTD Temperature—SEL-2600
24	Volts/Hertz
25	Synchronism Check
25A	Autosynchronizer
27	Undervoltage
32	Directional Power
40	Loss of Field
40P	Capability-Based Loss of Field
46	Current Unbalance
49	IEC 60255-Compliant Thermal Model
50BF	Breaker Failure Overcurrent
50N	Neutral Overcurrent
50 (P, G, Q)	Overcurrent (Phase, Ground, Neg. Seq.)
51C	Voltage-Controlled Inverse-Time Overcurrent
51N	Neutral Time-Overcurrent
51 (P, G, Q)	Time-Overcurrent (Phase, Ground, Neg. Seq.)
51V	Voltage-Restrained Inverse-Time Overcurrent
59	Overvoltage
64G1	Stator Ground (Fundamental Neutral Overvoltage)
64G2	Third-Harmonic Difference/Undervoltage
64G3	Third-Harmonic Ratio
64F	Rotor Ground—SEL 2664
64S	Stator Ground (Subharmonic Injection)—SEL 2664S
67 (P, G, Q)	Directional Overcurrent (Phase, Ground, Neg. Seq.)
78	Out-of-Step
81 (O, U)	Over- and Underfrequency
81A	Accumulated Frequency
81R (O, U)	Over- and Under-Rate-of-Change-of-Frequency
85 RIO	SEL MIRRORED BITS Communications
87 (U, R, Q)	Universal Differential (Unrestrained, Restrained, Neg. Seq.)
DFR	Event and Disturbance Reports
HMI	Operator Interface
INAD	Inadvertent Energization
LGC	Expanded SELOGIC Control Equations
LOP	Loss of Potential
MET	High-Accuracy Metering
PMU	Synchrophasors
REF	Restricted Earth Fault
RTU	Remote Terminal Unit
SER	Sequential Events Recorder

ADDITIONAL FUNCTIONS	
16 SEC	Access Security (Serial, Ethernet)
BRM	Breaker Wear Monitor
LDP	Load Data Profiling
SBM	Station Battery Monitor
SIP	Software-Invertible Polarities

Five-port Ethernet card ordering option depicted.

Figure 1 Functional Diagram

Features

- **Current and Voltage Inputs.** With 18 CT inputs and 6 PT inputs, the SEL-400G provides protection for generators ranging in size from small to large, and protection schemes ranging from simple to complex.
- **Universal Differential Protection (87Z).** The SEL-400G supports two independent universal differential elements that can provide fast, sensitive, and secure protection for as many as two independent protection zones.
- **Stator Winding Ground Fault Protection (64G/ 64S).** The SEL-400G offers passive and active methods for detecting ground faults across 100 percent of the stator winding without sacrificing security.
- **Field Winding Ground Fault Protection (64F).** The SEL-400G, when used in conjunction with the SEL-2664 Field Ground Module, can provide field winding ground fault protection. The element can be configured to provide either an alarm or trip functions for the first field winding to ground fault.

- **Restricted Earth fault Protection (REF).** The SEL-400G provides three REF elements that can provide fast, sensitive, and secure ground fault protection for a low impedance-grounded generator or for the wye winding of a generator step-up (GSU).
- **Stator Winding Turn-to-Turn Fault Protection (60P/60N).** The SEL-400G provides two sensitive split-phase protection elements that can turn-to-turn fault protection for multibranch hydro machines. The elements can adapt to standing current offset and secure for external faults.
- **Pumped Storage Logic.** The SEL-400G internally corrects the phasing introduced by the reversing switch.
- **Extended Range Frequency Tracking of 5–120 Hz.** The SEL-400G wide-range frequency tracking algorithm ensures that all protection functions are secure and dependable regardless of the frequency. The SEL-400G also independently tracks the generator and system frequencies.
- **Loss-of-Field Protection (40).** The SEL-400G offers two impedance-based loss-of-field (LOF) schemes and a generator capability-based LOF scheme to protect the generator during a LOF event.
- **Current Unbalance Protection (46).** The SEL-400G provides two negative-sequence overcurrent elements for generator current unbalance protection. Each element provides two levels, one definite and one inverse-time. Each element can be configured to operate on fundamental or harmonic negative-sequence current.
- **Overexcitation Protection (24).** The SEL-400G provides two volts-per-hertz elements that can provide overexcitation protection for both generator and GSU. Each element provides two levels of definite-time and two user-defined inverse time curves.
- **Inadvertent Energization Protection (INAD).** The SEL-400G provides as many as four inadvertent energization elements that arm themselves when the generator is taken offline and protect the generator from inadvertent energization.
- **Directional Power Protection (32).** The SEL-400G provides four sensitive directional power elements with independent time delays. Additionally, the SEL-400G provides a biased characteristic that ensures both security and dependability.
- **Out-of-Step Protection (78).** The SEL-400G provides two out-of-step (OOS) protection schemes: single or double blinder. The SEL-400G also includes a pole slip counter (PSC) that counts the number of pole slips a generator experienced during an OOS condition.
- **Over- and Underfrequency Protection (81).** The SEL-400G provides six levels of over- or underfrequency protection with undervoltage supervision. The protection can be configured for two independent frequency zones (generator and power system zone).
- **Rate-of-Change-of-Frequency Protection (81R).** The SEL-400G provides six levels of over- or under-rate-of change-of-frequency protection with undervoltage supervision. The protection can be configured for two independent frequency zones (generator and power system zone).
- **Frequency Accumulation Protection (81A).** The SEL-400G provides frequency accumulation protection by measuring the time-of-operation in as many as eight frequency bands. The relay also supports continuous bands.
- **Thermal Overload Protection (49).** The SEL-400G provides three independent general-purpose thermal elements that conform to IEC 60255-149 standard.
- **Breaker Failure Protection (50BF).** The SEL-400G provides high-speed breaker failure for as many as four circuit breakers. The logic is immune to subsidence current and complimented with breaker flashover detection logic.
- **System Backup Protection.** The SEL-400G provides phase distance (21P) elements, voltage-controlled time-overcurrent (51C) elements, and voltage-restrained time-overcurrent (51V) elements for system backup protection.
- **Synchronism Check (25).** The SEL-400G provides a synchronism-check function for as many as three breakers. The function provides supervision for acceptable voltage window and maximum percentage difference, maximum and minimum allowable slip frequency, target closing angle, and breaker closing delay.
- **Autosynchronizer (25A).** The SEL-400G provides comprehensive automatic synchronization control of governor and voltage regulators for as many as three breakers through use of pulse width modulated contact outputs.
- **Loss of Potential (60).** The SEL-400G provides loss-of-potential (LOP) elements for the V and Z terminals.
- **Synchrophasors.** The SEL-400G provides synchrophasor measurement of all 18 currents and 6 voltage channels. The relay complies with IEC/IEEE 60255-118-1:2018 (IEEE C37.118.1-2011, -2014a) and supports as many as five unique synchrophasor data streams that are compliant with IEEE C37.118.2-2011 via serial or Ethernet communications ports. The relay can record Synchrophasor data for as long as 120 seconds based on user-settable triggers.

- **Digital Relay-to-Relay Communications.** Use MIRRORED BITS® communications to monitor internal element conditions among relays within a station, or among stations, by using SEL fiber-optic transceivers. Send digital, analog, and virtual terminal data over the same MIRRORED BITS channel. Receive synchrophasor data from as many as two other devices transmitting IEEE C37.118 format synchrophasors at rates as fast as 60 messages per second.
- **Automation.** Take advantage of enhanced automation features that include programmable elements for local control, remote control, protection latching, and automation latching.
- **Comprehensive Metering.** Use full metering capabilities of the SEL-400G that include fundamental, rms, harmonics, maximum/minimum, demand/peak, energy, differential, station battery, temperature, sync check, and synchrophasor.
- **Breaker and Battery Monitoring.** The SEL-400G provides breaker monitoring for as many as four breakers. It records electrical and mechanical operating times for both the last operation and the average of operations since function reset. Battery monitoring provides notification of substation battery voltage problems using voltage dip detection during trip or close operations.
- **Comprehensive Temperature Monitoring (23).** When the SEL-400G is used in conjunction with the SEL-2600 RTD Module and/or SEL-2411 Programmable Automation Controller, as many as 24 temperature measurements over serial and 24 over Ethernet are available. Each can be programmed for two levels of thermal protection per element.
- **Ethernet Access.** Access all relay functions with the optional Ethernet card. Use IEC 61850, Modbus TCP, or DNP3 protocol directly to interconnect with automation systems. Use File Transfer Protocol (FTP) for high-speed data collection. Connect to substation or corporate LANs to transmit synchrophasors in the IEEE C37.118.2-2011 format, using TCP or UDP internet protocols.
- **Oscillography.** The SEL-400G provides high-resolution events that record unfiltered voltages and currents at sampling rates as high as 8 kHz with time-stamp accuracy of one microsecond. The SEL-400G also provides low-resolution events that record filtered voltages, currents, and other processed analogs and digitals at 400 Hz for as long as 24 seconds. The SEL-400G also provides integrated disturbance recorder that can record 20 analog and 800 digital channels at 50 Hz for as long as 300 seconds.
- **Sequential Events Recorder (SER).** Record the last 1000 entries, including setting changes, relay start-up, password access, and as many as 250 selectable logic elements.
- **Rules-Based Settings Editor.** Use an ASCII terminal to communicate and set the relay, or use the PC-based SEL Grid Configurator software to configure the SEL-400G, view a replica of the relay front-panel HMI, analyze fault records with relay element response, and view real-time phasors and harmonic levels.

SEL-400G Relay Applications

Steam Turbine Generator

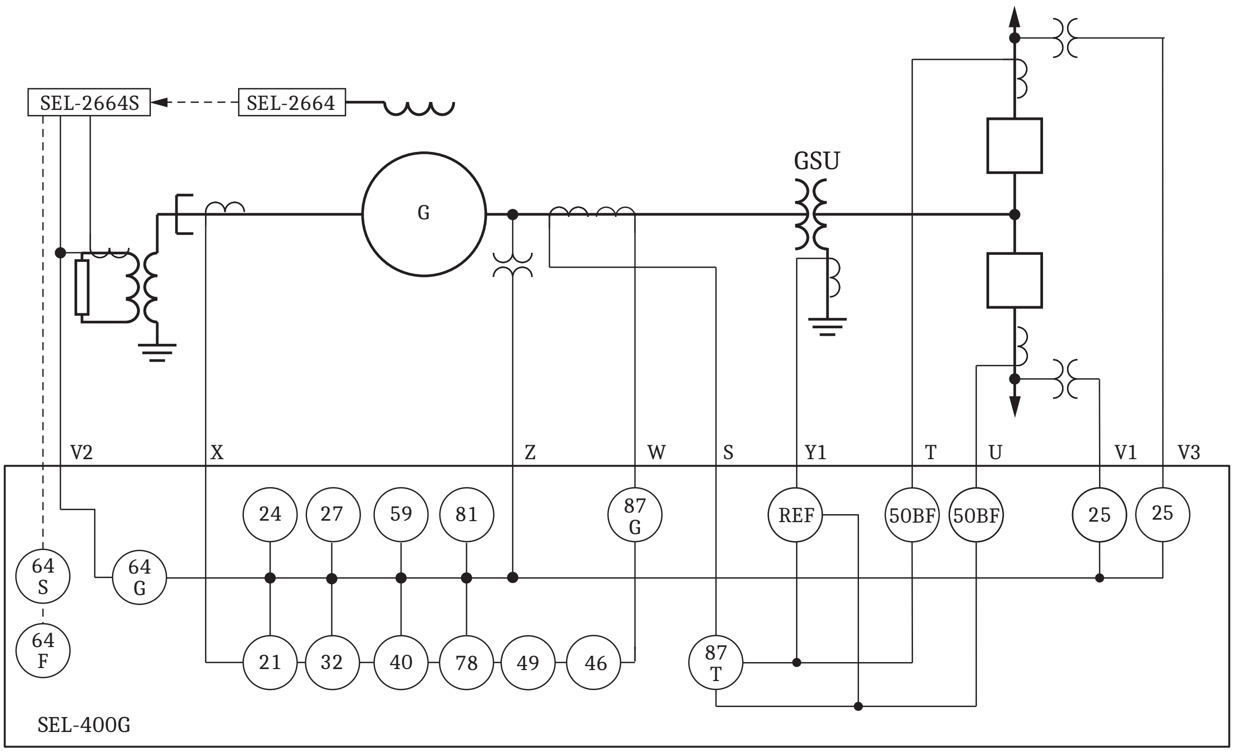


Figure 2 Steam Turbine Generator

Hydro Turbine Generator

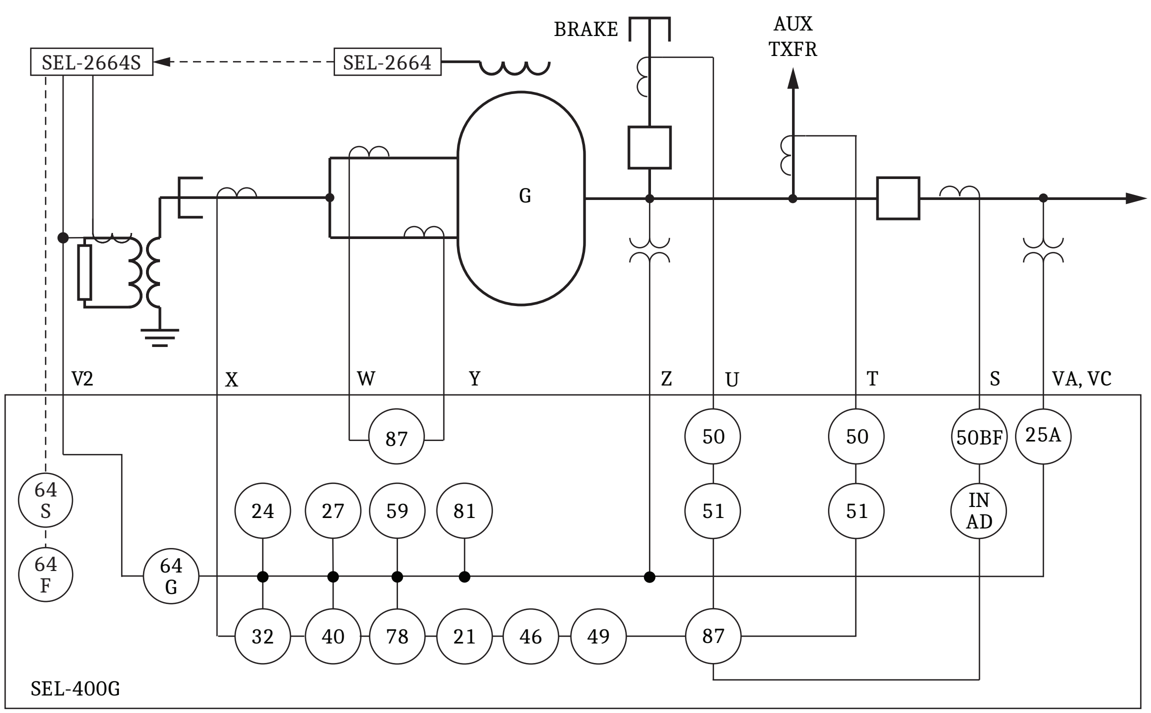


Figure 3 Hydro Turbine Generator

Combustion Gas Turbine Generator

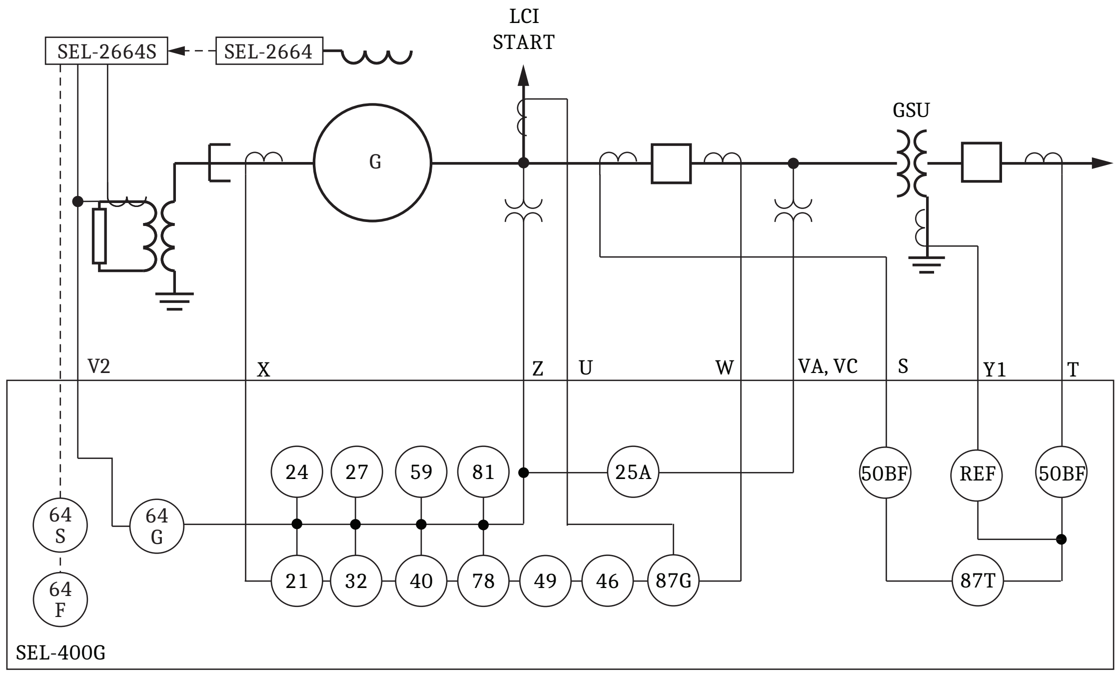


Figure 4 Combustion Gas Turbine Generator

Protection Features

Universal Differential Element (87)

The SEL-400G universal differential element provides current differential protection for either a generator or a transformer.

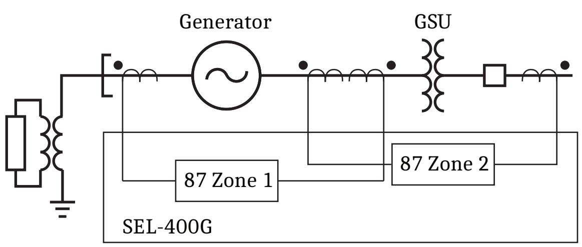


Figure 5 Two Universal Differential Elements (87) Enable Differential Protection for Both the Generator and the GSU

Alternatively, the SEL-400G can provide lateral differential protection and transverse differential protection for the overall generator.

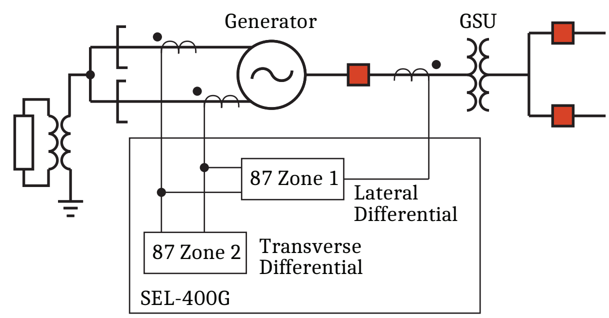


Figure 6 SEL-400G Provides Both Lateral Differential Protection and Transverse Differential Protection

The current differential element is implemented as a percentage restraint differential element with an adaptive slope. The slope of the percentage restraint differential element is controlled by the external fault detector (EFD). This allows the element to provide sensitivity for internal faults and at the same time provide security for external faults that can lead to CT saturation. *Figure 7* shows how the EFD adjusts the slope of the percentage restraint differential element.

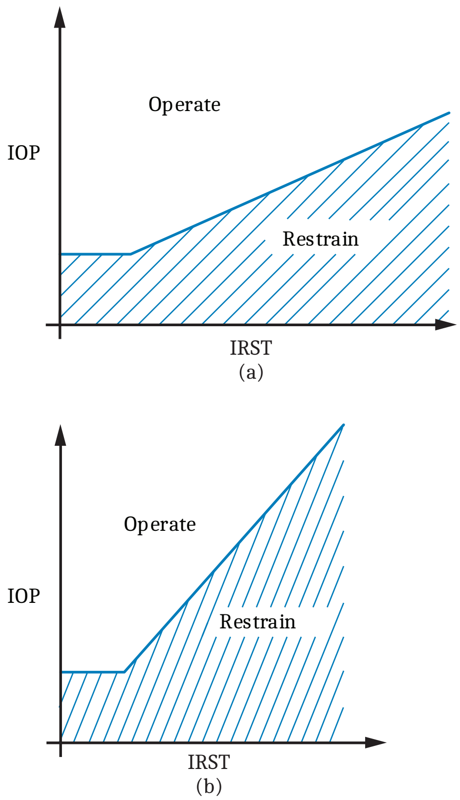


Figure 7 Dynamically Adaptive Differential Slopes in Response to Internal and External Fault

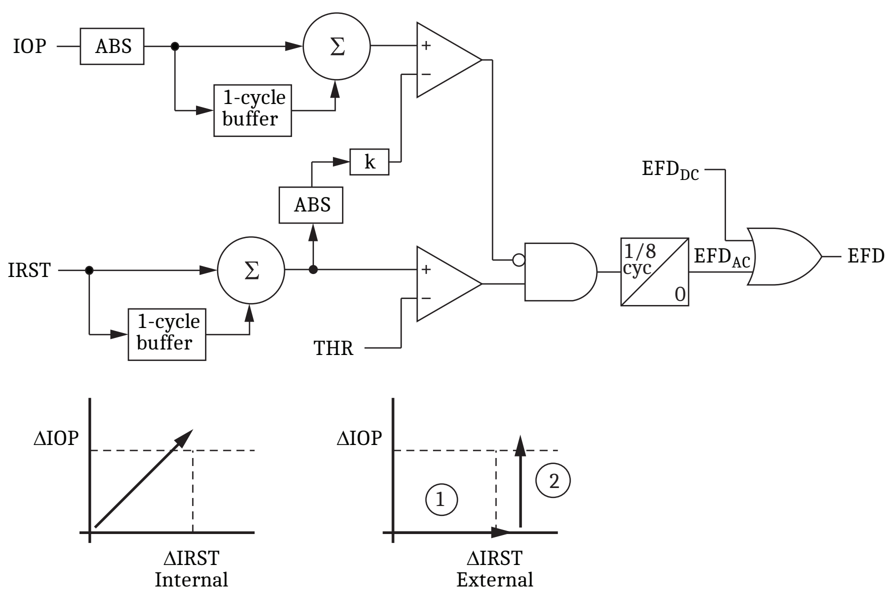


Figure 8 External AC Fault Detector Logic

If the logic detects an incremental change in the restraint current (ΔIRT) without an incremental change in the operating current (ΔIOP) within 1/8th of a power system cycle, the logic declares and external fault condition. When an external fault condition is declared the slope of the percentage differential element is increased to help secure the differential element during this external fault conditions.

The EFD switches the differential element to a more secure slope setting if one of the two following conditions is detected.

AC External Fault Detector

When a high-current fault external to the zone of protection occurs, one of the zone differential CTs can saturate very quickly (less than 1 cycle), which means that the CT will not accurately replicate the primary current and introduce errors into the differential calculation. Typically, during CT saturation, the operate current (IOP) increases and the restraint current (IRST) decreases, which challenges the security of the differential element. The ac external fault detector detects this external fault condition by comparing the incremental change in operating current against the incremental change if the restraint current. See *Figure 8*.

High DC Phase Current Detection Logic

Long lasting dc offsets such as those caused by transformer energization, line reactor energization, or slow clearing faults on power systems with a high X/R ratio can cause saturation of one of the zone differential CTs. The large dc component in the phase current results in slow saturation of the CT. If this condition goes undetected, the security of the differential element will be challenged. The high dc phase current detector logic in the SEL-400G detects this condition using the logic shown in *Figure 9*.

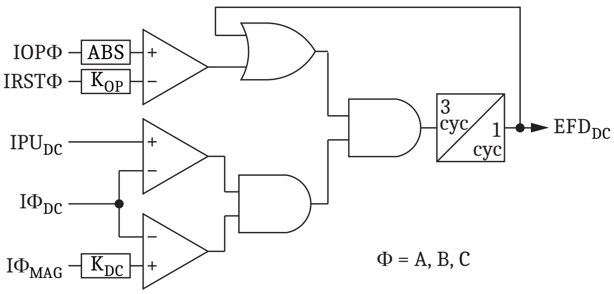


Figure 9 High DC Phase Current Detector Logic

The high dc phase current logic consists of two parts. The first part verifies that there is no fault present within the differential zone of protection by verifying that the operating current (IOPΦ) is below a fraction of the restrained current (IRSTΦ). The second part of the logic verifies that the dc component ($I\Phi_{DC}$) of the phase current is of sufficient magnitude and of a high enough ratio.

If both parts of the logic are satisfied, the logic declares a high dc phase current (EFD_{DC}) and switches the differential element into high security mode.

Stator Winding Ground Fault Protection (64G/64S)

The SEL-400G offers both passive and active methods for detecting ground faults across 100 percent of the stator winding without sacrificing security. Generator stator winding ground faults are the predominant generator faults. Because of the grounding of the generator, the magnitude of the fault current is low (typically 5–15 A), therefore, detecting these faults is generally a tradeoff between security and dependability.

- **Passive Stator Ground Fault Protection.** Neutral terminal fundamental overvoltage protection (64G1) protects approximately 5 to 100 percent of the stator winding. Third-harmonic differential voltage protection (64G2) or third-harmonic voltage ratio protection (64G3) provide protection of the stator winding from the neutral terminal to approximately 35 percent of the stator winding. Therefore, enabling the 64G1 and 64G2 or 64G3 affords protection for 100 percent of the stator winding without sacrificing security.
- **Active Stator Ground Fault Protection.** Injecting a current signal into the stator winding provides protection for 100 percent of the stator winding. The SEL-400G, in conjunction with the SEL-2664S Stator Ground Protection Relay, provides 100 percent dependable and secure stator winding protection. When the SEL-2664S is used in conjunction with the SEL-400G, it is possible to monitor the stator winding insulation resistance and capacitance to ground. This allows for the early detection of stator winding insulation failure. The major advantage of using an active stator ground fault detection method is that a stator winding ground fault can be detected when the generator is at standstill.

Most stator winding ground faults begin as arcing (intermittent) ground faults. The SEL-400G stator winding ground fault protection element includes an integrating timer that is specifically designed to detect intermittent ground faults and isolate the generator before the fault evolves into a permanent fault. Detecting a stator winding ground fault while the fault is still in the intermittent stage allows the damage to the generator to be contained.

In high-impedance grounded generators, stator ground faults in the upper 90 percent of the stator winding are detected by the 64G1 element, which measures the fundamental neutral voltage (59N) across the neutral grounding resistor of the generator. Because of the effect of the GSU interwinding capacitance, the fundamental neutral overvoltage threshold cannot be set below 10 percent of the generator terminal voltage; therefore, stator ground faults in the lower 10 percent of the stator winding (near the generator neutral) cannot be detected by the 64G1 element. To detect stator winding ground faults in the lower 10 percent of the stator winding, the third-harmonic voltages measured at the neutral and terminal of the generator are used (64G2/3). The SEL-400G offers two elements, 64G2 and 64G3, to detect ground faults in the lower 10 percent of the stator winding. The 64G2 and 64G3 elements use the fact that the ratio of the third-harmonic voltage at the terminals of the generator and the neutral of the generator under a nonfaulted condition is approximately constant. When the generator experiences a stator winding ground fault near the generator or neutral terminals, this ratio is disrupted, and the elements declare a stator winding ground fault. Therefore, as seen in *Figure 10*, combining the 64G1 and the 64G2 or 64G3 elements provide 100 percent protection for stator winding ground faults.

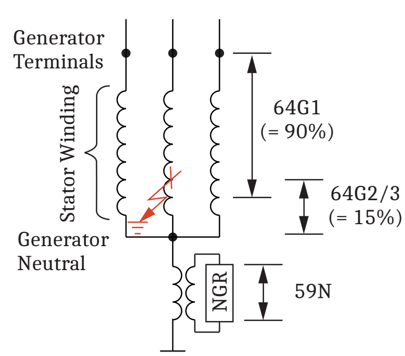


Figure 10 Combine the 64G1 and Either the 64G2 or 64G3 Element to Provide 100 Percent Protection for Stator Ground Faults

The SEL-400G also interfaces with the SEL-2664S, a stator ground protection relay. The SEL-2664S is capable of not only detecting stator winding ground faults but also monitoring the neutral grounding resistor (NGR). The SEL-2264S uses current injection to detect stator ground faults and can be applied as follows:

- ➤ Injecting current via the neutral generator resistor (NGR) when the NGR is located on the secondary side of the neutral grounding transformer (NGT), as shown in *Figure 11(a)*.
- ➤ Injecting current via the tap of the NGR with the NGR located on the secondary side of the NGT, as shown in *Figure 11(b)*.
- ➤ Injecting current via the secondary winding of a voltage transformer (VT) when the NGR is the primary of the generator neutral, as shown in *Figure 11(c)*.
- ➤ Injecting current via the tap of the NGR with the NGR located across the broken delta winding of the NGT this is typically the case when the neutral point of the generator is not earthed, as shown in *Figure 11(d)*.

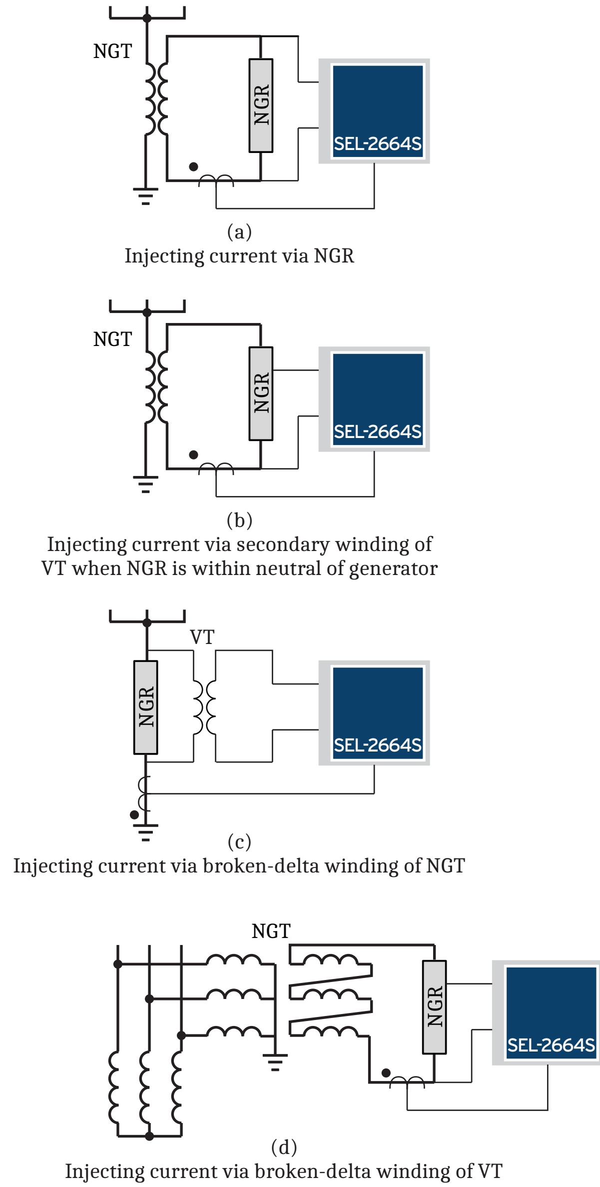


Figure 11 Application Examples of Using SEL-2664S for 100 Percent Stator Ground Fault Protection

When the SEL-400G is interfaced with the SEL-2664S, both devices can provide 100 percent stator ground fault protection independent of one another. The added benefit of using the SEL-2664S in conjunction with the SEL-400G is that the SEL-400G can record and trend the measured stator winding resistance and capacitance over time.

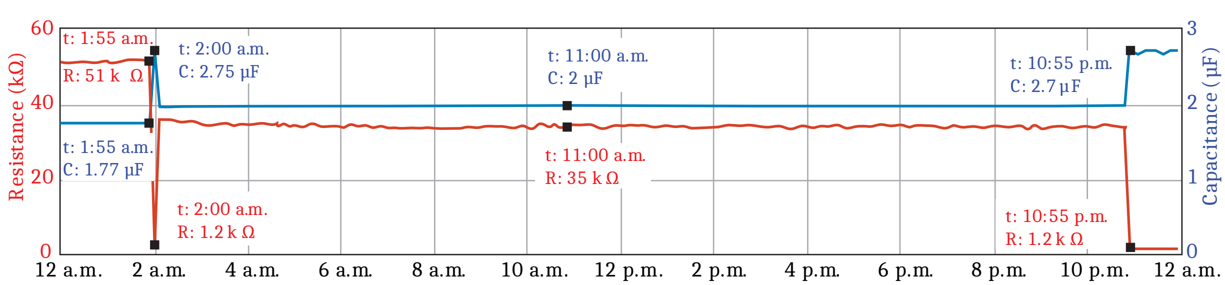


Figure 12 Stator Winding Insulation Resistance and Capacitance for 24 Hours

Field Ground Fault Protection (64F)

The first field winding-to-ground fault generally does not impact the performance of the generator. However, the second ground fault will short out part of the field winding. The field current in a large generator is considerable, and shorting out part of the field winding will divert a large part of the current and can damage the winding conductor very rapidly. Shorting out part of the field winding will create a non-symmetrical flux distribution in the generator, as shown in *Figure 13(b)*. This non-symmetrical flux distribution results in a non-symmetrical (unbalance) force within the generator

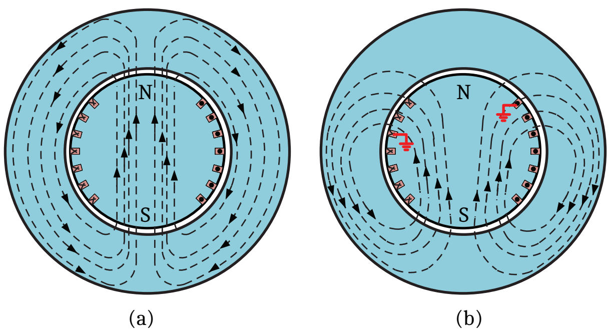


Figure 13 Flux Distribution (Symmetrical) in a Healthy Generator (a) and Flux Distribution (Non-Symmetrical) in a Generator With a Double-Rotor Ground Fault (b)

This unbalanced force rotates within the generator and can result in severe vibration (depending on the location of the second ground fault) within the generator. Therefore, it is important to detect the first field-winding-to-ground fault.

The SEL-2664 injects a low-frequency square wave voltage into the field winding of the generator and calculates the insulation resistance of the field winding. The field winding insulation resistance measured by the SEL-2664 is consumed by the field winding ground detection element (64F) in the SEL-400G. The 64F element can be configured to provide either an alarm or trip functions for the first field-winding-to-ground fault.

The SEL-400G also provides the user with the option to trend the field winding insulation resistance, allowing the user to predict when the field winding insulation resistance will reach a minimum allowable value and take the appropriate action before the generator incurs serious damage.

The SEL-400G provides rotor ground fault protection when paired with the SEL-2664. The SEL-2664 calculates the insulation resistance of the generator field winding to ground and transmits these data to the SEL-400G. The SEL-2664 can perform the insulation resistance calculation with the generator either offline or online. The SEL-2664 is connected in parallel with the exciter to the generator field winding, as shown in *Figure 14*.

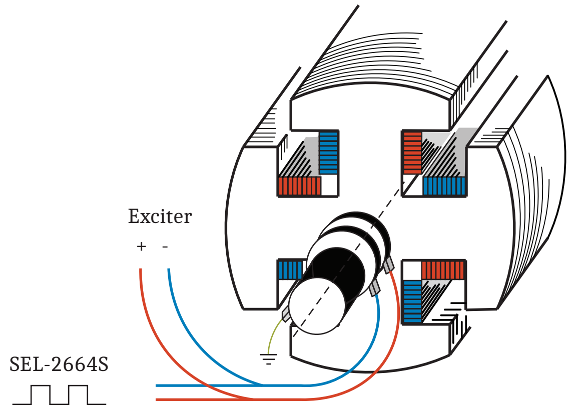


Figure 14 SEL-2664 Connected in Parallel With Generator Field Winding Exciter

The equivalent circuit of the SEL-2664 and the generator rotor field is as shown in *Figure 15(a)*. The SEL-2664 applies a pulsating voltage (V_{INJECT}) to the generator field and measures the magnitude of the voltage drop across an internal resistor to ground (R), as shown in *Figure 15(b)*. When the rotor insulation is normal or healthy, the major portion (>95 percent) of the injected voltage is dropped across the rotor insulation (V_{ROT_INS}) and very little voltage is dropped across the resistor internal (V_R) to the SEL-2664, *Figure 15(c)*. When the rotor field experience a ground fault, the major portion of the injected voltage is dropped across the internal resistor, as shown in *Figure 15(d)*.

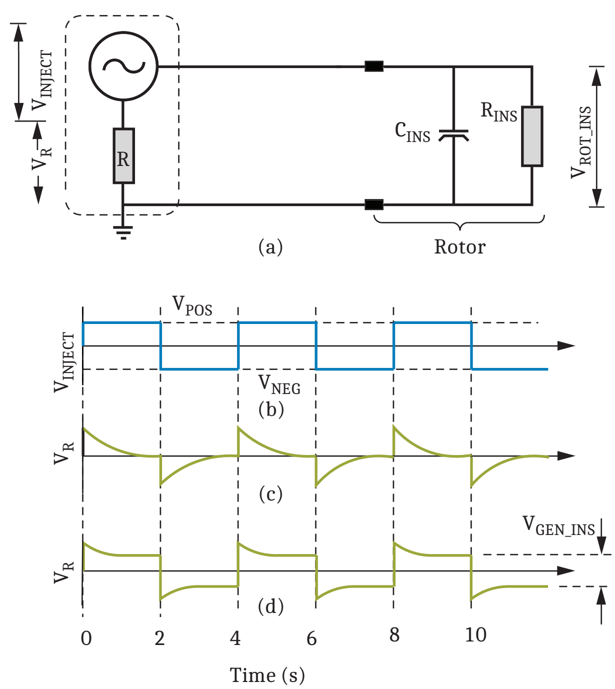


Figure 15 SEL-2664 Circuit Diagram (a); Injected Voltage and Current (b-d)

REF

The SEL-400G provides comprehensive protection for the GSU and includes a REF element to provide protection for ground faults on the GSU high-voltage winding close to the neutral point. The REF element can also be used to provide selective ground fault protection in applications where several low-impedance grounded generators share a common bus.

Stator Winding Turn-to-Turn Fault Detection (60P/60N/59)

Detection of a turn-to-turn fault is impossible using standard or conventional protection elements. Therefore, the SEL-400G includes several advanced protection elements for this purpose. The fault current developed in the shorted turn during a turn-to-turn fault is of such a large magnitude that it creates the possibility of a fire hazard. However, at the terminals of the generator where the differential current CTs are located, no differential current is generated, i.e., the current flowing into the faulted winding equals the current flowing out of the faulted winding. Therefore standard or conventional protection elements cannot be applied.

In multiwinding generator units, such as those typically used in hydro applications, split-phase protection is employed to detect turn-to-turn faults. This method requires many dedicated CTs, especially if the machine has multiple branches per phase. For single-branch generator units, such as those typically found in steam plants, the zero-sequence voltage overvoltage method is employed. The SEL-400G provides several protection elements to detects stator winding turn-to-turn faults.

Adaptive Split-Phase Protection

The split-phase protection elements (60P and 60N) in the SEL-400G provides sensitive turn-to-turn fault protection in a multibranch generator. The 60P element can be applied in the traditional split-phase configuration between winding branches, as shown in *Figure 16(a)*, and the 60N element can be applied if measuring the neutral current in a multibranch generator with multiple neutral terminals, as shown in *Figure 16(b)*.

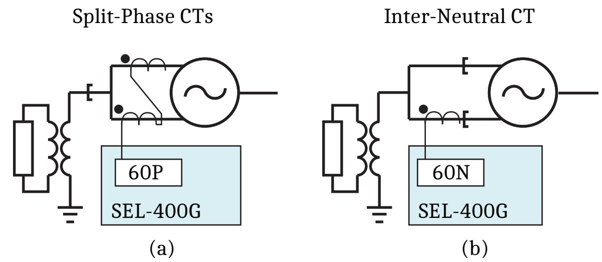


Figure 16 Traditional Split-Phase Protection for Detecting Stator Turn-to-Turn Fault (a), Using the Inter-Neutral CT to Detect a Stator Turn-to-Turn Fault (b)

To not compromise security for sensitivity, the split-phase element has an adaptive threshold that adjusts for non-fault changing system conditions (seasonal changes or changes because of a winding repair, etc.). Should the external fault detector element detect a fault external to the generator differential zone, it sends a signal to the split-phase element for added security.

Zero-Sequence Voltage Stator Overvoltage Element

The 60P/60N elements work well for detecting turn-to-turn faults in a generator where a phase is made up of multiple branches. This method cannot be used when only a single branch makes up a phase in the generator.

The zero-sequence impedance (Z_0) of a generator is very small (almost negligible) when compared to the positive-sequence impedance (Z_1). Therefore, the zero-sequence voltage drop (V_0) across the generator winding under normal operating conditions, stator winding ground faults, and external faults is negligible. However, should the generator develop a winding turn-to-turn fault, the voltage across that winding is reduced, which results in zero-sequence voltage developing in the generator stator winding. This zero-sequence voltage difference can be measured directly using the one of the two methods shown in *Figure 17*. The method shown in *Figure 17(a)* provides greater sensitivity. The method shown *Figure 17(b)* is simpler to apply because it does not require an HV cable but it does require that both VTs have the same ratio. This logic can be realized in the SEL-400G by using SELOGIC.

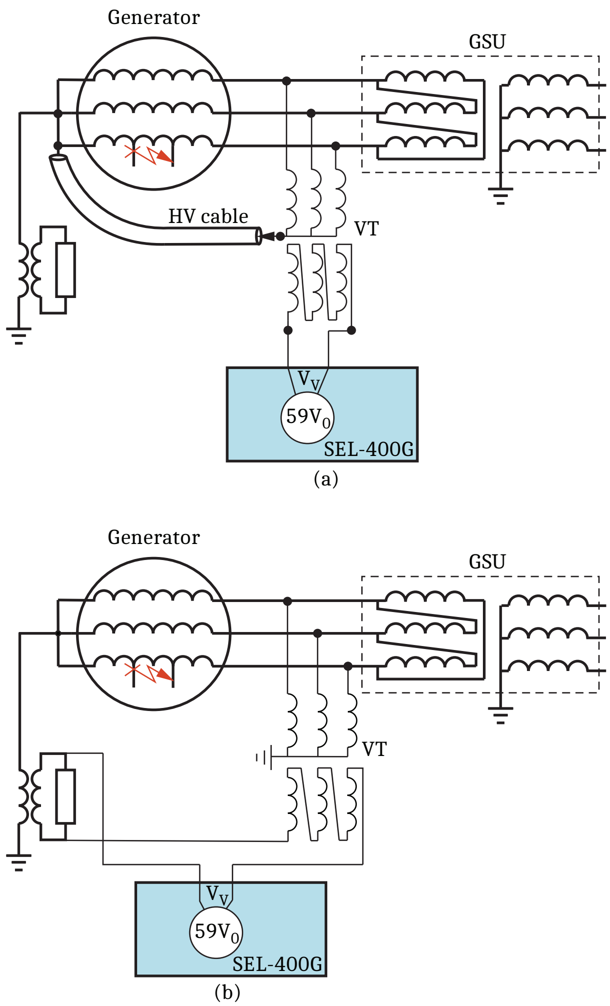


Figure 17 Using Zero-Sequence Voltage Overvoltage to Detect a Stator Turn-to-Turn in a Single-Branch Generator

Irrespective of the method used to obtain the zero-sequence voltage across the generator, connect the voltage input to one of the V-terminal voltage channels and configure an overvoltage element (59) to provide turn-to-turn protection for the generator.

Pumped Storage Logic

A pumped storage machine can operate either as a motor or a generator. Traditional protection philosophy has required external CT/PT switching or the use of separate relays, one to protect during motoring operation and one to protect during generator operation. The SEL-400G internally corrects the phasing introduced by the reversing switch. The logic ensures that the phasing of the differential element is correct and that the phase rotation is correct. This allows a pumped storage hydro unit to be protected with a single SEL-400G without the need to externally switch the CT or PT secondary wiring.

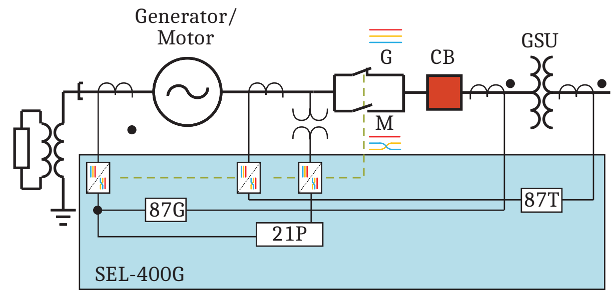


Figure 18 Single SEL-400G to Protect During Both Generating and Motoring Operation for Pumped Storage Application

Extended Range Frequency Tracking of 5–120 Hz

Generators may, at times, operate at frequencies significantly different than nominal. For example, hydro generators may overspeed by as much as 50 percent when rejected from the system. A hydro generator may be rejected on its own or as one of a group of machines. Conversely, large combustion gas turbines (CGTs) commonly employ static starting. During starting, the machine operates as a synchronous motor driven by a load commutated inverter (LCI). The excitation is varied to maintain a nominal V/Hz which, in turn, affects the terminal voltage. Total start time can be as long as 30 minutes. During this time, the frequency may be at or less than 20 Hz for an extended period. Similarly, pumped storage hydro and cross-compound steam turbines can operate at low frequency with field applied. The SEL-400G wide-range frequency tracking algorithm ensures that all protection functions are secure and dependable regardless of the system frequency. The SEL-400G also independently tracks the generator and system frequencies.

Loss-of-Field Protection (40)

The SEL-400G offers two impedance-based loss-of-field (LOF) schemes and a capability based LOF scheme, to protect the generator during a LOF event. When a generators field current is reduced there is a reduction in the generators interval voltage (E_I) and a reduction of the magnetic coupling between the generator stator and rotor.

Reducing the generator E_I reduces the reactive power (VAR) output of the generator and can result in the generator absorbing VARs from the power system. For a complete LOF condition, the VARs absorbed by the generator can be as high as two times the generator MVA rating. In a salient pole generator, a total LOF condition will result in the stator windings being overloaded.

In a cylindrical rotor generator, the stator end core heating is the limiting factor. When the field current is reduced in a cylindrical rotor generator, the rotor end iron transitions from being saturated to being unsaturated. The transition of the rotor end iron from the saturated region to the unsaturated region reduces the reluctance path between the stator end core and rotor end iron. When the reluctance path between the stator end core and rotor end iron decreases, the flow of flux (leakage flux/fringe flux) between them is increased, as shown in *Figure 19*. The increase in flux flow between the stator end core and the rotor end core results in increased stator end core heating.

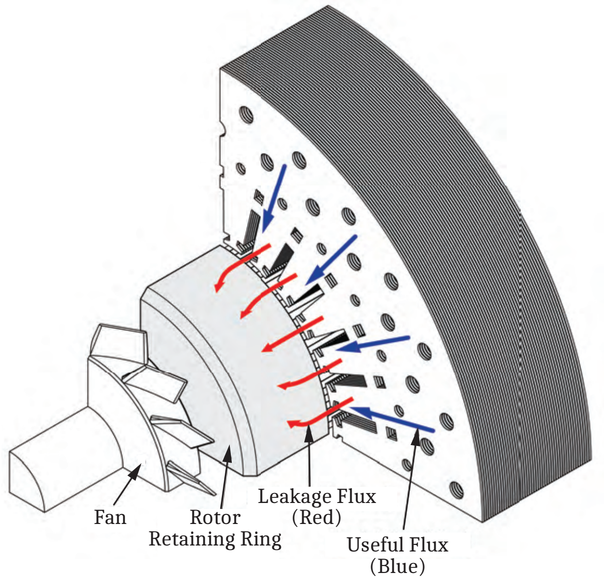


Figure 19 Flow of Leakage Flux (Fringe Flux) When the Rotor Retaining Ring Comes Out of Saturation

Reducing the magnetic coupling between the generator stator and the rotor reduces the ability of the stator and rotor to remain in synchronism. If this coupling is weakened sufficiently, the generator will lose synchronism and the generator will transition from a synchronous to induction operation requiring an increase in rotor speed ($\varpi_r > \varpi_{sync}$). Steam turbines generally have a low tolerance to overspeed. The resulting slip also induces currents into damper bars and rotor body. This can lead to overheating of the rotor and possible damage if the slip is high.

The SEL-400G offers an impedance-based LOF scheme and a PQ-based LOF scheme, to protect the generator during a LOF.

Impedance-Based LOF Elements

The SEL-400G offers an impedance-based LOF element that can be configured for either of the two following schemes:

Negative-Offset Zone 2 Scheme

The negative offset scheme is comprised of two mho elements. The inner element (Zone 1) provides protection for a loaded generator (30 to 100 percent) and is coordinated so that an unstable swing does not enter Zone 1. Zone 1 is set with a minimum delay.

Zone 2 is meant to detect a LOF for a lightly loaded machine. Its greater coverage makes it more likely to pick up during a stable swing. Therefore, this zone requires a longer delay setting.

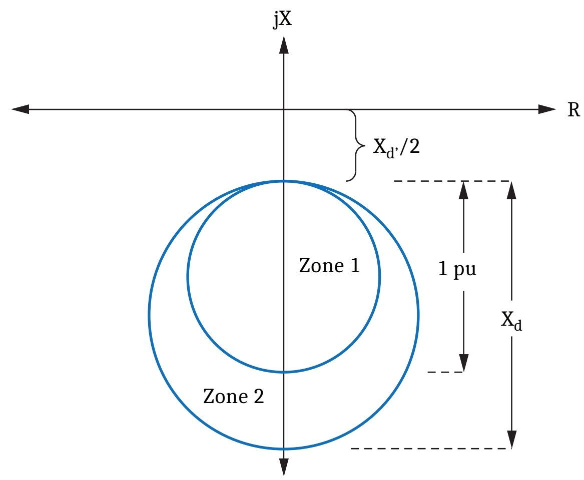


Figure 20 Negative-Offset Zone 2 Scheme

Positive-Offset Zone 2 Scheme

This scheme is also known as a qualified trip scheme and is supervised by an undervoltage (UV) and directional element. This scheme determines a LOF condition if the impedance locus enters the mho characteristic and is lower than the directional element. In a weak power system, the system voltage collapses, and the scheme operating time accelerates. In a strong power system, the operator has time to correct the situation.

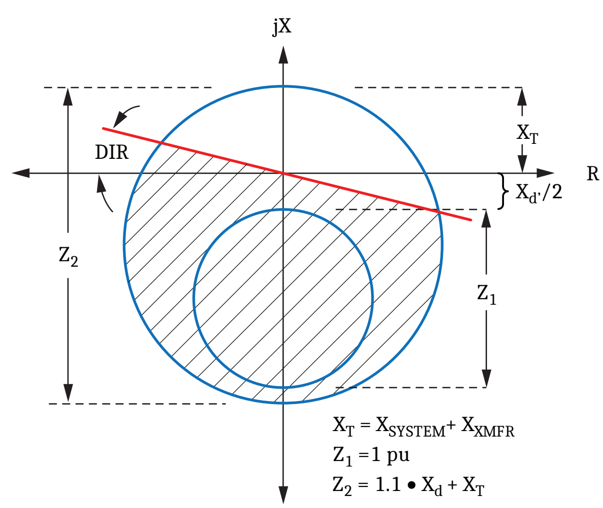


Figure 21 Positive-Offset Zone 2 Scheme

Capability-Based LOF Element

In addition to the two impedance-based schemes, the SEL-400G also offers a LOF element based on the generator capability curve (GCC) defined in the P-Q plane, as shown in *Figure 22*.

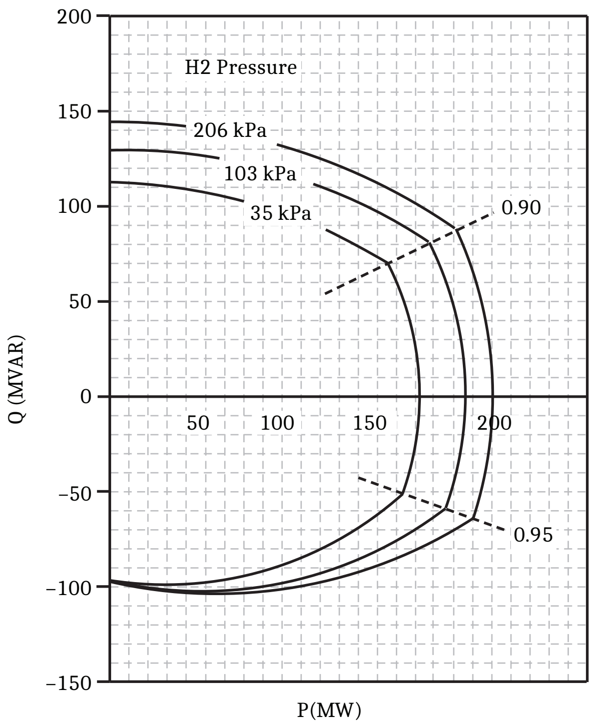


Figure 22 Generator Capability Curve

This element offers several advantages over the impedance-based LOF elements. Use this function to more effectively coordinate with the GCC, steady-state stability limit (SSSL), and under-excitation limiter (UEL). The element is comprised of four zones, as shown in *Figure 23*.

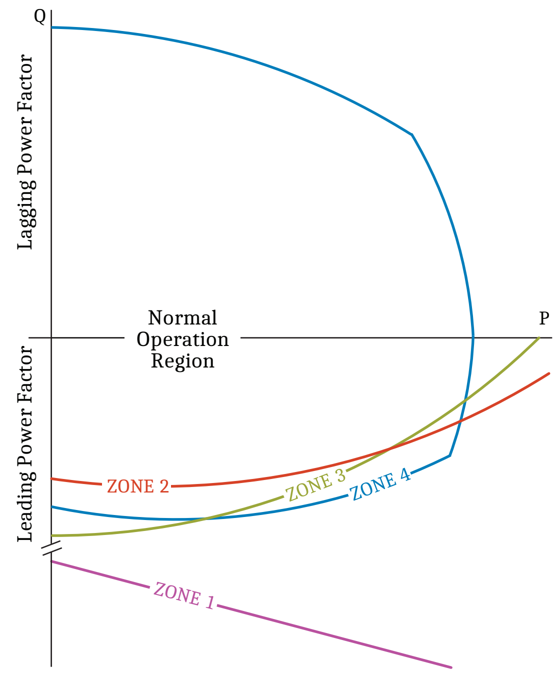


Figure 23 Capability Curve-Based LOF Function With Four Zones

Zone 1

This zone provides high-speed operation for severe LOF events. Zone 1 is defined as a straight line in the P-Q plane but operates as an admittance element. The characteristic is located farther from the GCC, which makes it more secure during stable power swings. This allows it to be set with a short delay with no additional supervision, which is important for dependability.

Zone 2

This zone protects against sustained operation in the underexcited region of the P-Q plane. Round rotor generators can suffer thermal damage because of end iron heating when operating in this region. Underexcited operation can occur for several reasons, including high system voltage or problems with nearby generators. The role of the UEL is to prevent operation in the underexcited region. It is paramount that the 40P element does not operate for an event that can be corrected via the generator controls. Therefore, this zone is designed to closely coordinate with the UEL.

Zone 3

This zone is intended to detect of a loss of steady-state stability. This can occur when the AVR is operated in manual mode. Manual mode operation is normally not permitted but some AVRs transfer to manual mode when a loss of potential occurs because of a VT fuse failure. Often, in strong power systems, the SSSL will be situated outside the GCC, but for weak systems, the SSSL can encroach into the GCC. In this case, the generator could lose synchronism while still operating within the

GCC. The 40P Zone 3 element is intended to detect this occurrence. The characteristic requires only two settings: the equivalent system impedance (X_S) and the steady-state direct axis impedance (X_d). Because Zone 3 replicates the SSSL, it is static in the impedance plane. If studies show that the SSSL cannot intrude into the GCC (because of a strong system), or if the excitation system does not allow the possibility of operating in manual mode (because of design redundancies), you can disable Zone 3. Zone 3 can be supervised by an input from the AVR when the AVR transitions to manual mode.

Zone 4

This zone is intended to provide an alarm when the generator is operated outside of the GCC. The GCC can be divided into three segments: the upper segment, which is the field current limited; the right segment, which is stator current limited; and the lower segment, which is the underexcitation limit. Each segment is represented by a curve fitted to three pairs of PQ coordinates. Because the segments intersect, a total of seven PQ coordinates define this characteristic. This segment can also contract or expand dynamically by using a signal representing the cooling capability of the generator (for example, hydrogen pressure).

Current Unbalance Protection (46)

Fundamental negative-sequence current in the stator winding of the generator induces a double-frequency current in the generator amortisseur (damper) windings, resulting in rapid overheating. The negative-sequence definitive-time element provides an early-stage warning alarm for an unbalance system operating condition, and, should the condition persist, the inverse time-overcurrent element provides tripping to prevent damage to the generator rotor.

Unlike other generator protection relays, the SEL-400G current unbalance element measures the harmonic currents in the rotor in compliance with the IEEE C50.12 and IEEE C50.13 thermal model. As specified by IEEE C50.12, the 46 element in the SEL-400G scales each harmonic order by a weighting factor determined by the harmonics sequence and frequency to account for skin effect, as shown in *Equation 1*.

$$I_{2eq} = \sqrt{I_2^2 + \sum_n \left(\sqrt{\frac{n+1}{2}}\, i_{n2}^2 + \sqrt{\frac{n-1}{2}}\, i_{n1}^2 \right)}, n = 2 \ldots 15$$

Equation 1

By correctly accounting for the harmonic currents, the SEL-400G 46 element affords greater thermal protection to the generator rotor and amortisseur windings.

Geomagnetically induced currents (GIC) can cause the core of the GSU to become saturated, which results in the GSU drawing non-sinusoidal currents rich in harmonics. These harmonic currents do not negatively impact the GSU but do contribute to the heating of the amortisseur winding in the generator rotor. Correctly accounting for the harmonic currents provides better protection of the generator rotor and amortisseur winding during a GIC event.

Overexcitation Protection (24)

For a generator or transformer to generate or transfer power, a mutual magnetic field (flux) must be created. The strength of the magnetic field determines the amount of power that can be generated or transferred. In general, the maximum power transfer of the generator or transformer determines the maximum magnetic field (flux) of the generator or transformer. The generator stator core, as well as the transformer core, have a maximum flux density (flux per unit area) they can support. A flux density above the design limit results in the generator or transformer operating in the saturation region and results in heating of the stator or transformer core above its design limits. Operating a generator or transformer in the saturation region for an extended period damages the generator stator or transformer core.

The SEL-400G provides volts-per-hertz (V/Hz) elements to provide protection for overfluxing. The V/Hz elements calculate the ratio of the normalized voltage (V) to the normalized frequency (f). This ratio (*Equation 2*) is proportional to the flux (ϕ) in the generator stator or transformer core if the voltage is perfectly sinusoidal.

$$\frac{V}{f} = k\phi$$

Equation 2

The V/Hz element provides two levels of definitive-time V/Hz protection. Two user-defined inverse time curves are also available.

Inadvertent Energization (INAD)

When voltage is applied to the generator terminals without the rotor field winding being energized, the generator behaves like an induction motor being started directly online. Similarly to the induction motor, the generator draws current several times the rated current of the generator for a prolonged period until the rotor comes close to synchronous speed. During the rotor acceleration period, currents are induced into the rotor circuit, resulting in excessive heating of the rotor, which can result in damage. The SEL-400G provides an inadvertent energization logic that arms itself when the generator is taken offline. If the generator is energized inadvertently, the logic detects this condition and takes the appropriate action. Rather than providing a single element at the generator neutral, the SEL-400G provides an element for each breaker. This allows the element to be applied in applications that employ static starting or dynamic braking.

Directional Power Protection (32)

When the prime mover of a generator is lost, the mechanical power input to the generator decreases to zero and the generator transitions from generating to motoring mode. This transition has no negative impact on the generator, but it does negatively impact the prime movers. In steam turbines, normal steam flow removes heat from the turbine blades and other turbine parts. In motoring mode, there is insufficient steam flow for cooling. The resultant temperature buildup causes the turbine blades, especially the low-pressure turbine blades, to be annealed or distorted. In gas turbines, the drive gear is generally designed for unidirectional operation i.e., the prime mover driving the generator. Should the generator drive the prime mover, the drive gear will experience excessive wear.

In motoring mode, the power the generator draws from the power system is dependent on the prime mover; hydro turbines with their turbine blades above the tail race water level and steam turbine that are under vacuum will draw between 0.2–3 percent of their rated power. Therefore, to detect that a generator is in motoring mode, a very sensitive power element is required. The SEL-400G provides four instances of sensitive power elements with independent time delays. Additionally, the SEL-400G provides a biased characteristic that ensures both security and dependability for the cases when the generator is exporting a large amount of reactive power and is in motoring, as shown in *Figure 24*. In these cases, small instrument transformer angle error can negatively impact the sensitive power calculations and jeopardize the security or dependability of the element.

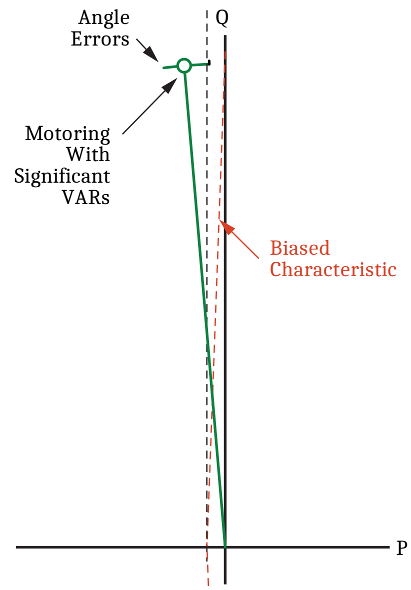


Figure 24 Biased Characteristic to Ensure Dependability and/or Security During High Reactive Power but Low Active Power Conditions

Out-of-Step Protection (78)

The SEL-400G provides out-of-step (OOS) protection that can be configured for either of the following two schemes:

Single-Blinder Scheme

The single-blinder scheme (see *Figure 25*) measures the time it takes the positive-sequence impedance (Z_1) to traverse the positive-sequence impedance plane to distinguish between an OOS condition and a power system fault. A power system fault will traverse the positive-sequence impedance plane much more rapidly than an OOS condition. The scheme declares an OOS condition if the time between the positive-sequence impedance entering the mho element and one of the blinders (R_1 or R_1') is longer than 1/2 a power system cycle. The scheme will issue an out-of-step trip (OOST) command if the positive-sequence impedance traverses the positive-sequence impedance plane from left to right or vice versa.

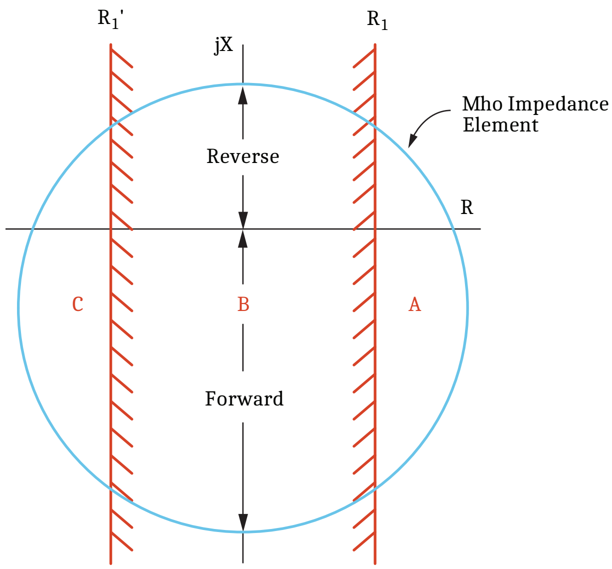


Figure 25 Single-Blinder OOS Detection Scheme

Double-Blinder Scheme

The double-blinder scheme in *Figure 26* measures the time it takes the positive-sequence impedance (Z_1) to traverse the positive-sequence impedance plane between the R_1 and R_2 blinders. If Z_1 enters the R_1 blinder but does not enter the R_2 blinder within a predetermined period, a power system swing is declared. In the event of a stable swing, Z_1 exits the R_1 blinder without entering the R_2 blinder. For an unstable swing or OOS, Z_1 enters R_2 after the predetermined period of time. This scheme offers the ability to detect a power swing and an OOS condition but does require a more detailed system study.

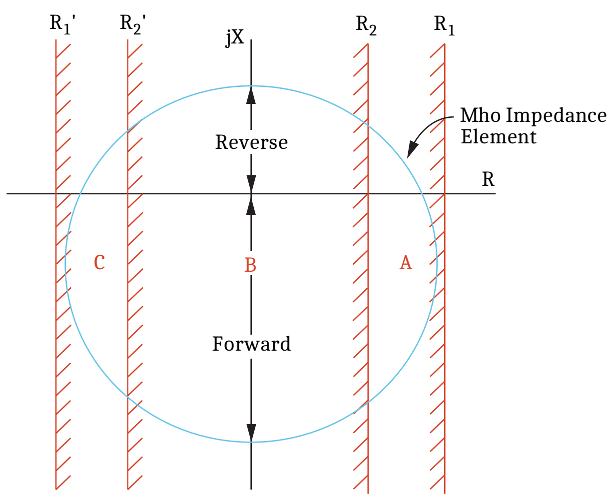


Figure 26 Double-Blinder OOS Detection Scheme

Pole Slip Counter

The SEL-400G also includes a pole slip counter (PSC) that counts the number of pole slips a generator experienced during an OOS condition. The logic further differentiates whether the trajectory of the OOS went through the power system or through the generator and increments the appropriate counters.

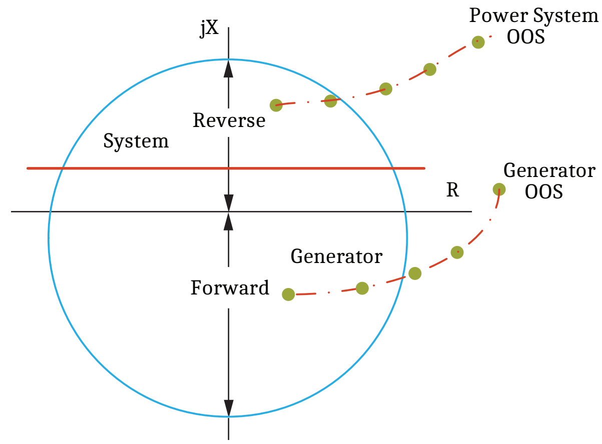


Figure 27 Pole Slip Counter

By discriminating whether the OOS trajectory went through the generator or the power system, you can select tripping to either occur after the first pole slip (if the trajectory is through the generator) or after a certain number of slips (if the trajectory is through the power system).

Over- and Underfrequency Protection (81)

The SEL-400G calculates the frequency of as many as two independent frequency zones (generator and power system zone). The frequency from these two independent zones is available to the over- and underfrequency protection elements to provide protection for over- and underfrequency conditions. The threshold for the over- and underfrequency elements are independent of one another and allow for independent tripping for an over- and underfrequency condition.

Rate-of-Change-of-Frequency Protection (81R)

The SEL-400G calculates the rate-of-change of frequency (ROCOF) for as many as two independent frequency zones (generator zone and power system zone). The ROCOF logic within the SEL-400G discriminates between a positive and negative ROCOF condition and allows for setting a tripping threshold independently for positive and negative ROCOF conditions.

Frequency Accumulation Protection (81A)

The turbine blades of a generator prime mover are designed to operate within a very narrow band around the nominal frequency of the generator. If the turbine speed fall outside this nominal band, it can excite frequencies that coincide with the natural frequency of the turbine blades. If this occurs, the turbine blades are exposed to vibration stress well above their design limits, resulting in fatigue of the turbine blades. Turbine blade fatigue is cumulative and non-reversible; therefore, turbine manufacturers provide maximum time limits that the turbine can be operated for frequency outside of the nominal frequency, as shown in *Figure 28*.

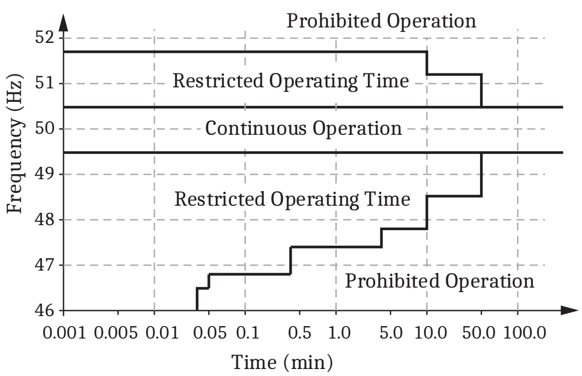


Figure 28 Time Restrictions for Safe Turbine Operation at Different Frequency Bands

The SEL-400G provides frequency accumulation elements that enable the user to configure the frequency bands according to the generator turbine specification. The element accumulates the total duration the turbine blades were exposed to frequencies within the band. If the accumulated time exceed the predefined value, the element generates an output that can be used for alarm purposes.

Thermal Overload Protection (49)

Operating a generator beyond its rated capacity (outside its thermal capability) for an extended period leads to damage to the generator in the form of stator and rotor winding insulation degradation. The greatest heat generated during normal generator operation is by the resistive losses in the stator and rotor windings (copper losses). The SEL-400G can use the combined positive (I_1) and negative (I_2) current ($\sqrt{I_1^2 + I_2^2}$) or the rms current. It can also use the measured ambient temperature to calculate the thermal capacity in the generator and the time before the generator exceeds its thermal capability limit. The measured ambient temperature is obtained from either an SEL-2600 series RTD module, an SEL-2411 controller, or a temperature unit that sends data through IEC 61850 GOOSE messages. The SEL-400G support three general-purpose thermal models that conform with the IEC 60255-149 standard.

Breaker Failure Protection (50BF)

The SEL-400G provides high-speed breaker failure for as many as four circuit breakers. Breaker failure is initiated via a user-defined condition and is qualified by either phase current or residual current, if so selected. The breaker failure logic is supervised by a high-speed open-phase detection logic that is immune to subsidence current that may be present after fault clearing. The breaker failure logic is complimented with breaker flashover detection logic to protect the generator and generator breaker from a flashover just prior to synchronization.

System Backup Protection (21P/51C/51V/27/59)

Distance Protection Elements

The SEL-400G provides two zones of offset mho phase distance protection to provide backup protection of the generator. Zone 1 is typically set to provide backup protection for bus faults and breaker failures, and to coordinate with Zone 1 of the line protection relay; therefore, Zone 1 is typically set with a short reach and a short time delay. Zone 2 is coordinate with the Zone 2 of the line protection; therefore, Zone 2 is typically set with a longer reach and a greater time delay.

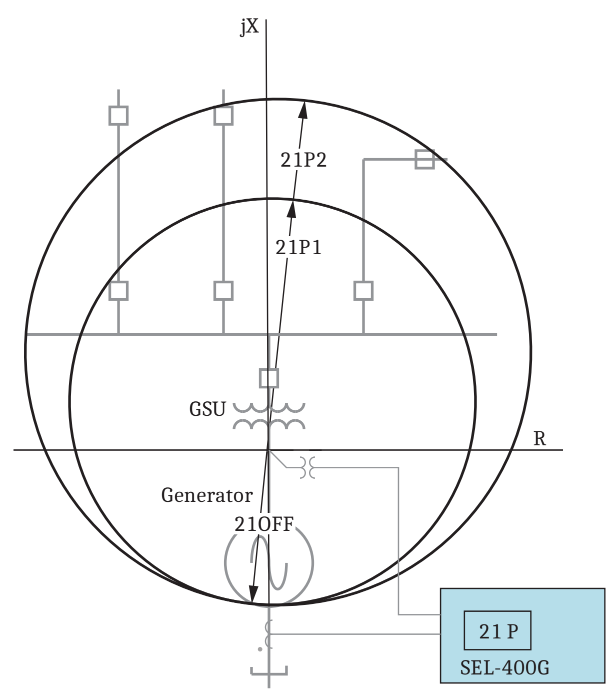


Figure 29 Two Zones of Offset Mho Phase Distance to Provide Backup Protection

Voltage-Controlled Overcurrent Elements

Under a sustained three-phase fault condition, the generators impedance increases from $X_{d''}$ (≈0.25 pu) to X_d (≈1.2 to1.9 pu). This increase in generator impedance (X_d) reduces the magnitude of fault current and voltage at the terminals of the machine. Because $X_d > 1.0$, the three-phase fault current will be lower than the full load current of the generator, therefore, traditional overcurrent elements cannot be used for backup protection. The SEL-400G includes voltage-controlled overcurrent elements (51C) and a voltage-restrained overcurrent elements (51V) that can be used to provide backup protection for the generator in this instance.

Over- and Undervoltage Protection

Phase, phase-to-phase, and positive-sequence undervoltage (27), overvoltage (59), residual overvoltage (59G), and negative-sequence overvoltage (59Q) help you create protection and control schemes such as undervoltage load shedding or standby generation start/stop schemes. Six over- and six undervoltage elements are provided. The over- and undervoltage elements support definite-time, inverse-time, and integration timers (for the detection of intermittent ground faults).

Synchronism Check (25)

In the SEL-400G, four synchronization-check elements are provided. The synchronism-check function is extremely accurate and provides supervision for acceptable voltage window and maximum percentage difference, maximum and minimum allowable slip frequency, target closing angle, and breaker closing delay.

Autosynchronizer (25A)

The SEL-400G monitors the voltage across the selected breaker and sends variable control pulses to the generator field voltage regulator and the prime mover speed control governor. The following pulse control modes are supported:

➤ **Proportional Width (PW).** The pulse width (W in *Figure 30*) is proportional to the error signal (slip or voltage difference) and the pulse period is fixed.

➤ **Proportional Frequency (PF).** The pulse width is fixed and the pulse frequency (F in *Figure 30*) is proportional to the error signal. PF may be more suitable in control systems that require a definite minimum pulse width.

➤ **Fixed (FD).** Both the pulse-width and the pulse frequency are fixed. This control mode may be more suitable for control using certain distributed control systems.

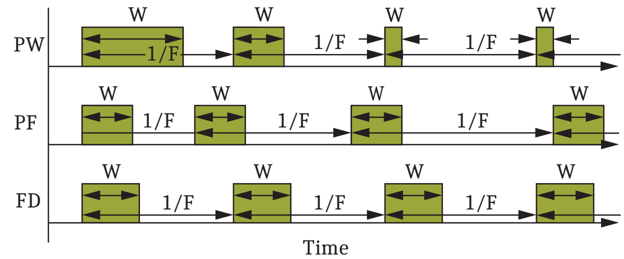


Figure 30 Control Pulses

Once frequency, voltage, and phase are matched, the function sends a close command to the selected breaker. The close command is time-advanced using the slip measurement and breaker close time so that the primary contacts close when the voltage angle across the breaker is zero. Use the disturbance recorder to capture each synchronizing event.

Loss-of-Potential Logic (60)

The SEL-400G provides loss-of-potential (LOP) elements for the V and Z terminals that use voltage and current to determine if the generator protection system is experiencing LOP conditions. Each LOP element includes:

➤ **Incremental Voltage Logic.** When the element detects an incremental decrease in the positive-sequence voltage over one power system cycle without a corresponding change in the positive- or negative-sequence current during the same cycle, the element declares a LOP condition.

➤ **Negative-Sequence Voltage LOP Element.** The element declares a LOP condition if it measure negative-sequence voltage with no corresponding negative-sequence current while load current is present.

In addition, the SEL-400G includes a voltage-balance LOP element. This element compares the positive-sequence voltage between two VT terminals. If the difference between the positive-sequence voltages is greater than a preset threshold, the logic declares a LOP condition. This element requires two three-phase VTs or a VT with dual secondaries. The V voltage terminal must also be configured as a three-phase input. This element is ideal for verifying that the generator is not experiencing a LOP condition before it is brought online.

Automation, Communication, and Control

Flexible Control Logic and Integration Features

Use the SEL-400G control logic to replace the following:

- ➤ Traditional panel-control switches
- ➤ RTU-to-relay wiring
- ➤ Traditional latching relays
- ➤ Traditional indicating panel lights

Eliminate traditional panel-control switches with 32 local control points (local bits). Set, clear, or pulse local control points with the front-panel pushbuttons and display. Program the local control points to implement your control scheme via SELOGIC control equations. Use the same local control points for functions such as taking a terminal out of service for testing.

Eliminate RTU-to-relay wiring with 32 remote control points. Set, clear, or pulse remote control points via serial port commands. Incorporate the remote control points into your control scheme via SELOGIC control equations. Use remote control points for SCADA-type control operations (e.g., trip, settings group selection).

Replace traditional-latching relays for such functions as remote control enable with 32 latching control points. Program latch-set and latch-reset conditions with SELOGIC control equations. Set or reset the latch control points via control inputs, remote control points, local control points, or any programmable logic condition. The relay retains the states of the latch control points after turning on following a power interruption.

Replace traditional indicating panel lights and switches with 24 tri-color latching target LEDs and 12 programmable pushbuttons with LEDs. Define custom messages to report power system or relay conditions on the large format LCD. Control displayed messages via SELOGIC control equations by driving the LCD display via any logic point in the relay.

High-Accuracy Timekeeping

Using high-accuracy IRIG-B from a global positioning satellite clock, the SEL-400G can time-tag oscillography to within 1 µs accuracy. This high accuracy can be combined with the high sampling rate of the relay to synchronize data from across the system with an accuracy of better than 1/4 electrical degree. This allows examination of the generation system state at given times, including load angles, system swings, and other system-wide events. Triggering can be via external signal (contact or communications port), set time, or system event. Optimal calibration of this feature requires a knowledge of primary-input component (VT and CT) phase delay and error. A high-accuracy IEEE C37.118 IRIG-B time-code input synchronizes the SEL-400G time to be within ±1 µs of the time-source input when the time-source input jitter is less than 500 ns and the time error is less than 1 µs.

Precision Time Protocol (PTP) Time Synchronization

In addition to using IRIG-B for high-accuracy timekeeping, the relay can use IEEE 1588 Precision Time Protocol, version 2 (PTPv2) to obtain time synchronization through the Ethernet network. When connected directly to a grandmaster clock providing PTP at 1-second synchronization intervals, the relay can be synchronized to an accuracy of ±100 ns. The relay can receive as many as 32 sync messages per second.

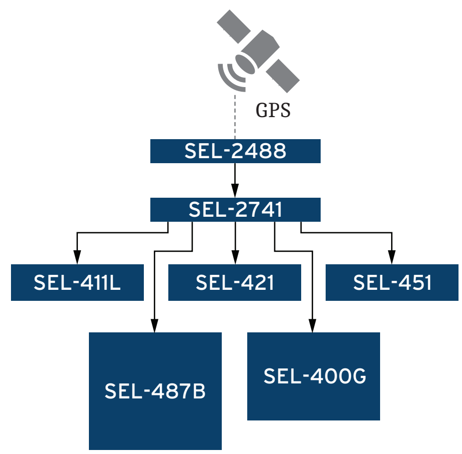


Figure 31 Example PTP Network

SNTP Time Synchronization

Use SNTP to cost-effectively synchronize SEL-400G equipped with Ethernet communication to as little as ±1 ms over standard Ethernet networks. Use SNTP as a primary time source or as a backup to a higher accuracy IRIG-B time input to the relay.

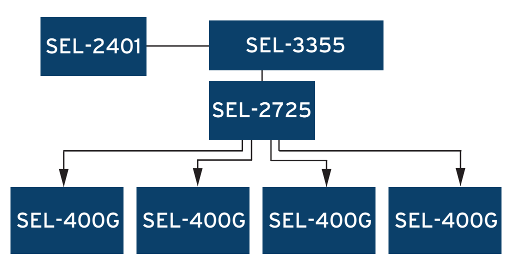


Figure 32 SNTP

SELOGIC Control Equations With Expanded Capabilities and Aliases

Expanded SELOGIC control equations (*Table 1*) put relay logic in the hands of the protection engineer. Use 250 lines of freeform protection logic, operating at protection processing speed, and 1000 lines of freeform automation logic operating once per second to design a wide variety of custom applications. Assign the relay inputs to suit your application, logically combine selected relay elements for various control functions, and assign outputs to your logic functions. Programming SELOGIC control equations consists of combining relay elements, inputs, and outputs with SELOGIC control equation operators. Any of the relay internal variables (Relay Word bits) can be used in these equations. For complex or unique applications, these expanded SELOGIC control equation functions allow superior flexibility. Add programmable control functions to your protection and automation systems. New functions and capabilities enable you to use analog values in conditional logic statements. Use the alias capability to assign more meaningful relay variable names. This improves the readability of customized programming. Use as many as 200 aliases to rename any digital or analog quantity. The following is an example of possible applications of SELOGIC control equations using aliases:

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

Table 1 Expanded SELOGIC Control Operators

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

Serial Communications Features

The SEL-400G offers the following serial communications features:

- Four independent EIA-232 serial ports
- Full access to event history, relay status, and meter information from the communications ports
- Settings and group switching password control
- SEL unsolicited block transfer for communication with as many as two SEL-2600 modules
- Sixty message-per-second synchrophasor data via C37.118 data format
- Receive synchophasor data from other IEEE C37.118-compliant devices for control
- SEL ASCII, SEL Compressed ASCII, SEL Fast Operate, SEL Fast Meter, SEL Fast SER, and Enhanced SEL MIRRORED BITS serial protocols are standard with each relay
- SEL Unsolicited Fast Message Write for transfer of analog quantities between other devices communicating these protocols
- DNP Serial protocol provides the SEL-400G with DNP3 Level 2 Outstation functionality

Table 2 Serial Communications Protocols (Sheet 1 of 2)

Type	Description
ASCII	Plain-language commands for human and simple machine communication. Use for metering, setting, self-test status, event reporting, and other functions.
Compressed ASCII	Comma-delimited ASCII data reports allow external devices to obtain relay data in an appropriate format for direct import into spreadsheets and database programs. Data are checksum protected.

Table 2 Serial Communications Protocols

Type	Description
Extended SEL Fast Meter, SEL Fast Operate, and SEL Fast SER	Binary protocol for machine-to-machine communication. Quickly updates SEL communications processors, RTUs, and other substation devices with metering information, relay element, I/O status, time-tags, open and close commands, and summary event reports. Data are checksum protected.
Ymodem	Support for reading event, settings, and oscillography files.
Optional DNP3 Level 2 Outstation	Distributed Network Protocol with point remapping. Includes access to metering data, protection elements, contact I/O, targets, SER, relay summary event reports, and settings groups.
MIRRORED BITS	SEL protocol for exchanging digital and analog information among SEL relays and for use as low-speed terminal connection.

Open Communications Protocols

The SEL-400G does not require special communications software. ASCII terminals, printing terminals, or a computer supplied with terminal emulation and a serial communications port are all that is required.

SEL Unsolicited Block Transfer Communications

The SEL-400G has the capability to operate as a client for unsolicited SEL Fast Message communications between the relay and as many as two SEL-2600 modules. Any of the four EIA-232 serial ports on the SEL-400G can be set for direct communication with a SEL-2600. Use the SEL-2600 to provide the SEL-400G with as many as 24 channels of temperature information, updated every 600 ms.

SEL Unsolicited Fast Message Write (Remote Analogs)

From the perspective of the SEL-400G, remote analogs (RA01–RA256) are specific, pre-allocated memory addresses. These memory addresses are available to accept and store values from remote devices such as an SEL-3530 Real-Time Automation Controller (RTAC). Once these values from the remote devices are written into the memory addresses in the SEL-400G, you can use these values similar to any other analog quantity in the relay, including display points and SELOGIC programming.

Ethernet Communications

The SEL-400G provides Ethernet communications capabilities with an optional Ethernet card. This card has five small form-factor pluggable (SFP) ports.[a] **PORT 5A** and **PORT 5B** are reserved for the process bus network. **PORT 5C** and **PORT 5D** are reserved for the station bus network. The process and station bus networks support PRP, HSR, and fast failover redundancy modes. **PORT 5E** operates on an isolated network with a unique IP address, making it ideal for engineering and data access. All ports support 100 Mbps speeds. **PORT 5A** and **PORT 5B** also support 1 Gbps speeds to satisfy potentially large traffic requirements on the process bus. The process bus, station bus, and engineering access networks use separate MAC addresses and are logically delineated, including in the Configured IED Description (CID) file.[b]

The Ethernet card provides PTP for data time synchronization. Use Telnet applications for easy terminal communication with SEL relays and other devices. Transfer data at high speeds for fast file uploads. The Ethernet card can communicate using File Transfer Protocol (FTP) applications for easy and fast file transfers.

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

- 10/100BASE-T Twisted Pair Network[c]
- 100BASE-FX Fiber-Optic Network
- 1000BASE-X Fiber-Optic Network[d]

Telnet and FTP

Order the SEL-400G with Ethernet communications and use built-in Telnet and FTP (File Transfer Protocol) that come standard with Ethernet to establish communications sessions. Use Telnet to access relay settings and metering and event reports remotely by using the ASCII interface. Transfer event reports and settings files to and from the relay by using FTP.

IEEE C37.118 Synchrophasor Data Over Ethernet

The SEL-400G can provide synchrophasor data compliant with the IEEE C37.118 synchrophasor protocol when equipped with Ethernet communication. This protocol provides standardized packet content of synchrophasor data for use with other IEEE C37.118-compliant net-

[a] SFP transceivers are not included with the card and must be ordered separately. See selinc.com/products/sfp for a list of compatible SFP transceivers.
[b] This paragraph describes the five-port Ethernet card ordering option. It does not apply to the four-port Ethernet card ordering option.
[c] Four-port Ethernet card ordering option only.
[d] Gigabit speeds are only available on **PORT 5A** and **PORT 5B** of the five-port Ethernet card ordering option.

works and devices. The Ethernet card in the SEL-400G provides two independent connections through use of either TCP/IP, UDP/IP, or a combination thereof. Each data stream can support as many as 60 frames per second. Each of the two connections can be configured from five custom setting configurations that the SEL-400G supports.

DNP LAN/WAN

The DNP3 LAN/WAN option provides the SEL-400G with DNP3 Level 2 Outstation functionality over Ethernet. As many as six DNP3 sessions can be configured with as many as five custom DNP3 data maps that can be configured for use with multiple DNP3 masters.

PTP

The SEL-400G supports IEEE 1588 Precision Time Protocol, version 2 (PTPv2) for data time synchronization. PTP support includes the Default, Power System (IEEE C37.238-2011), and Power Utility Automation (IEC/IEEE 61850-9-3-2016) PTP Profiles.

Parallel Redundancy Protocol (PRP)

This protocol is used to provide seamless recovery from any single Ethernet network failure, in accordance with IEC 62439-3:2010. The station bus and process bus Ethernet networks support PRP.[e]

High-Availability Seamless Redundancy (HSR) Protocol

Provide seamless recovery from any single Ethernet network failure with this protocol, in accordance with IEC 62439-3. You can connect all HSR compatible devices in a ring, fully duplicate the traffic, and send the traffic in both clockwise and counterclockwise directions around the ring. The station bus and process bus Ethernet networks support HSR.[e]

IEC 61850 Ethernet Communications

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

[e] Only the five-port Ethernet card ordering option supports PRP on both the station bus and the process bus. HSR is only supported on the five-port Ethernet card.

The SEL-400G can be ordered with IEC 61850 Edition 2.1 protocol operating on 100 Mbps or 1 Gbps Ethernet.[f] Use the IEC 61850 Ethernet protocol for relay monitoring and control functions, including:

- As many as 128 incoming GOOSE messages. The incoming GOOSE messages can be used to control as many as 256 binary bits in the relay with minimal latency from device to device. These messages provide binary inputs to the relay for high-speed control functions and monitoring.
- As many as eight outgoing GOOSE messages. Outgoing GOOSE messages can be configured for Boolean or analog data. Boolean data are provided with minimal latency from device to device. Use outgoing GOOSE messages for high-speed control and monitoring of external breakers, switches, and other devices.
- IEC 61850 Data Server. The SEL-400G equipped with embedded IEC 61850 Ethernet protocol provides data according to predefined logical node objects. Each relay supports as many as seven simultaneous MMS client sessions, with support to association-based and indexed reports. Relevant Relay Word bits are available within the logical node data, so status of relay elements, inputs, outputs, or SELOGIC equations can be monitored using the IEC 61850 data server provided in the relay.
- Association of as many as 256 virtual bits to incoming GOOSE message data points. Virtual bits are available for use in SELOGIC control equations.
- As many as 64 remote analog outputs that you can assign to virtually any analog quantity available in the relay. You can also use SELOGIC math variables to develop custom analog quantities for assignment as remote analog outputs. Remote analog outputs using IEC 61850 provide peer-to-peer transmission of analog data. Each relay can receive as many as 256 remote analog inputs and use those inputs as analog quantities within SELOGIC control equations.
- The SEL-400G supports IEC 61850 standard operating modes such as Test, Blocked, Test-Blocked, On, and Off.

MMS File Services

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

[f] Gigabit speeds are only available on **PORT 5A** and **PORT 5B** of the five-port Ethernet card ordering option.

MMS Authentication

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

ACSELERATOR Architect® SEL-5032 Software

Use Architect to manage the IEC 61850 configuration for devices on the network. This Microsoft Windows-based software provides easy-to-use displays for identifying and binding IEC 61850 network data between logical nodes by using IEC 61850-compliant CID files. CID files are used by Architect to describe the data that will be provided by the IEC 61850 logical node within each relay.

Modbus TCP

The Modbus TCP option provides the SEL-400G with Modbus functionality over Ethernet. As many as two Modbus TCP sessions can be configured with one custom Modbus Map.

HTTP

The HTTP protocol provides the SEL-400G with read access to webpages. The relay provides webpages that contain metering, reports, communications statistics, settings, and status information.

Table 3 Ethernet Communications Protocol

Type	Description
FTP and Telnet	Use Telnet to establish a terminal-to-relay connection over Ethernet. Use FTP to move files in and out of the relay over Ethernet.
IEC 61850	Ethernet-based international standard for interoperability among intelligent devices in a substation.
SNTP	Ethernet-based SNTP for time synchronization among relays.
Precision Time Protocol	Ethernet-based network time protocol for high-accuracy time synchronization among relays.
Modbus TCP	Ethernet-based protocol that provides client/server communication among relays.
HTTP	Ethernet-based client/server protocol that provides access to webpages within relays.

Metering and Monitoring

Metering Capabilities

The SEL-400G provides extensive metering capabilities for real-time current, voltage, power, energy qualities, V/Hz, and differential quantities, as well as phase demand and peak demand current values. Harmonic content from the fundamental to the fifth harmonic for all ac current inputs are included for the differential protection. Thermal metering, synchrophasor data metering, differential metering, rms metering, and minimum/maximum metering are also included.

The following metering types are supported:

- Fundamental
- Energy
- Max/Min
- RMS
- Demand
- Math Variables
- Differential
- Harmonics
- Synchrophasors
- Temperature
- Sync Check
- Battery

Table 4 SEL-400G Metering Quantities (Sheet 1 of 2)

Capabilities	Description
Fundamental and RMS	
Fundamental voltages: V*p* (V, Z), V*pp*, 3V0, V1, 3V2	Voltages measured at the fundamental frequency of the power system.
RMS voltages: V*p* (Z), V*pp*	RMS voltages include fundamental plus all measurable harmonics.

Table 4 SEL-400G Metering Quantities (Sheet 2 of 2)

Capabilities	Description
Fundamental currents: I*p* (S, T, U, Y, G), 3I0, I1, 3I2	Currents measured at the fundamental frequency of the power system.
RMS currents: I*p* (G)	RMS currents include fundamental plus all measurable harmonics.
Power/Energy Metering Quantities	
Fundamental power quantities: S*p*, P*p*, Q*p* (S, T, U, Y, G) S3, P3, Q3 (S, T, U, Y, G)	Power quantities calculated using fundamental voltage and current measurements; S = MVA, P = MW, Q = MVAR.
Differential Metering	
Differential: IOP*p* (1, 2) IRT*p* (1, 2)	IOP, operate current magnitude (per unit) for zone (1, 2). IRT, restraint current magnitude (per unit) for zone (1, 2).
Harmonics: 2nd: IOP*p*F2 (1, 2) 4th: IOP*p*F4 (1, 2) 5th: IOP*p*F5 (1, 2)	Differential harmonic quantities represent the effective harmonic content of the operate current. This content is what the relay uses for harmonic blocking and harmonic restraint.
Synchrophasors	
Voltages (Primary Magnitude, Angle) V*p*, V1 (V, Z)	Primary phase quantities (kV) for each of the six voltage sources available and their positive sequence.
Currents (Primary Magnitude, Angle) I*p*, I1 (S, T, U, W, X, Y)	Primary phase quantities (A) for each of the eighteen current sources available and their positive sequence.
Frequency FREQ dF/dT	Frequency (Hz) as measured by frequency source potential inputs. Rate-of-change of frequency (Hz/s).

Event Reporting and SER

Event reports and SER features simplify post-fault analysis and help improve your understanding of both simple and complex protective scheme operations. These features also aid in testing and troubleshooting bay settings and control schemes.

Event Reporting

In response to a user-selected internal or external trigger, the voltage, current, and element status information contained in each event report confirms relay, scheme, and system performance for every fault. The SEL-400G provides raw events as fast as 8 kHz called high-resolution (HR) event and filtered events at 400 Hz called low-resolution (LR) events. The relay also provides disturbance events at 50 Hz called disturbance recording (DR) events. All three events are available in the IEEE C37.111-2013 COMTRADE standard.

The HR event can be configured to trigger for 8 kHz, 4 kHz, 2 kHz, or 1 kHz resolution. The relay can store events as long as 24 seconds at 1 kHz resolution or events as long as 3 seconds at 8 kHz resolution. The relay supports inclusion of 20 user-configurable analogs in the events. Reports are stored in nonvolatile memory. Relay settings operational in the relay at the time of the event are appended to each event report.

Each SEL-400G provides event reports for analysis with software such as SEL-5601-2 SYNCHROWAVE® Event Software. With SYNCHROWAVE Event, you can display events from several relays to make the fault analysis easier and more meaningful. Because the different relays time stamp the events with values from their individual clocks, be sure to time synchronize the SEL-400G with an IRIG-B clock input or PTP source to use this feature.

Event Summary

Each time the relay generates a standard event report, it also generates a corresponding event summary. This is a concise description of an event that includes the following information:

- Relay/terminal identification
- Event date and time
- Event type
- Event number
- Time source

- ➤ Active settings group
- ➤ Targets asserted during the fault
- ➤ Frequency
- ➤ Current magnitudes and angles
- ➤ Voltage magnitudes and angles
- ➤ Differential currents
- ➤ Breaker status and trip and close times for this fault

With an appropriate setting, the relay will send an event summary in ASCII text automatically to one or more serial or Ethernet ports each time an event report is triggered.

SER

Use this feature to gain a broad perspective of relay element operation. Items that trigger an SER entry are selectable and can include as many as 250 monitoring points such as input/output change-of-state, element pickup/dropout. The relay SER stores the latest 1000 events.

Load-Profile Monitoring

The SEL-400G provides analog signal profiling for as many as 20 analog quantities. Any analog quantity measured or calculated by the SEL-400G can be selected for analog signal profiling. Signal sampling rates of 1, 5, 15, 30, and 60 minutes can be selected through settings. The analog signal profile report provides a comma-separated variable (CSV) list that can be loaded into any spreadsheet or database for analysis and graphical display.

SELOGIC enable/disable functions can start and stop signal profiling based on Boolean or analog comparison conditions.

Substation Battery Monitoring

The SEL-400G measures and reports the substation battery voltage. Programmable threshold comparators and associated logic provide alarm and control of batteries and charger. The relay also provides battery system ground detection.

The measured dc voltage is reported in the meter display via serial or Ethernet port communications, on the HMI, and in the event report. The event report data provide an oscillographic display of the battery voltage for monitoring substation battery voltage drop during trip, close, and other control operations.

Breaker Contact Wear Monitoring

Circuit breakers experience mechanical and electrical wear every time they operate. Effective scheduling of breaker maintenance compares published manufacturer breaker wear data, interruption levels, and operation count with actual field data. The SEL-400G breaker monitoring function captures the total interrupted current and number of operations for as many as five three-pole breakers. Each time a monitored breaker trips, the relay integrates the interrupted current with previously stored current values. When the results exceed the threshold set with reference to the breaker wear curve, the relay can alarm via an output contact or the HMI.

The breaker wear monitor accumulates current by phase and so calculates wear for each pole separately. When first applying the relay, preload any previous estimated breaker wear. The incremental wear for the next interruption, and all subsequent interruptions, adds to the prestored value for a total wear value. Reset the breaker monitor operation counters, cumulative interrupted currents by pole, and percent wear by pole after breaker maintenance or installing a new breaker. The breaker wear monitor report lists all breakers, number of internal and external trips for each breaker, total accumulated rms current by phase, and the percent wear by pole.

Software

SEL Grid Configurator

SEL Grid Configurator combines an easy-to-use interface, powerful protection visualization, and comprehensive reporting to deliver a seamless and efficient configuration and commissioning experience. You want to be confident that your SEL-400G will perform as expected, and SEL Grid Configurator is the key tool to help you verify that the relay configuration is exactly what you expect.

Protection Element View

The Protection Elements View in SEL Grid Configurator provides a single place to enable and configure settings for all protection functions.

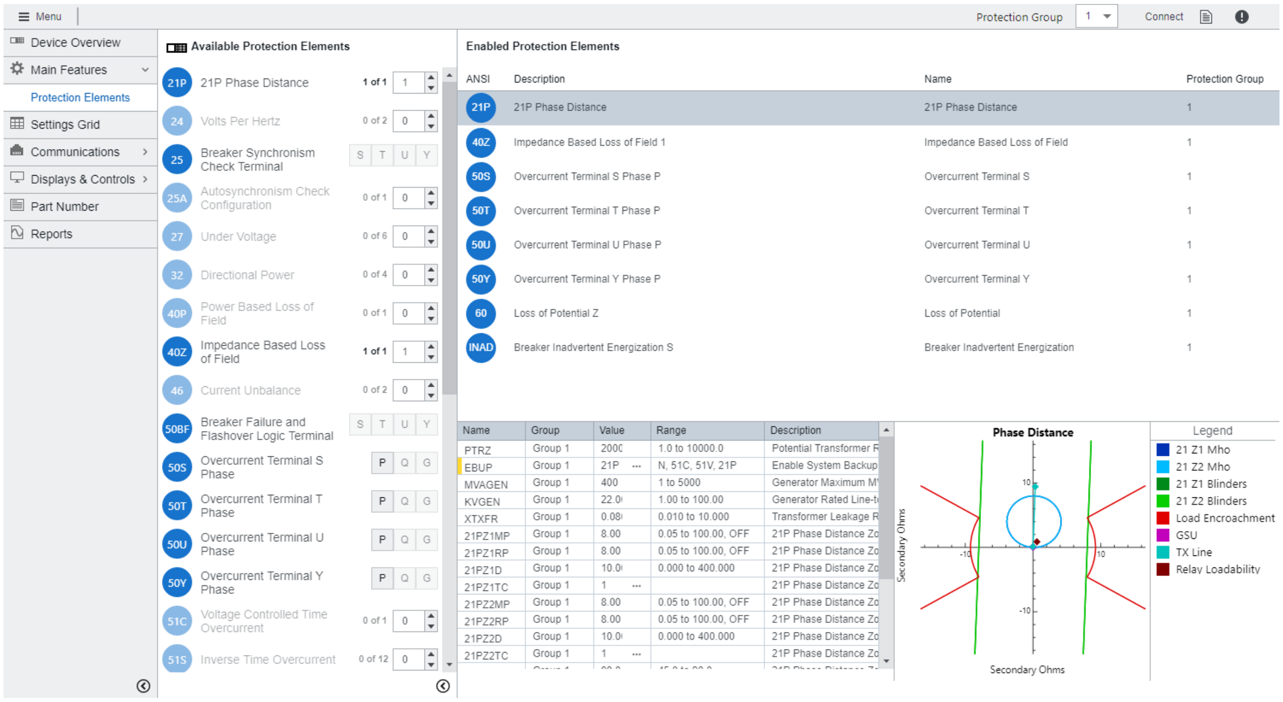


Figure 33 Protection Element View

Protection Visualization

SEL Grid Configurator enables graphical visualization of number of core protection functions of the SEL-400G. These visualization tools make your configuration process faster and give you confidence that the relay is configured just as you intend.

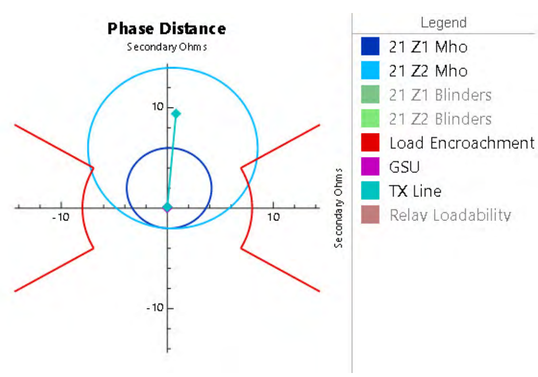


Figure 34 Protection Visualization View

Device Reporting

Whether during commissioning or normal operation, you need to quickly and accurately identify and download all relevant IED reports. The reporting view in SEL Grid Configurator enables you to view and download reports for one or many devices. Filter by date, report type, or device type and download reports to your computer.

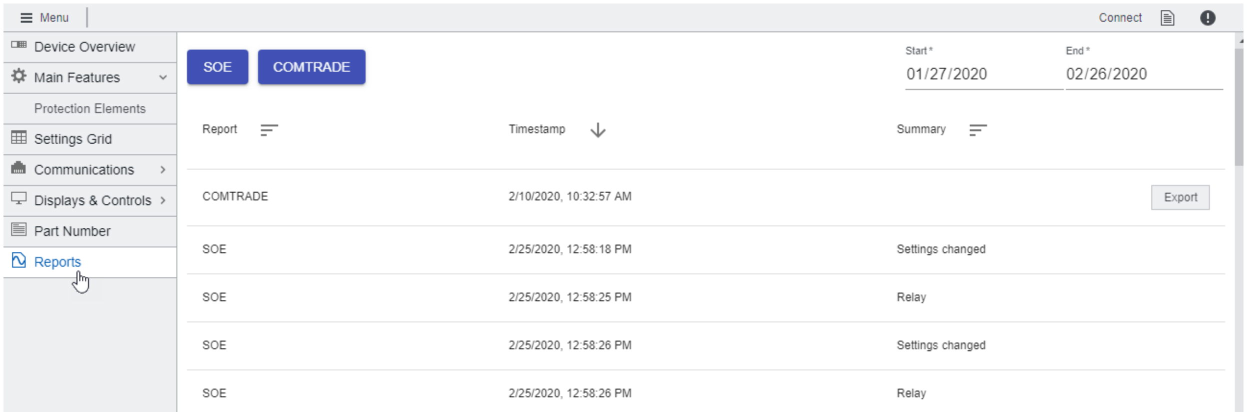


Figure 35 View Reports

Architect IEC 61850 Configurator

Design and configure the SEL-400G in IEC 61850 installations using SEL Grid Configurator and Architect together. Architect provides a means to configure and document the IEC 61850 communications settings between SEL devices and devices from multiple manufacturers.

SYNCHROWAVE Event Visualization

Use SYNCHROWAVE Event to display and analyze disturbance events. Records from multiple relays can be easily merged and time-aligned; allowing easy analysis of an event spanning one or more generating facilities.

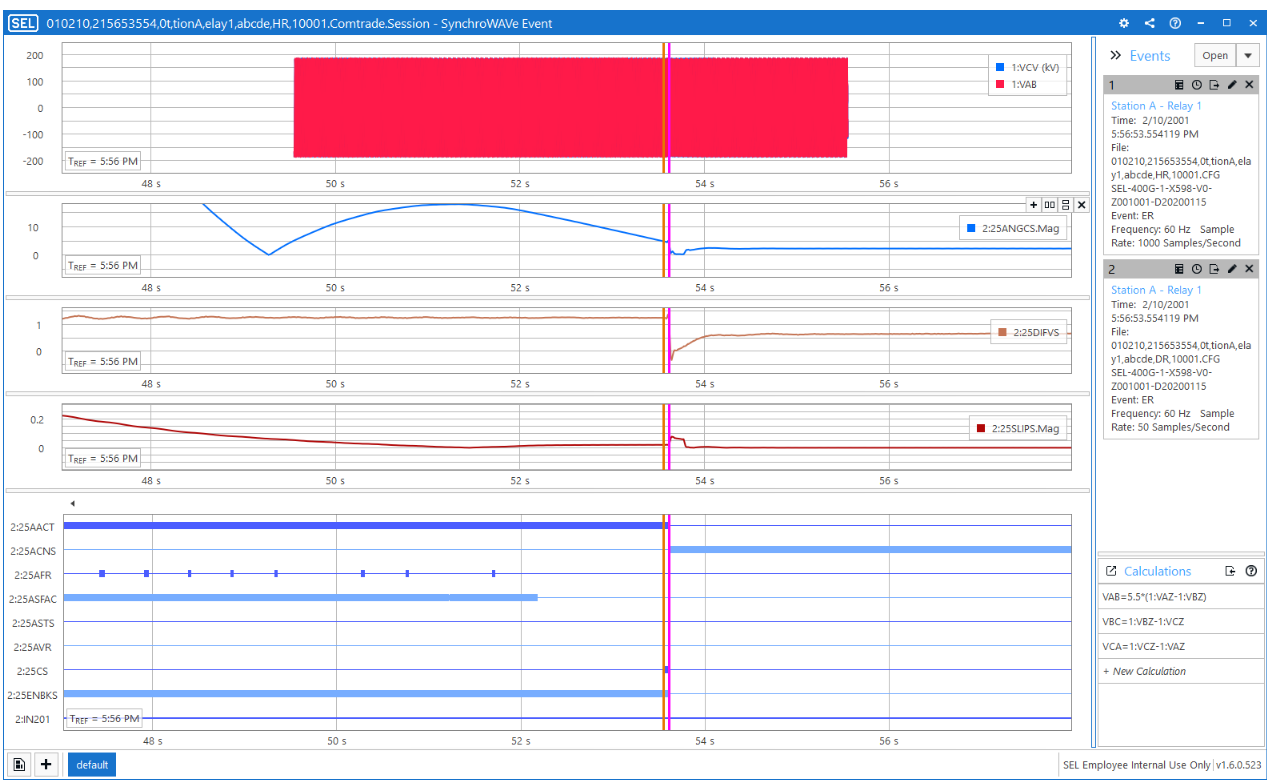


Figure 36 SYNCHROWAVE

TEAM Event Collection

Use ACSELERATOR TEAM® SEL-5045 Software for automatic event archiving and secure remote file retrieval. The same software can be used to archive COMTRADE and SOE files from the SEL-400G and other relays in your generation facility.

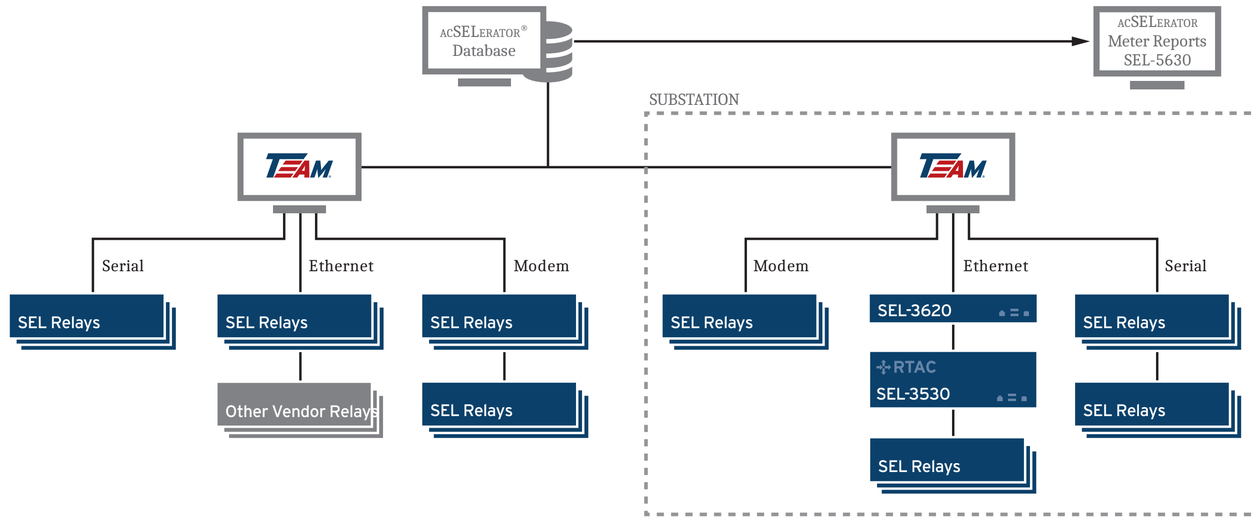


Figure 37 TEAM Works With Multiple Devices in a Variety of Configurations to Meet System Needs

Diagrams and Dimensions

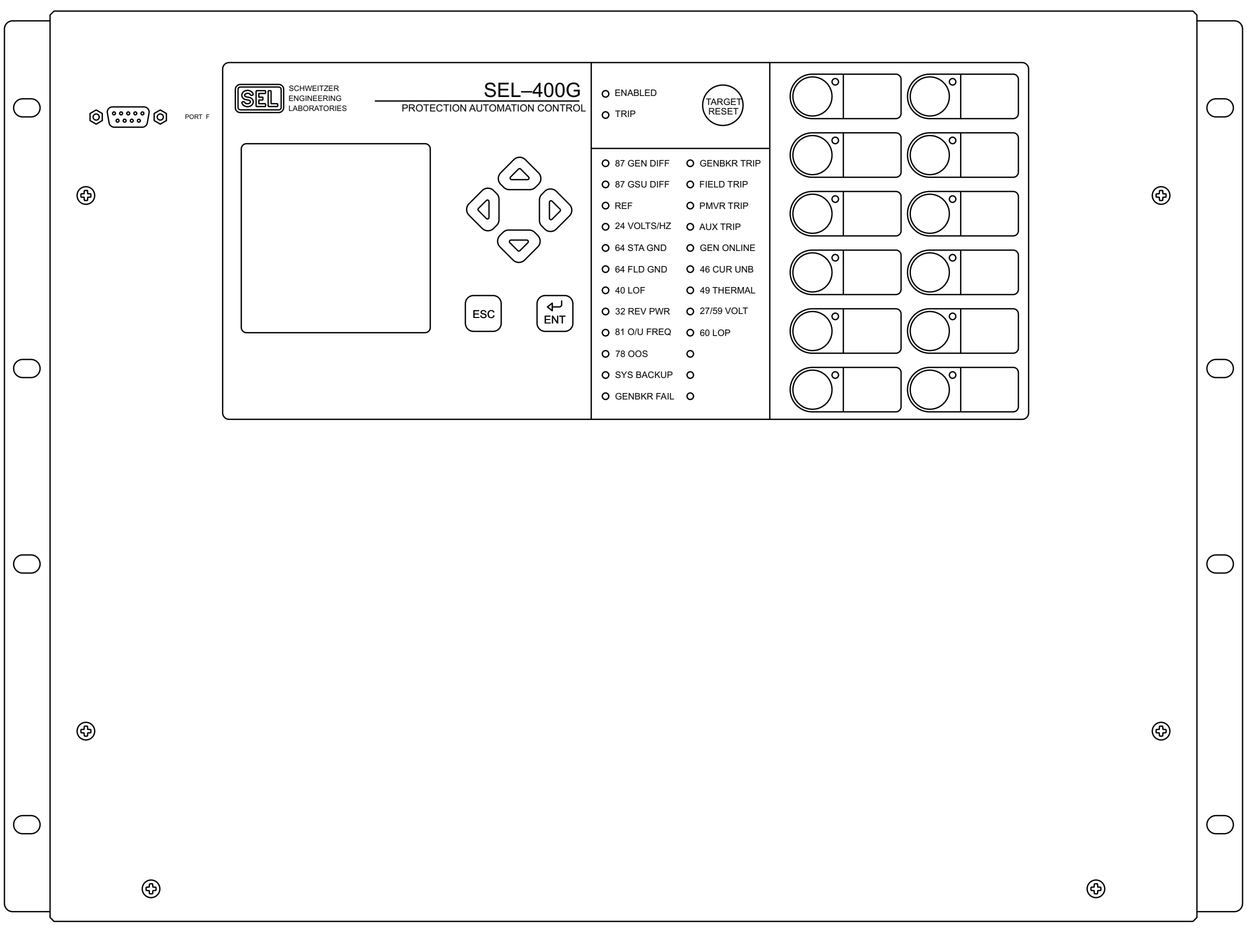
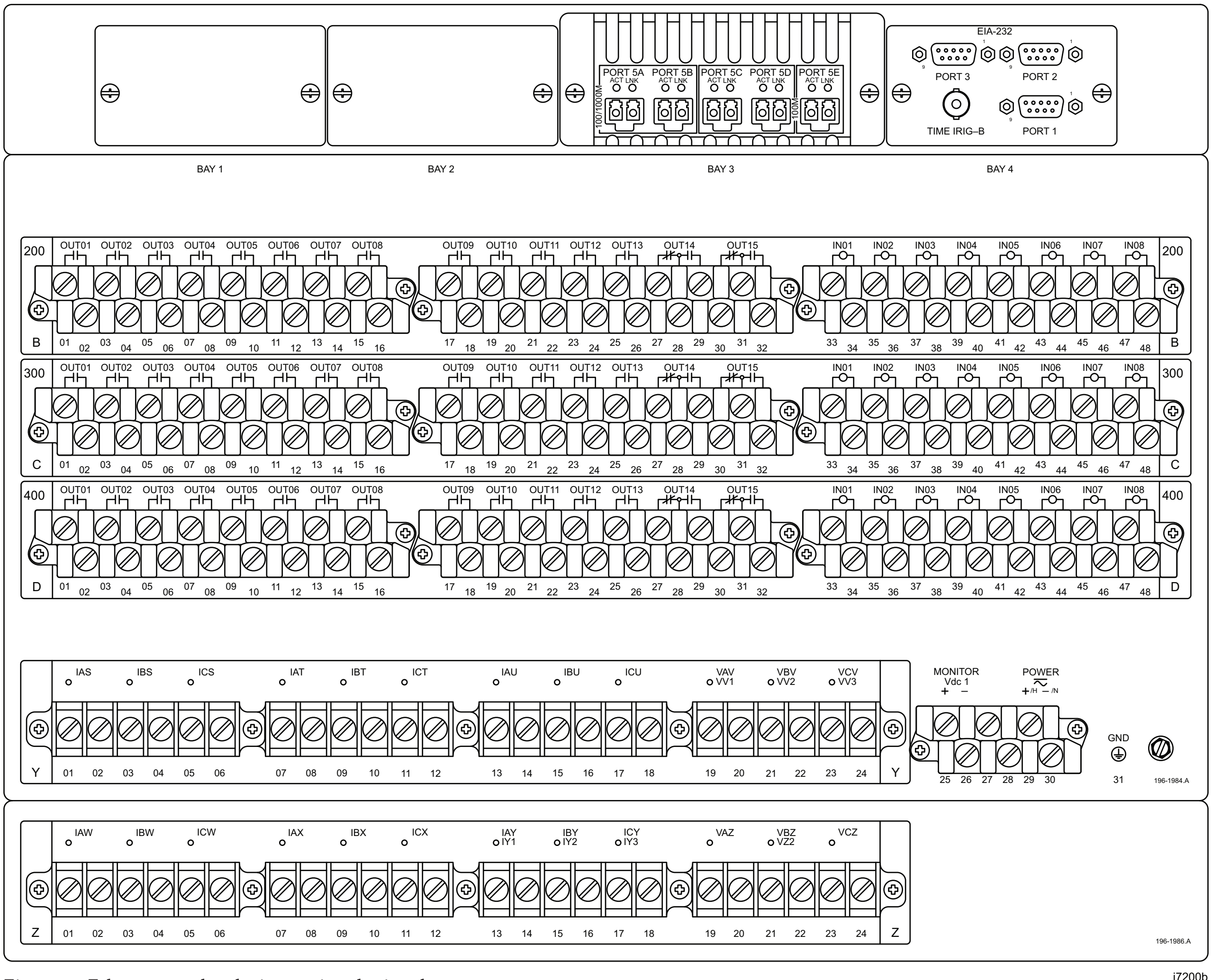
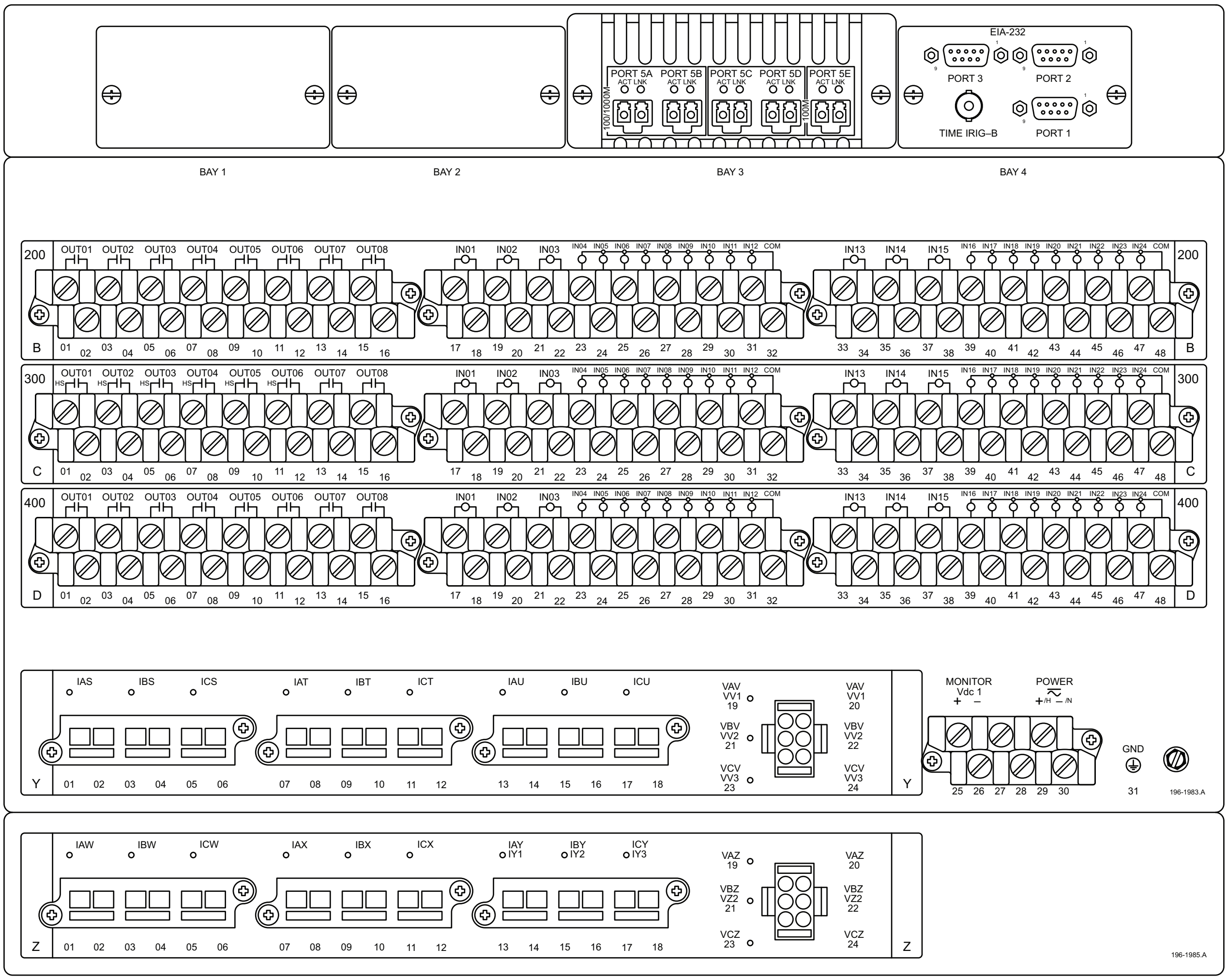


Figure 38 SEL-400G Front-Panel Diagram



Five-port Ethernet card ordering option depicted.

Figure 39 SEL-400G Rear-Panel Diagram With Fixed Terminal Blocks



Five-port Ethernet card ordering option depicted.

i7200b

Figure 40 SEL-400G Rear-Panel Diagram With Connectorized Terminal Blocks

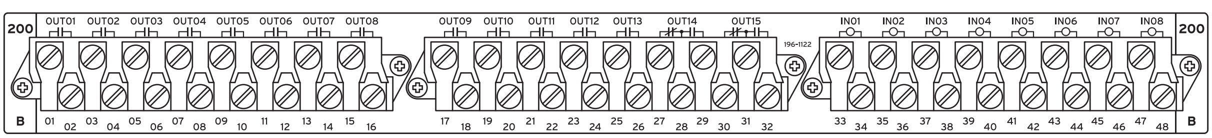


Figure 2.5 I/O Interface Board INT2

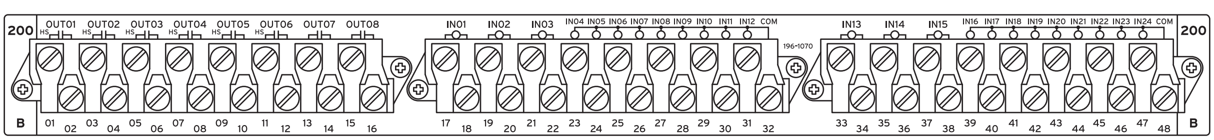


Figure 2.6 I/O Interface Board INT4

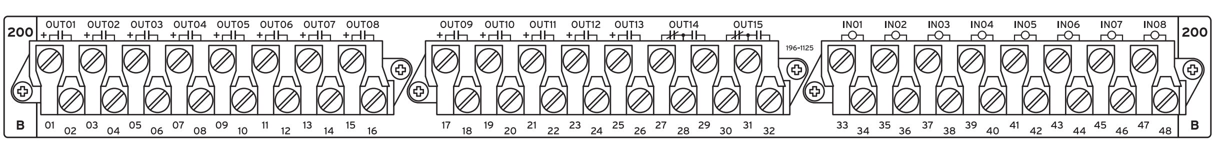


Figure 2.7 I/O Interface Board INT7

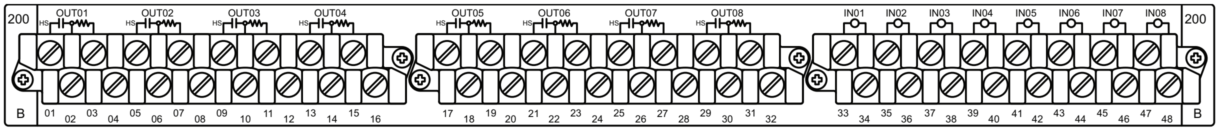


Figure 2.8 I/O Interface Board INT8

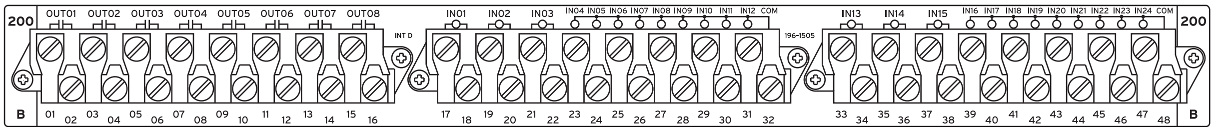


Figure 2.9 I/O Interface Board INTD

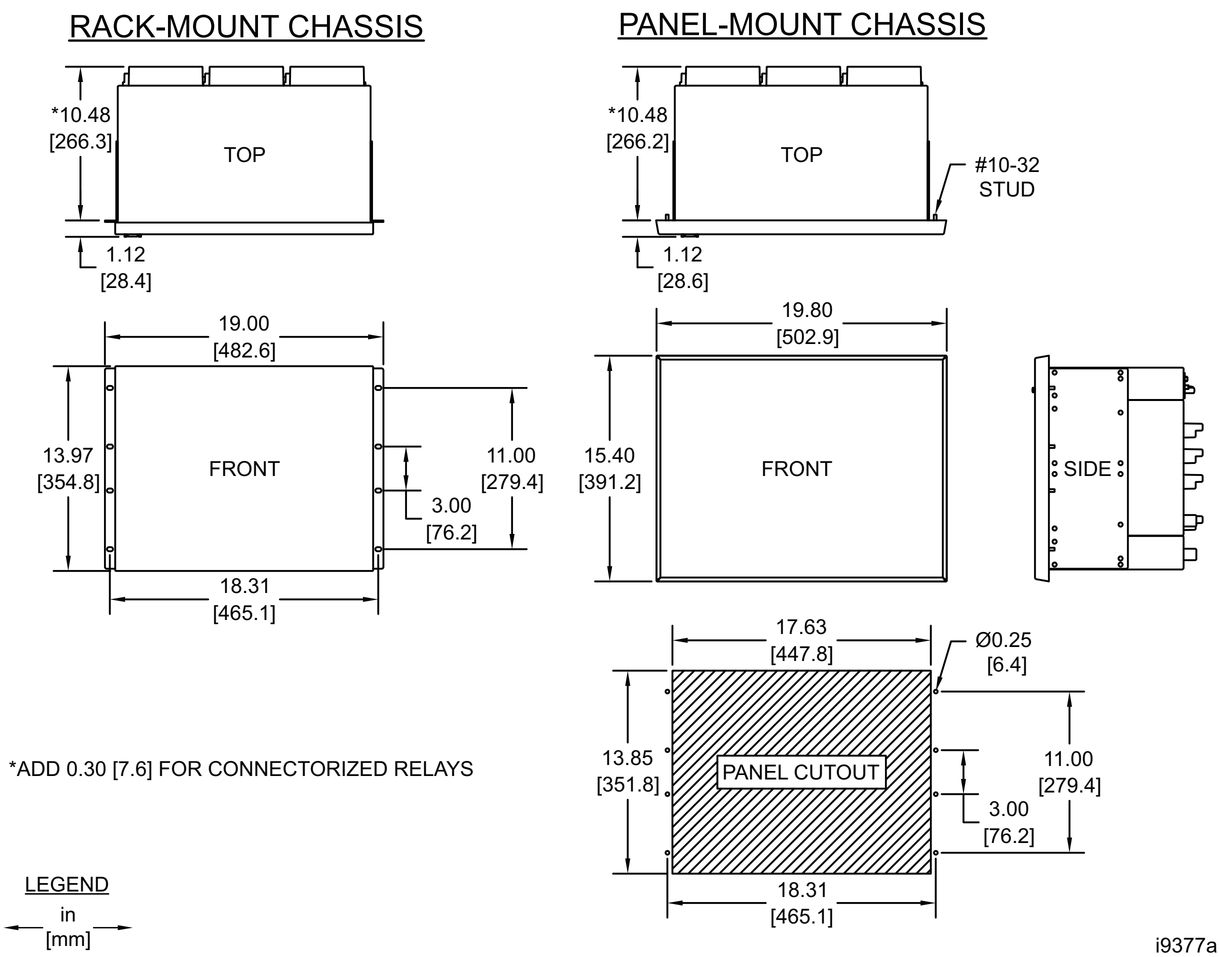


Figure 3 SEL-400G Dimensions for Rack- and Panel-Mount Models

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

General

AC Analog Inputs

Sampling Rate:	8 kHz

AC Current Inputs (Secondary Circuits)

Note: Current transformers are Measurement Category II.

Input Current

5 A Nominal:	S, T, U, W, X, and Y terminals
1 A Nominal:	S. T, U, W, X, and Y terminals
0.2 A/1 A/5 A Nominal:	Y terminal only (REF)

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

5 A Nominal:	91.0 A
1 A Nominal:	18.2 A
0.2 A Nominal:	3.64 A

Continuous Thermal Rating

5 A Nominal:	15 A 20 A (+55°C)
1 A Nominal:	3 A 4 A (+55°C)
0.2 A Nominal:	0.6 A 0.8 A (+55°C)

Saturation Current (Linear) Rating

5 A Nominal:	100 A
1 A Nominal:	20 A
0.2 A Nominal:	4 A

One-Second Thermal Rating

5 A Nominal:	500 A
1 A Nominal:	100 A
0.2 A Nominal:	20 A

One-Cycle Thermal Rating

5 A Nominal:	1250 A-peak
1 A Nominal:	250 A-peak
0.2 A Nominal:	50 A-peak

Burden Rating

5 A Nominal:	≤0.5 VA at 5 A
1 A Nominal:	≤0.1 VA at 1 A
0.2 A Nominal:	≤0.02 VA at 0.2 A

A/D Current Limit

Note: Signal clipping may occur beyond this limit.

5 A Nominal:	247.5 A
1 A Nominal:	49.5 A
0.2 A Nominal:	9.9 A

AC Voltage Inputs

Three-phase, four-wire (wye), and two PT delta and single-phase (only V terminal) connections are supported.

Rated Voltage Range:	55–250 V_{LN} (V and Z terminals)
Operational Voltage Range:	0–300 V_{LN}
Ten-Second Thermal Rating:	600 Vac
Burden:	≤0.1 VA @ 125 V

Frequency and Rotation

Rotation:	ABC ACB
Nominal Frequency Rating:	50 60
Frequency Tracking (Requires PTs):	Tracks between 5.0–120.0 Hz Below 5.0 Hz = 5.0 Hz Above 120.0 Hz = 120.0 Hz
Maximum Slew Rate:	30 Hz/s

Power Supply

24–48 Vdc

Rated Voltage:	24–48 Vdc
Operational Voltage Range:	18–60 Vdc
Vdc Input Ripple:	15% per IEC 60255-26:2013
Interruption:	20 ms at 24 Vdc, 100 ms at 48 Vdc per IEC 60255-26:2013
Burden:	<40 W

48–125 Vdc or 110–120 Vac

Rated Voltage:	48–125 Vdc, 110–120 Vac
Operational Voltage Range:	38–140 Vdc 85–140 Vac
Rated Frequency:	50/60 Hz
Operational Frequency Range:	30–120 Hz
Vdc Input Ripple:	15% per IEC 60255-26:2013
Interruption:	14 ms @ 48 Vdc, 160 ms @ 125 Vdc per IEC 60255-26:2013
Burden:	<40 W, <90 VA

125–250 Vdc or 110–240 Vac

Rated Voltage:	125–250 Vdc, 110–240 Vac
Operational Voltage Range:	85–300 Vdc 85–264 Vac
Rated Frequency:	50/60 Hz
Operational Frequency Range:	30–120 Hz
Vdc Input Ripple:	15% per IEC 60255-26:2013
Interruption:	46 ms @ 125 Vdc, 250 ms @ 250 Vdc per IEC 60255-26:2013
Burden:	<40 W, <90 VA

Control Outputs

Note: IEEE C37.90-2005 and IEC 60255-27:2013

Update Rate: 2.5 ms

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

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

Mechanical Endurance: 10,000 operations

Standard

Rated Voltage: 24–250 Vdc
110–240 Vrms

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

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

Short-Time Thermal Withstand: 50 A for 1 s

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

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

Limiting Breaking Capacity/ Electrical Endurance: 10,000 operations
10 operations in 4 seconds, followed by 2 minutes idle

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

Hybrid (High-Current Interrupting)

Rated Voltage: 24–250 Vdc

Operational Voltage Range: 0–300 Vdc

Operating Time: Pickup ≤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
4 Adc at 85°C

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

Limiting Breaking Capacity/ Electrical Endurance: 10,000 operations
4 operations in 1 second, followed by 2 minutes idle

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

Note: Do not use hybrid control outputs to switch ac control signals.

Fast Hybrid (High-Speed High-Current Interrupting)

Rated Voltage: 24–250 Vdc

Operational Voltage Range: 0–300 Vdc

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

Short-Time Thermal Withstand: 50 Adc for 1 s

Continuous Contact Current: 6 Adc at 70°C
4 Adc at 85°C

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

Limiting Breaking Capacity/ Electrical Endurance: 10,000 operations
4 operations in 1 second, followed by 2 minutes idle

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

Note: Do not use hybrid control outputs to switch ac control signals.

Control Inputs

Optoisolated (Use With AC or DC Signals)

INT2, INT7, and INT8 Interface Boards: 8 inputs with no shared terminals

INT4 and INTD Interface Boards: 6 inputs with no shared terminals
18 inputs with shared terminals (2 groups of 9 inputs with each group sharing one terminal)

Voltage Options: 24, 48, 110, 125, 220, 250 V

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

DC Thresholds (Dropout Thresholds Indicate Level-Sensitive Option)

24 Vdc: Pickup 19.2–30.0 Vdc
Dropout: <14.4 Vdc

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

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

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

220 Vdc: Pickup 176–264 Vdc;
Dropout <132 Vdc

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

AC Thresholds (Ratings Met Only When Recommended Control Input Settings Are Used—see *Table 2.1*.)

24 Vac: Pickup 16.4–30.0 Vac rms
Dropout: <10.1 Vac rms

48 Vac: Pickup 32.8–60.0 Vac rms;
Dropout <20.3 Vac rms

110 Vac: Pickup 75.1–132.0 Vac rms;
Dropout <46.6 Vac rms

125 Vac: Pickup 89.6–150.0 Vac rms;
Dropout <53.0 Vac rms

220 Vac: Pickup 150.3–264 Vac rms;
Dropout <93.2 Vac rms

250 Vac: Pickup 170.6–300 Vac rms;
Dropout <106 Vac rms

Sampling Rate: 2 kHz

Communications Ports

EIA-232: 1 front and 3 rear

Serial Data Speed: 300–57600 bps

Ethernet Card Slot for the Optional Four-Port Ethernet Card

Ordering Option: 10/100BASE-T

Connector Type: RJ45

Ordering Option: 100BASE-FX Fiber-Optic

Connector Type: LC

Fiber Type: Multimode

Wavelength: 1300 nm

Source: LED

Min. TX Power: –19 dBm

Max. TX Power: –14 dBm

RX Sensitivity: –32 dBm

Sys. Gain: 13 dB

Ethernet Card Slot for the Optional Five-Port Ethernet Card

Ordering Option: 100BASE-FX fiber-optic Ethernet SFP transceiver

Part Number: 8103-01 or 8109-01

Mode: Multi

Wavelength (nm): 1310

Source: LED

Connector Type: LC

Min. TX Pwr. (dBm): –24

Max. TX Pwr. (dBm): –14

Min. RX Sens. (dBm): –31

Max. RX Sens. (dBm): –12

Approximate Range: 2 km

Transceiver Internal Temperature Accuracy: ±3.0°C

Transmitter Average Optical Power Accuracy: ±3.0 dB

Received Average Optical Input Power Accuracy: ±3.0 dB

Ordering Option: 1000BASE-LX fiber-optic Ethernet SFP transceiver

Part Number: 8130-01, 8130-02, 8130-03, or 8130-04

Mode: Single

Wavelength (nm): 1310

Source: LED

Connector Type: LC

	Part Number			
	8130-01	8130-02	8130-03	8130-04
Min. TX Pwr. (dBm)	–9.5	–6	–5	–2
Max. TX Pwr. (dBm)	–3	–1	0	3
Min. RX Sens. (dBm)	–21	–22	–24	–24
Max. RX Sens. (dBm)	–3	–3	–3	–3
Approximate Range (km)	10	20	30	40

Transceiver Internal Temperature Accuracy: ±3.0°C

Transmitter Average Optical Power Accuracy: ±3.0 dB

Received Average Optical Input Power Accuracy: ±3.0 dB

Ordering Option: 1000BASE-XD fiber-optic Ethernet SFP transceiver

Part Number: 8130-05

Mode: Single

Wavelength (nm): 1550

Source: LED

Connector Type: LC

Min. TX Pwr. (dBm): –5

Max. TX Pwr. (dBm): 0

Min. RX Sens. (dBm): –24

Max. RX Sens. (dBm): –3

Approximate Range: 50 km

Transceiver Internal Temperature Accuracy: ±3.0°C

Transmitter Average Optical Power Accuracy: ±3.0 dB

Received Average Optical Input Power Accuracy: ±3.0 dB

Ordering Option: 1000BASE-ZX fiber-optic Ethernet SFP transceiver

Part Number: 8130-06, 8130-08, or 8130-10

Mode: Single

Wavelength (nm): 1550

Source: LED

Connector Type: LC

	Part Number		
	8130-06	8130-08	8130-10
Min. TX Pwr. (dBm)	0	1	5
Max. TX Pwr. (dBm)	5	5	8
Min. RX Sens. (dBm)	–24	–36	–36
Max. RX Sens. (dBm)	–3	–10	–10
Approximate Range (km)	80	160	200

Transceiver Internal Temperature Accuracy: ±3.0°C

Transmitter Average Optical Power Accuracy: ±3.0 dB

Received Average Optical Input Power Accuracy: ±3.0 dB

Ordering Option: 1000BASE-SX fiber-optic Ethernet SFP transceiver

Part Number: 8131-01

Mode: Multi

Wavelength (nm): 850

Source: LED

Connector Type: LC

Min. TX Pwr. (dBm): –9

Max. TX Pwr. (dBm): –2.5

Min. RX Sens. (dBm): –18

Max. RX Sens. (dBm): 0

Approximate Range: 300 m for 62.5/125 µm; 550 m for 50/125 µm

Transceiver Internal Temperature Accuracy: ±3.0°C

Transmitter Average Optical Power Accuracy: ±3.0 dB

Received Average Optical Input Power Accuracy: ±3.0 dB

Time Inputs

IRIG Time Input—Serial PORT 1

Input:	Demodulated IRIG-B
Rated I/O Voltage:	5 Vdc
Operational Voltage Range:	0–8 Vdc
Logic High Threshold:	≥2.8 Vdc
Logic Low Threshold:	≤0.8 Vdc
Input Impedance:	2.5 kΩ

IRIG-B Input—BNC Connector

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

PTP

Input:	IEEE 1588 PTPv2
Profiles:	Default, C37.238-2011 (Power Profile), IEC/IEEE 61850-9-3-2016 (Power Utility Automation Profile)
Synchronization Accuracy:	±100 ns @ 1-second synchronization intervals when communicating directly with master clock

Operating Temperature

–40° to +85°C (–40° to +185°F)

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

Humidity

5% to 95% without condensation

Weight (Maximum)

6U Rack Unit:	15.9 kg (35 lb)
7U Rack Unit:	17.6 kg (39 lb)
8U Rack Unit:	20.4 kg (45 lb)

Terminal Connections

Rear Screw-Terminal Tightening Torque, #8 Ring Lug

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

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

Wire Sizes and Insulation

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

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

Type Tests

Installation Requirements

Overvoltage Category:	2
Pollution Degree:	2

Safety

Product Standards
IEC 60255-27:2013
IEEE C37.90-2005
21 CFR 1040.10

Dielectric Strength:
IEC 60255-27:2013, Section 10.6.4.3
2.5 kVac, 50/60 Hz for 1 min: Analog Inputs, Contact Outputs, Digital Inputs
3.6 kVdc for 1 min: Power Supply, Battery Monitors
2.2 kVdc for 1 min: IRIG-B
1.1 kVdc for 1 min: Ethernet

Impulse Withstand:
IEC 60255-27:2013, Section 10.6.4.2
IEEE C37.90-2005
Common Mode:
±1.0 kV: Ethernet
±2.5 kV: IRIG-B
±5.0 kV: All other ports
Differential Mode:
0 kV: Analog Inputs, Ethernet, IRIG-B, Digital Inputs
±5.0 kV: Standard Contact Outputs, Power Supply Battery Monitors
+5.0 kV: Hybrid Contact Outputs

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

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

Ingress Protection:
IEC 60529:2001 + CRGD:2003
IEC 60255-27:2013
IP30 for front and rear panel
IP10 for rear terminals with installation of ring lug
IP40 for front panel with installation of serial port cover
IP52 for front panel with installation of dust protection accessory

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

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

Electromagnetic (EMC) Immunity

Product Standards:
IEC 60255-26:2013
IEC 60255-27:2013
IEEE C37.90-2005

Surge Withstand Capability (SWC):
IEC 61000-4-18:2006 + A:2010
IEEE C37.90.1-2012
Slow Damped Oscillatory, Common and Differential Mode:
±1.0 kV
±2.5 kV
Fast Transient, Common and Differential Mode:
±4.0 kV

Electrostatic Discharge (ESD):	IEC 61000-4-2:2008 IEEE C37.90.3-2001 Contact: ±8 kV Air Discharge: ±15 kV
Radiated RF Immunity:	IEEE C37.90.2-2004 IEC 61000-4-3:2006 + A1:2007 + A2:2010 20 V/m (>35 V/m, 80% AM, 1 kHz) Sweep: 80 MHz to 1 GHz Spot: 80, 160, 450, 900 MHz 10 V/m (>15 V/m, 80% AM, 1 kHz) Sweep: 80 MHz to 1 GHz Sweep: 1.4 GHz to 2.7 GHz Spot: 80, 160, 380, 450, 900, 1850, 2150 MHz
Electrical Fast Transient Burst (EFTB):	IEC 61000-4-4:2012 Zone A: ±2 kV: Communication ports ±4 kV: All other ports
Surge Immunity:	IEC 61000-4-5:2005 Zone A: ±2 kV_{L-L} ±4 kV_{L-E} ±4 kV: Communication ports **Note:** Cables connected to IRIG-B ports shall be less than 10 m in length for Zone A compliance. Zone B: ±2 kV: Communication ports
Conducted Immunity:	IEC 61000-4-6:2013 20 V/m; (>35 V/m, 80% AM, 1 kHz) Sweep: 150 kHz–80 MHz Spot: 27, 68 MHz
Power Frequency Immunity (DC Inputs):	IEC 61000-4-16:2015 Zone A: Differential: 150 V_{RMS} Common Mode: 300 V_{RMS}
Power Frequency Magnetic Field:	IEC 61000-4-8:2009 Level 5: 100 A/m; ≥60 Seconds; 50/60 Hz 1000 A/m 1 to 3 Seconds; 50/60 Hz **Note:** 50G1P ≥0.05 (ESS = N, 1, 2) 50G1P ≥0.1 (ESS = 3, 4)
Power Supply Immunity:	IEC 61000-4-11:2004 IEC 61000-4-17:1999/A1:2001/A2:2008 IEC 61000-4-29:2000 AC Dips & Interruptions Ripple on DC Power Input DC Dips & Interruptions Gradual Shutdown/Startup (DC only) Discharge of Capacitors Slow Ramp Down/Up Reverse Polarity (DC only)
Damped Oscillatory Magnetic Field:	IEC 61000-4-10:2016 Level 5: 100 A/m

EMC Compatibility

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

Environmental

Product Standards:	IEC 60255-27:2013
Cold, Operational:	IEC 60068-2-1:2007 Test Ad: 16 hours at –40°C
Cold, Storage:	IEC 60068-2-1:2007 Test Ad: 16 hours at –40°C
Dry Heat, Operational:	IEC 60068-2-2:2007 Test Bd: 16 hours at +85°C
Dry Heat, Storage:	IEC 60068-2-2:2007 Test Bd: 16 hours at +85°C
Damp Heat, Cyclic:	IEC 60068-2-30:2005 Test Db: +25°C to +55°C, 6 cycles (12 + 12-hour cycle), 95% RH
Damp Heat, Steady State:	IEC 60068-2-78:2013 Severity: 93% RH, +40°C, 10 days
Cyclic Temperature:	IEC 60068-2-14:2009 Test Nb: –40°C to +80°C, 5 cycles
Vibration Resistance:	IEC 60255-21-1:1988 Class 2 Endurance, Class 2 Response
Shock Resistance:	IEC 60255-21-2:1988 Class 1 Shock Withstand, Class 1 Bump Withstand, Class 2 Shock Response
Seismic:	IEC 60255-21-3:1993 Class 2 Quake Response

Reporting Functions

High-Resolution Data

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

Note: Per IEEE C37.111-2013, *Common Format for Transient Data Exchange (COMTRADE) for Power Systems*.

Event Reports

Length:	0.25–24 seconds (based on LER and SRATE settings)
Volatile Memory:	3 s of back-to-back event reports sampled at 8 kHz
Nonvolatile Memory:	At least 4 event reports of a 3 s duration sampled at 8 kHz
Resolution:	2.5 ms

Disturbance Recorder

Length:	60–300 seconds (based on DRLER setting)
Volatile Memory:	At least 1 DR event of 300 s duration sampled at 50 Hz
Nonvolatile Memory:	At least 4 DR events of 300 s duration sampled at 50 Hz
Resolution:	20 ms for all elements

Event Summary

Storage:	100 summaries

Breaker History

Storage:	128 histories

Sequential Events Recorder

Storage:	1000 entries
Trigger Elements:	250 relay elements
Resolution:	0.5 ms for contact inputs
Resolution:	2.5 ms for all elements

Processing Specifications

AC Voltage and Current Inputs

8000 samples per second, 3 dB low-pass analog filter cut-off frequency at 3.1 kHz, ±5%
Digital filtering
Full-cycle cosine after low-pass analog filtering

Analog Update Rate (Arate)

Frequency (Hz)	Update Rate (ms)
20 < F ≤ 120	2.5
10 < F ≤ 20	5
5 < F ≤ 10	7.5

Protection and Control Processing

2.5 ms (minimum)

Control Points

64 remote bits
64 local control bits
32 latch bits in protection logic
32 latch bits in automation logic

Relay Element Pickup Ranges and Accuracies

Differential Elements (General)

Number of Zones: 2 (A, B, and C elements)
Number of Terminals: 6
TAP Pickup: (0.1–32.0) • I_{NOM} A secondary
TAP Range: TAP_{MAX}/TAP_{MIN} ≤35
Time-Delay Accuracy: ±0.1% plus ±2.5 ms

Differential Elements (Restraint)

Pickup Range: 0.1–4.0 per unit
Pickup Accuracy: 1 A nominal: ±5%
5 A nominal: ±5% ±0.10 A
Pickup Time (If E87UNB = N): 1.25 cyc minimum
1.25 cyc + 2.5 ms typical
1.25 cyc + 5.0 ms max
Pickup Time (If E87UNB = Y): 0.5 cyc minimum
0.5 cyc + 2.5 ms typical
1.5 cyc max
Slope Setting Range: 5%–90%

Differential Elements (Unrestraint)

Pickup Range: (1.0–20.0) • TAP
Pickup Accuracy: ±5% of user setting, ±0.02 • I_{NOM} A
Pickup Time (Filtered Unrestraint): 0.7 cyc minimum
0.85 cyc typical
1.2 cyc maximum
Pickup Time (Raw Unrestraint): 0.25 cyc minimum
0.5 cyc typical
1.0 cyc maximum

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

Harmonic Elements (2nd, 4th, 5th)

Setting Range: OFF, 5–100% of fundamental
Pickup Accuracy: 1 A nominal ±5% ±0.02 A
5 A nominal ±5% ±0.10 A
Time-Delay Accuracy: 0.1% + 1 processing interval

Negative-Sequence Differential Element

Pickup Range: 0.05–1 per unit
Slope Range: 5–100%
Pickup Accuracy: ±5% of user setting, ±0.02 • I_{NOM} A
Maximum Pickup/Dropout Time: 2 cycles
Winding Coverage: 2%

Incremental Restraint and Operating Threshold Current Supervision

Setting Range: 0.1–10.0 per unit
Accuracy: ±5% ±0.02 • I_{NOM}

Open-Phase Detection Logic

3 elements per terminal (S, T, U, Y)
Pickup Range
1 A Nominal: 0.04–1.00 A
5 A Nominal: 0.2–5.00 A
Maximum Pickup/Dropout Time: 1/2 cyc + 0.0025 ms

Restricted Earth Fault (REF)

Three Elements: 1 per IY1, IY2, IY3
Setting Range: 0.05–3 per unit
Pickup Accuracy
1 A Nominal: 0.01 A
5 A Nominal: 0.05 A
Maximum Pickup/Dropout Time: 1.25 cyc + Arate + 0.0025 s

Instantaneous/Definite-Time Overcurrent Elements (50)

Phase- and Negative-Sequence, Ground-Residual Elements
Setting Range
5 A Nominal: 0.25–100.00 A secondary, 0.01-A steps
1 A Nominal: 0.05–20.00 A secondary, 0.01-A steps
Accuracy (Steady State)
5 A Nominal: ±0.05 A plus ±3% of setting
1 A Nominal: ±0.01 A plus ±3% of setting
Transient Overreach (Phase and Ground Residual)
5 A Nominal: ±5% of setting, ±0.10 A
1 A Nominal: ±5% of setting, ±0.02 A
Transient Overreach (Negative Sequence)
5 A Nominal: ±6% of setting, ±0.10 A
1 A Nominal: ±6% of setting, ±0.02 A
Time-Delay Range: 0.00–400 s
Timer Accuracy: ±0.005 s plus ±0.1% of setting
Maximum Pickup/Dropout Time: 1.25 cyc + Arate + 0.005 s

Adaptive Time-Overcurrent Elements (51S and 51CV)

Setting Range (Adaptive Within the Range)
5 A Nominal: 0.25–16.00 A secondary, 0.01 A steps
1 A Nominal: 0.05–3.20 A secondary, 0.01 A steps
Accuracy (Steady State)
5 A Nominal: ±0.05 A plus ±3% of setting
1 A Nominal: ±0.01 A plus ±3% of setting
Transient Overreach
5 A Nominal: ±5% of setting, ±0.10 A
1 A Nominal: ±5% of setting, ±0.20 A
Time Dial Range
U.S.: 0.50–15.00, 0.01 steps
IEC: 0.05–1.00, 0.01 steps
Timing Accuracy: ±1.25 cyc ± 5 ms ±4% of curve time (for current between 2 and 30 multiples of pickup)

Curves operate on definite time for current greater than 30 multiples of pickup.

Reset: 20 ms or electromechanical reset emulation time

Voltage-Controlled Overcurrent Element

Setting Range: 0.25–16.00 A, sec
Curve: U1–U5, C1–C5

Time Dial: 0.05–15.0

EM Reset: Y, N

Pickup Accuracy: ±1.25 cyc + Arate + 0.005s

Time-Delay Accuracy: ±0.1% of setting ±0.005 s

Voltage-Restrained Overcurrent Element

Setting Range: 2.00–16.00 A, sec

Curve: U1–U5, C1–C5

Time Dial: 0.50–15.00

EM Reset: Y, N

Pickup Accuracy: ±1.25 cyc + Arate + 0.005 s

Time-Delay Accuracy: ±0.1% of setting ±0.005 s

Phase Directional Elements (67)

Number: 4 (1 each for S, T, U, Y)

Outputs: Forward and reverse

Accuracy: ±0.05 Ω secondary

Transient Overreach: +5% of set reach

Maximum Delay: 1.25 cycles + Arate + 5 ms

Ground Directional Elements

Number: 4 (1 each for S, T, U, Y)

Outputs: Forward and reverse

Polarization Quantity: Zero-sequence voltage

Operate Quantity: Zero-sequence current ($3I_0$) (where $3I_0$ = IA + IB + IC)

Sensitivity: 0.05 • I_{NOM} A of secondary $3I_0$

Accuracy: ±0.05 Ω secondary

Transient Overreach: +5% of set reach

Maximum Delay: 1.25 cycles + Arate + 5 ms

Negative-Sequence Directional Element

Number: 4 (1 each for S, T, U, Y)

Outputs: Forward and reverse

Polarization Quantity: Negative-sequence voltage

Operate Quantity: Negative-sequence current ($3I_2$)

Sensitivity: 0.05 • I_{NOM} A of secondary $3I_2$

Accuracy: ±0.05 Ω secondary

Transient Overreach: +5% of setting

Maximum Delay: 1.25 cycles + Arate + 5 ms

Undervoltage and Overvoltage Elements (27/59)

Setting Ranges

- Phase Elements: 2–300 V_{LN} in 0.01-V steps
- Phase-to-Phase Elements: 4–520 V_{LL} in 0.01-V steps
- Sequence Elements: 2–300 V_{LN} in 0.01-V steps

Pickup Accuracy (Steady State)

- Phase Elements: ±3% of setting, ±0.5 V
- Phase-to-Phase Elements Wye): ±3% of setting, ±0.5 V
- Phase-to-Phase Elements (Delta): ±3% of setting, ±1 V
- Sequence Elements: ±5% of setting, ±1 V

Pickup Accuracy (Transient Overreach)

- Phase Elements: ±5%
- Phase-to-Phase Elements Wye): ±5%
- Phase-to-Phase Elements (Delta): ±5%
- Sequence Elements: ±5%

Maximum Pickup/Dropout Time

- Phase Elements: 1.25 cycles ± Arate + 5.0 ms
- Phase-to-Phase Elements Wye): 1.25 cycles ± Arate + 5.0 ms
- Sequence Elements: 1.25 cycles ± Arate + 5.0 ms
- Time Delay Accuracy: ±0.1% of user setting ±5 ms
- Inverse Time Delay Accuracy: ±1% of user setting ±5 ms

Underfrequency and Overfrequency Elements (81)

Setting Range: 5.01–119.99 Hz, 0.01-Hz steps

Accuracy, Steady State Plus Transient: ±0.005 Hz for frequencies between 40.00 and 70.00 Hz

Maximum Pickup/Dropout Time: 3.0 cycles

Setting Range, Undervoltage Blocking: 20.00–200.00 V_{LN} (Wye) or V_{LL} (Open-Delta)

Pickup Accuracy, Undervoltage Blocking: ±2% ±0.5 V

Time-Delay Range: 0.05–400.00 s, 0.01-s increment

Time-Delay Accuracy: ±0.1% of setting ±0.005 seconds

Accumulated Frequency Elements (81A)

Setting Range: 5.01–119.99 Hz, 0.01-Hz steps

Accuracy, Steady State Plus Transient: ±0.005 Hz for frequencies between 40.00 and 70.00 Hz

Maximum Pickup/Dropout Time: 0–400 s for 81AD and 0.5–6000 for band times

Time-Delay Range: 0.050–80.000 s, 0.005-s increment

Time-Delay Accuracy: ±0.1% of setting ±0.005 seconds

Rate-of-Change-of-Frequency Elements (81R)

Setting Range: –29.95 to 29.95 Hz/s, 0.05-Hz/s steps

Setting Range, Undervoltage Blocking: 20.00–200.00 V_{LN} (wye) or V_{LL} (open-delta)

Accuracy: ±0.005 Hz/s frequencies between 20.00 and 80.00 Hz

Pickup Accuracy, Undervoltage Blocking: ±2% ±0.5 V

Time-Delay Range: 0.050–80.000 s, 0.005 s increment

Time-Delay Accuracy: ±0.1% of setting ±5 ms seconds

Mho Phase Distance Elements

Number of Zones: 2

Pickup Range

- 5 A Nominal: OFF, 0.05 to 100 ohms, sec
- 1 A Nominal: OFF, 0.25 to 500 ohms, sec

Offset Range

- 5 A Nominal: 0.00–10 ohms, sec
- 1 A Nominal: 0.00–50 ohms, sec

Pickup Accuracy: ±5% of user setting ±0.1 Inom

Maximum Operating Time: 1.00 cycle + Arate + 10 ms

Time Delay Accuracy: ±0.1% of user setting ± 5 ms

Breaker Inadvertent Energization Protection Logic

Setting Range, Overcurrent

- 5 A Nominal: 0.25–5.00 A secondary, 0.01 A steps
- 1 A Nominal: 0.05–1.00 A secondary, 0.01 A steps

Accuracy (Steady State)

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

Transient Overreach	
5 A Nominal:	±5% of setting, ±0.10 A
1 A Nominal:	±5% of setting, ±0.20 A
Setting Range, Undervoltage:	1.00–300 V, sec in 0.01-V steps
Accuracy, Undervoltage:	±2% ±0.5 V
Time-Delay Range (Arm/ Disarm):	0.0000–100 s
Time-Delay Range:	0.0000–10 s
Time-Delay Accuracy:	±0.1% of setting ±0.005 s

Volts/Hertz Elements (24)

Definite-Time Element

Setting Range:	100–200% steady state
Pickup Accuracy, Steady-State:	±1% of set point
Maximum Pickup/Dropout Time:	1.5 cycles + delay time setting
Time-Delay Range:	0.040–6000 s
Time-Delay Range, Reset:	0.040–6000 s
Time-Delay Accuracy:	±0.1% of setting ±5 ms

User-Definable Curve Element

Setting Range:	100–200%
Pickup Accuracy:	±1% of set point
Reset Time-Delay Range:	0.040–6000 s
Timing Accuracy:	±0.1% ±0.1% of curve time ±5 ms

Synchronism-Check Elements (25)

Slip Frequency PU Range:	0.005-0.500 Hz, 0.001 Hz steps
Slip Frequency PU Accuracy:	±0.0025 Hz plus ±2% of setting
Close Angle Range:	0.1-80 degrees, 0.1-degree steps
Close Angle Accuracy:	±0.1 degrees

Autosynchronism Elements (25A)

Frequency Matching	
Raise/Lower:	Digital Output
Setting Range, Control Pulse Mode:	OFF, Proportional Width, Fixed Duration, Proportional Frequency
Setting Range, Control Slope:	0.01–100 Hz/s
Setting Range, Control Pulse Period:	0.000–60 s
Setting Range, Control Pulse Duration:	0.000–60 s
Timing Accuracy:	±1% ±5.0 ms
Voltage Matching	
Raise/Lower:	Digital Output
Setting Range, Control Pulse Mode:	OFF, Proportional Width, Fixed Duration, Proportional Frequency
Setting Range, Control Slope:	0.01–100 V/s
Setting Range, Control Pulse Period:	0.000–60 s
Setting Range, Control Pulse Duration:	0.000–60 s
Timing Accuracy:	±0.1% ±5.0 ms
Time-Delay Range, Control Expiration:	0.000–400 s
Time-Delay Accuracy, Control Expiration:	±0.1% of setting ±5 ms

Breaker Failure Instantaneous Overcurrent

Setting Range	
5 A Nominal:	0.50–50 A secondary, 0.01-A steps
1 A Nominal:	0.10–10.0 A, 0.01-A steps
Accuracy	
5 A Nominal:	±0.05 A, ±3% of setting
1 A Nominal:	±0.01 A, ±3% of setting
Transient Overreach	
5 A Nominal:	±5%, ±0.10 A
1 A Nominal:	±5%, ±0.02 A
Maximum Pickup Time:	1.25 cyc + Arate + 5 ms
Maximum Dropout Time:	1.25 cyc + Arate + 5 ms
Maximum Reset Time:	1.25 cyc + Arate + 5 ms
Time-Delay Range:	0.0000–20 s, 0.0025 s steps
Time-Delay Accuracy:	±0.1% of setting ±5 ms

Breaker Flashover Elements

Setting Range:	0.50–50 A secondary, 0.01 A steps
Accuracy, Steady State Plus Transient:	±5% of setting, ±0.10 A
Maximum Pickup/Dropout Time:	1.25 cyc + Arate + 2.5 ms
Time-Delay Range:	0.00–100.00 s, 0.01-s steps
Time-Delay Accuracy:	±0.1% of setting ±5 ms

Directional Overpower/Underpower Element (32)

Operating Quantities:	OFF, 3P*m*F, 3Q*m*F,3P*qp*F, 3Q*qp*F (*m* = S, T, U, Y, G *qp* = ST, TU, UW, WX)
Setting Range	
5 A:	–2000.00 to 2000.00 VA, 0.02 VA, sec steps
1 A:	–400.00 to 400.00 VA, 0.02 VA, sec steps
Pickup Accuracy:	±3% of setting and ±5 VA, power factor >±0.5 at nominal frequency
Time-Delay Range:	0.000–400 s
Time-Delay Accuracy:	±0.1% of setting ±5 ms

Impedance-Based Loss of Field Element (40Z)

Zone 1

Setting Range, Mho Diameter	
5 A Nominal:	OFF, 0.1–100 ohms, sec
1 A Nominal:	OFF, 0.5–500 ohms, sec
Setting Range, Offset Reactance	
5 A Nominal:	–50.0 to 0 ohms, sec
1 A Nominal:	–250.0 to 0 ohms, sec
Pickup Accuracy:	±3% at an impedance angle of –90 degrees

Zone 2

Setting Range, Mho Diameter	
5 A Nominal:	OFF, 0.1–100 ohms, sec
1 A Nominal:	OFF, 0.5–500 ohms, sec
Setting Range, Offset Reactance	
5 A Nominal:	–50.0 to 50 ohms, sec
1 A Nominal:	–250.0 to 250 ohms, sec
Setting Range, Supervision Angle:	–20.0 to 0 deg in 0.1 deg steps
Pickup Accuracy:	±3% at an impedance angle of –90 degrees
Time-Delay Range:	0.000–400 s
Time-Delay Accuracy:	±0.1% of setting ±0.005 s

PQ-Based Loss of Field Element (40P)

Setting Range, Zones 1, 2, 4	
5 A Nominal:	–2000.00 to –1.00 VA sec, 0.01 VA sec step
1 A Nominal:	–400.00 to –0.20 VA, sec, 0.01 VA sec step
Setting Range, Zones 2 and 4 (Ranges Depend on GCC Point Specifying)	
5 A Nominal:	–2000.00 to 2000.00 VA sec, 0.01 VA sec steps
1 A Nominal:	–400.00 to 400.00 VA sec, 0.01 VA sec steps
Pickup Accuracy:	±3% of setting and ±5 VA, power factor > ±0.5 at nominal frequency
Time-Delay Range:	0.000–400 s
Time-Delay Accuracy:	±0.1% of setting ±0.005 s

Current Unbalance Element (46)

Operate Quantity:	I2GP, I2GPEQ
Setting Range %:	OFF, 2.0–100
Level 1 Delay:	0.000–1000.000 s
Level 2 Time Dial:	1–100 s
Pickup Accuracy:	Harmonic filtering is run every 5 s
Time-Delay Accuracy:	±0.1% of setting ±0.005 seconds
Harmonic Filtering Accuracy Range:	20–80 Hz of tracked frequency

Split-Phase Element (60P/N)

Setting Range	
5 A Nominal:	0.1–100 A, sec, 0.01 A sec step
1 A Nominal:	0.02–20 A, sec, 0.01 A sec steps
0.2 A Nominal:	0.01–4 A, sec, 0.01 A sec steps
Time-Delay Range:	0.000–400 s
Time-Constant Range:	1–2400 s
Pickup Accuracy:	±1% of setting
Time-Delay Accuracy:	±0.1% of setting ±5.0 ms

100% Stator Ground Element (64G)

Setting Range, Voltage:	0.1-150.0 volts sec
Pickup Accuracy:	±3% of setting, ±0.1 V
Setting Range, Power Supervision	
5 A Nominal:	OFF, 1.00–2000 VA sec, 0.01 VA steps
1 A Nominal:	OFF, 0.20–400 VA sec, 0.01 VA steps
Time-Delay Range:	0.000–400 s
Time-Delay Accuracy:	±0.1% of setting ±5.0 ms

Field Ground Element (64F)

Setting Range:	OFF, 0.5–200 kilohms
Pickup Accuracy:	Defined by the SEL-2664
Time-Delay Range:	0.000–400 seconds
Time-Delay Accuracy:	±0.1% of setting ±5.0 ms

Injection-Based Stator Ground Element (64S)

Setting Range:	OFF, 0.1–10 kilohms
Pickup Accuracy:	Defined by the SEL-2664S
Time-Delay Range:	0.000–400 seconds
Time-Delay Accuracy:	±0.1% of setting ±5.0 ms

Out-of-Step Element (78)

Setting Range, Mho and Blinder Reach	
5 A Nominal:	0.05 to 100 ohms, sec
1 A Nominal:	0.25 to 500 ohms, sec
Setting Range, Current Supervision	
5 A Nominal:	1.00–100 A, sec
1 A Nominal:	0.20–20 A, sec
Time-Delay Range, OOS:	0.000–1 s
Time-Delay Range, Trip:	0.000–1 s
Time-Delay Range, Trip Duration:	0.000–5 s
Setting Range, Generator Slip Counter:	1–5
Setting Range, System Slip Counter:	OFF, 1–10
Setting Range, Total Slip Counter:	OFF, 1–10
Time-Delay Range, Slip Counter Reset:	0.000–1 s
Accuracy (Steady State)	
5 A Nominal:	±5% of setting plus ±0.01 A for SIR (source to line impedance ratio) < 30 ±10% of setting plus ±0.01 A for 30 ≤ SIR ≤ 60
1 A Nominal:	±5% of setting plus ±0.05 A for SIR (source to line impedance ratio) < 30 ±10% of setting plus ±0.05 A for 30 ≤ SIR ≤ 60
Transient Overreach:	<5% of setting plus steady-state accuracy
Time-Delay Accuracy:	±0.1% of setting ±5.0 ms

Load Encroachment Element

Setting Range, Impedance Reach	
5 A Nominal:	0.05 to 64 ohms, sec
1 A Nominal:	0.25 to 320 ohms, sec
Setting Range, Forward Load Angle:	–90.0 to 90 deg
Setting Range, Reverse Load Angle:	90.0 to 270 deg
Impedance Accuracy:	±3%
Time-Delay Accuracy:	±0.1% of setting ±5.0 ms

Bay Control

Breakers:	4 maximum
Disconnects (Isolators):	10 maximum
Time-Delay Range:	0.020–2000 s, 5 ms step
Time-Delay Accuracy:	±0.1% of setting ±5.0 ms

Station DC Battery System Monitor

Rated Voltage:	15–300 Vdc
Operational Voltage Range:	0–350 Vdc
Input Sampling Rate:	2 kHz
Processing Rate:	5 ms
Operating Time:	≤1.5 seconds (element dc ripple) ≤30 ms (all elements but dc ripple)
Setting Range	
DC Settings:	1 Vdc Steps (OFF, 15–300 Vdc)
AC Ripple Setting:	1 Vac Steps (1–300 Vac)
Pickup Accuracy:	±10% ±2 Vdc (dc ripple) ±3% ±2 Vdc (all elements but dc ripple)

Metering Accuracy

All metering accuracies are based on an ambient temperature of 20°C and nominal frequency.

Currents

Phase Current Magnitude

5 A Model:	±0.2% plus ±4 mA (0.05–3.0) • I_{NOM}
1 A Model:	±0.2% plus ±0.8 mA (0.05–3.0) • I_{NOM}
0.2 A Model:	±0.2% plus ±0.8 mA (0.05–0.5) • I_{NOM} ±0.2% plus ±0.4 mA (0.5–3.0) • I_{NOM}

Phase Current Angle

5 A Model:	±0.6° in the current range (0.05–0.5) • I_{NOM} ±0.2° in the current range (0.5–3.0) • I_{NOM}
1 A Model:	±0.6° in the current range (0.05–0.5) • I_{NOM} ±0.2° in the current range (0.5–3.0) • I_{NOM}
0.2 A Model:	±1.5° in the current range (0.05–0.5) • I_{NOM} ±0.3° in the current range (0.5–3.0) • I_{NOM}

Sequence Current Magnitude

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

Sequence Current Angle

All Models:	±0.3°

Voltages

300 V Maximum Inputs

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

Power

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

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

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

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

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

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

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

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

Energy

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

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

MVARh (Q), Per Phase (Wye), 3ϕ (Wye or Delta)

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

Demand/Peak Demand Metering

Time Constants:	5, 10, 15, ..., 250, 255, 300 minutes
IA, IB, and IC per Terminal:	±0.2% ±0.0008 • I_{NOM}, (0.1–1.2) • I_{NOM}
3I2 per Terminal 3I0 (IG) per Terminal (Wye-Connected Only):	±0.3% ±0.0008 • I_{NOM}, (0.1–20) • I_{NOM}

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

24 RTD inputs via SEL-2600 Series RTD Module and SEL-2800 Fiber-Optic Transceiver

Monitor Ambient or Other Temperatures

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

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

Synchrophasor

Synchrophasor Measurement:	IEC/IEEE 60255-118-1:2018 (IEEE C37.118.1:2011, 2014a)
Synchrophasor Data Transfer:	IEEE C37.118.2:2011
Number of Synchrophasor Data Streams:	5

Number of Synchrophasors for Each Stream:
24 Phase Synchrophasors (6 Voltage and 18 Currents)
8 Positive-Sequence Synchrophasors (2 Voltage and 6 currents)

Number of User Analogs for Each Stream:	16
Number of User Digitals for Each Stream:	64
Synchrophasor Data Rate:	As many as 60 messages per second (60 Hz) As many as 50 messages per second (50 Hz)
Synchrophasor Accuracy:	Class P
Synchrophasor Data Recording:	Records as much as 120 s IEEE C37.232-2011, File Naming Convention

Breaker Monitoring

Running Total of Interrupted Current (kA) per Pole:	±5% ±0.02 • I_{NOM}
Percent kA Interrupted for Trip Operations:	±5%
Percent Breaker Wear per Pole:	±5%
Compressor/Motor Start and Run Time:	±1 s
Time Since Last Operation:	±1 day

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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