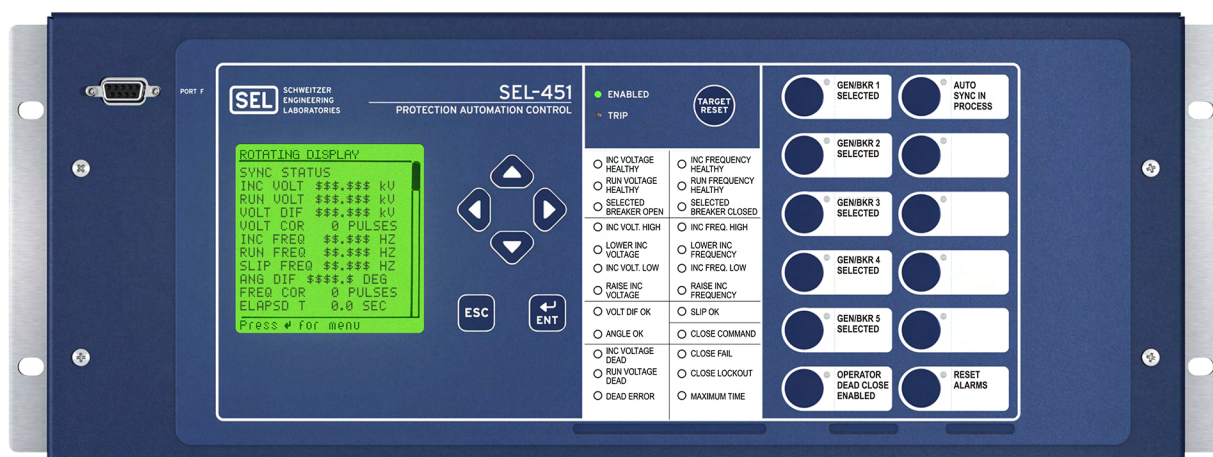




SEL-451-Based Advanced Automatic Synchronizer

Flexible Digital Automatic Synchronizer for Generator and Microgrid Synchronizing



Key Features and Benefits

SEL combines Quickset Designer Template technology with the SEL-451-5 Protection, Automation, and Bay Control System to offer a fully featured, single-function, advanced automatic synchronizer (A25A) that can match the incoming (controlled side) voltage and frequency to the running (system side) of the synchronizing breaker for as many as five generator and breaker combinations. The A25A also closes the synchronizing breaker at the exact moment of phase coincidence to smoothly synchronize two independent power systems.

NOTE: The A25A Quickset Designer Templates are compatible with SEL-451-5 firmware versions R324 and later. The A25A templates are not compatible with the SEL-451A single-breaker variant.

When the SEL-451-5 is configured as an A25A, SEL does not recommend using it for protection of associated circuits. The A25A implementation uses multiple setting groups. These setting groups will change when the unit turns on or off. Each setting group change causes the SEL-451-5 to go offline for approximately two seconds. While the relay is offline, all functions are unavailable, resulting in a temporary loss of protection and other relay capabilities.

The A25A is available in two configurations:

- A single-phase synchronizer that can internally select incoming and running signals from its six VT inputs. These VT inputs can be configured for two incoming and four running signals or for one incoming and five running signals. If an A25A application to synchronize multiple generator and breaker combinations requires other configurations, you may need external circuits for switching the VT inputs.
- A two channel, three-phase synchronizer for applications requiring two channel verification from two sources of incoming and running signals, three-phase verification of incoming and running signals, or both. This configuration requires external switching circuits to connect the incoming and running signals when used for multiple generator and breaker combinations.

The A25A includes the following standard features:

- **Simplicity of application.** Take advantage of a fully engineered synchronizer with simple I/O and Global settings and fewer than 30 settings needed to configure a generator and breaker combination for synchronizing.
- **Device-specific setting interface.** Use the A25A QuickSet Designer Template to configure the A25A. The A25A designer template hides all of the settings for unused features of the SEL-451-5 relay and organizes all of the user settings required to configure the A25A features.
- **High-accuracy measurement of synchronizing parameters.** Use the A25A where high accuracy is desired. The A25A has slip measurements with $\pm 2.5 \text{ mHz} \pm 2\%$ of setting accuracy compared to alternative devices with typical accuracies of $\pm 10 \text{ mHz}$ or even $\pm 20 \text{ mHz}$. Close angle accuracy is $\pm 3^\circ$.
- **Numerical VT magnitude and angle compensation.** Eliminate the need for special ratio matching auxiliary VTs in applications with incoming and running VTs separated by the generator step-up transformer or for applications with dissimilar incoming and running VT ratios.
- **Breaker close delay compensation.** Optimize closing by using a slip-compensated advanced close angle; issue the close signal in advance of zero degrees such that the breaker main contacts close as the generator phase angle difference reaches zero degrees.
- **Generator frequency and voltage matching control.** Pulse governor and exciter reference points to bring the generator or microgrid island into synchronism acceptance windows. Pulse interval and pulse width parameters are configurable for multiple synchronization situations. The control functions support fixed or proportional pulse width control characteristics. The voltage and frequency control functions can be individually turned off when not needed.
- **IF > RF (anti-motoring) control.** Improve synchronizing performance in weak systems and applications with prime movers with extremely sensitive reverse power protection. When enabled, the A25A requires incoming frequency (IF) greater than running frequency (RF) to cause initial power flow to be out of the generator and can prevent the reverse power protection from tripping upon initial synchronization of the generator.
- **Dead scope control.** Improve synchronizing times by preventing a near-zero slip-rate condition (dead scope) where the two systems that are being synchronized move very slowly relative to one another. A dead scope condition causes the systems to take a long time to rotate into phase. This function generates a frequency raise pulse to increase slip when slip less than 20 mHz is detected.
- **IV > RV control.** Improve synchronizing performance in weak systems. Apply in situations where it is desirable to prevent the generator from absorbing VARs from the system and pulling down the system voltage on initial synchronization. When enabled, the system requires incoming voltage (IV) greater than running voltage (RV).
- **Three close conditions.** Select the conditions for closing the synchronizing breaker. The system can close the controlled circuit breaker under three conditions with specific close acceptance criteria: automatic synchronizing close (phase angle is slipping), parallel close (zero-slip conditions), and dead close.
- **Operator close permissive.** Implement multiple-level close supervision schemes by using the operator close permissive function.
- **Easy-to-tune settings.** Simply set the interval for correction pulses and set the slope or duration based upon observed response characteristics of the generator controls.
- **Digital relay-to-relay communications.** Use MIRRORING BITS[®] communications or IEC 61850 GOOSE communications over fiber-optic links to remotely control breakers or to locate the device remote from the generator control room. Just add an appropriate remote I/O (RIO) module such as the SEL-2505 Remote I/O Module or the SEL-2440 DPAC Discrete Programmable Automation Controller to locate the synchronizer close to the controlled synchronizing breaker and synchronizing VTs. The RIO can be located at the generator exciter and governor.
- **Advanced communications options.** Easily integrate into your existing control system with serial or optional Ethernet communications by using SEL, DNP3, and/or IEC 61850 protocols.
- **Oscillography and Sequential Events Recording.** Record current and voltage waveforms to analyze operation of each automatic synchronization operation. Record sequential events for binary status points for fine-tuning automatic synchronization system operation and getting to root cause of disturbances.
- **Synchronizing operational parameters displayed.** Troubleshoot and optimize the automatic synchronization operation by using incoming frequency and voltage data recorded for the most recent eight correction pulses. The elapsed time of automatic synchronization operation is also displayed.

Ordering Information

Contact your SEL sales representative and request a quote for a single-phase A25A or a two channel, three-phase A25A with the SEL-451-5 model option selections required for your application.

SEL will create a special configuration based on your part number that will be configured as an A25A. The factory will build the SEL-451-5 with the specified options, load in the A25A Design Template, and install the appropriate configurable label such that the SEL-451-5 is factory-configured for application as a single-function advanced automatic synchronizer device.

Functional Overview

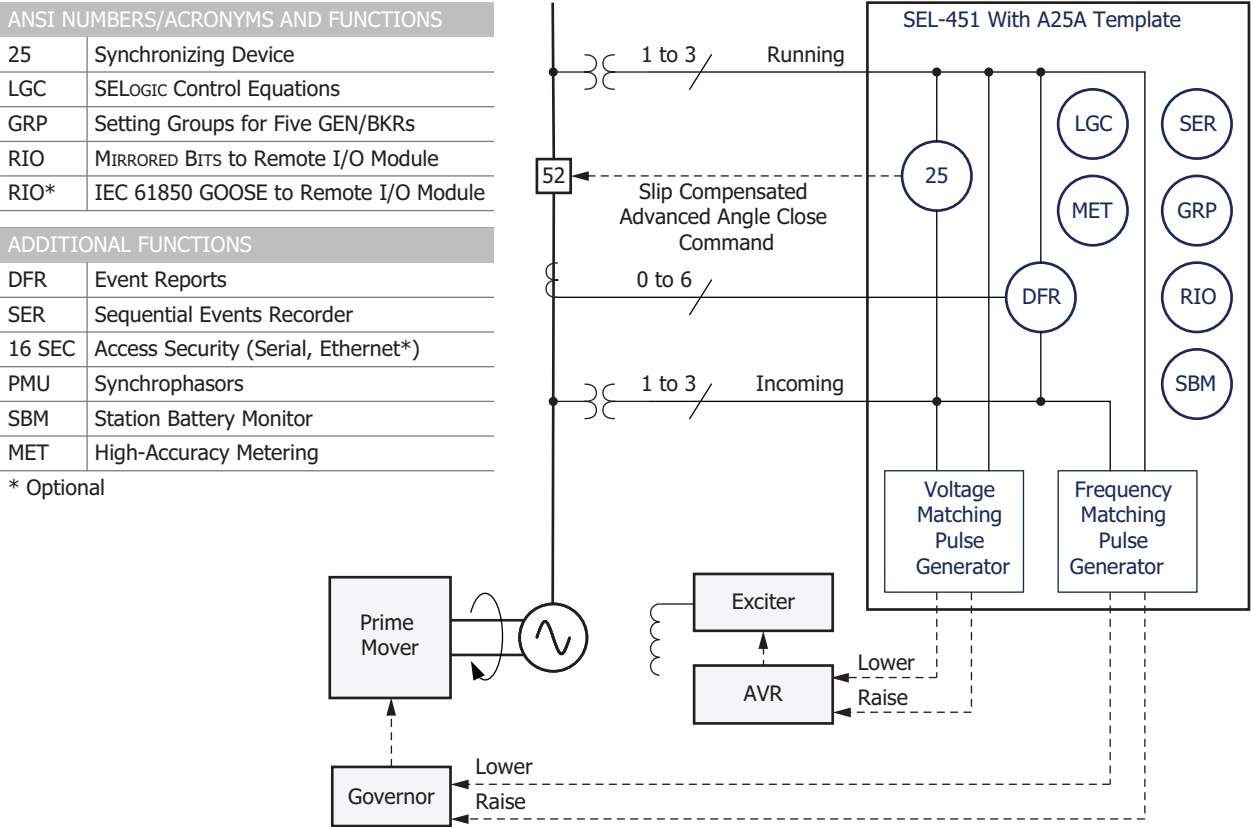


Figure 1 Functional Diagram

For more information on the application of synchronizing systems, see [1], [2], [3], and [4].

Physical Overview

The SEL-451-5 relay is a 19" rack mount chassis with options for 3U and 4U sizes to easily replace legacy 3U and 4U automatic synchronizers. 5U and 8U sizes are also available for applications requiring additional I/O. Both rack-mount and panel-mount versions are available as well as horizontal and vertical versions.

The A25A template default front-panel programming uses the programmable LEDs, along with a multi-line LCD display, to create an information-rich interface to improve operator situational awareness on any synchronizing panel. The 4U and larger chassis offers an optional front panel with 24 target LEDs, 12 operator control pushbuttons, and tricolor LEDs. This is the preferred front-panel configuration. See *Figure 9* for the

default LED programming and default configurable labels. The 3U chassis includes a front panel with 16 target LEDs, 8 operator control pushbuttons, and amber LEDs. See Figure 10 for the default LED programming and default configurable labels. The user can reconfigure the front-panel programming and configurable labels as needed to optimize the operator interface for the application.

The SEL-451-5 has conventional secondary inputs and thus must be hardwired to instrument transformers. The A25A QuickSet Design Template is not compatible with

the SEL-451-6 that supports digital secondary systems (DSS) such as IEC 61850 sampled values or TiDL® inputs. DSS technology can be used to build synchronizing systems using fiber-optic links from merging units to digitize the binary and analog data. For more information, see [5]. Contact SEL Engineering Services, Inc. for a proposal to design and build DSS-based synchronizing systems.

Consult the SEL-451 Protection, Automation, and Bay Control System data sheet for additional details.

QuickSet Design Templates and Aliases

ACSELERATOR QuickSet® SEL-5030 Software is free software available for download from the SEL website. QuickSet is used to create settings files and load them into SEL devices, among other uses.

ACSELERATOR QuickSet Designer software is used to create a customized user interface for setting QuickSet-compatible devices. The end user does not need to have QuickSet Designer to use the Design Templates.

SEL-451-5 relays have the capability to store the template in the nonvolatile memory of the relay, making it possible to both read and send settings in an A25A application.

The A25A template is shown in *Figure 2*. All settings required to set the A25A functions can be set in this view.

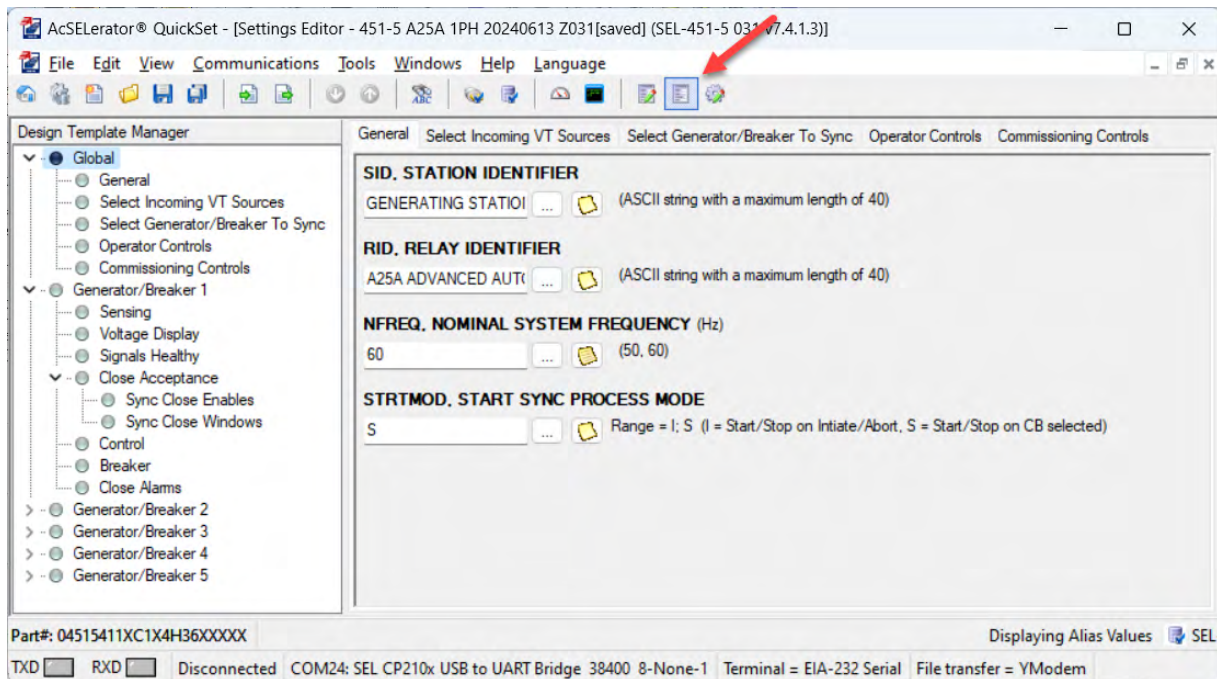


Figure 2 A25A Design Template View

Settings for configuring I/O and logic settings, communications, etc., that are not tied to the template can be made by toggling over to the Settings Editor screen as shown in

Figure 3. In this view, any SEL-451-5 settings that are controlled by the template are colored blue and not editable.

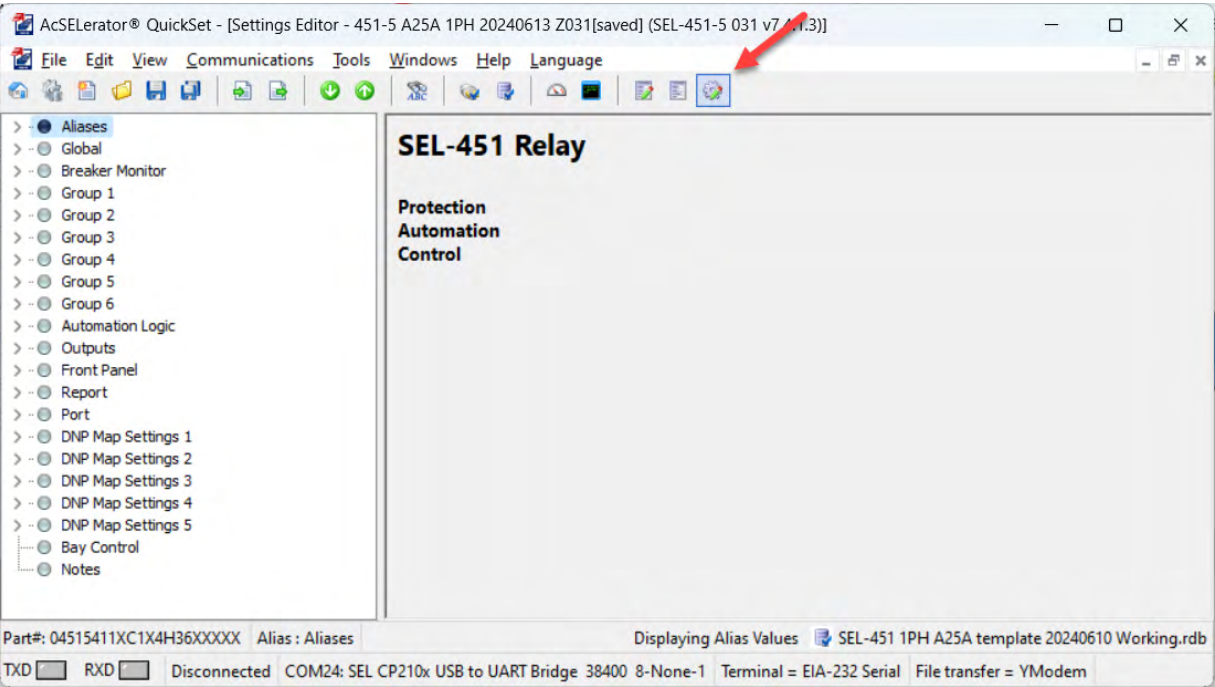


Figure 3 SEL-451 Settings Editor View in QuickSet

The A25A uses the alias functions available in the SEL-451-5 to rename SELOGIC® variables. All settings and operational logic variables used to create the A25A

functionality have been changed from their generic SELOGIC numbers to application-specific, meaningful Relay Word bit names.

Features

Synchronizing Close

The slip-compensated advanced angle close function is the main feature of an automatic synchronizer. As the two systems rotate into phase, the breaker close mechanism is energized at an angle in advance of zero degrees such that the main contacts close at precisely zero degrees phase coincidence. The advance angle is calculated by using dimensional analysis *Equation 1*.

$$ADVANG^{\circ} = \frac{SLIP \text{ cyc}}{\text{second}} \cdot \frac{\text{second}}{FREQNOM \text{ cyc}} \cdot \frac{360^{\circ}}{\text{cyc}} \cdot TCLSBK \text{ cyc}$$

Equation 1

where:

SLIP is the frequency difference between the incoming system and the running system in Hz.

FREQNOM is the nominal system frequency in Hz.

TCLSBK is the breaker closing mechanism time in cycles.

The user typically obtains setting TCLSBK from breaker travel analyzer tests at the time of commissioning.

With the high-accuracy slip measurement of the SEL-451-5 relay, the A25A can typically achieve zero degrees phase coincidence at closure with more precision and consistency than a skilled operator.

Start Synchronizing Process Mode

The A25A can be configured to start the synchronizing process in two ways:

- Start/stop on Generator/Breaker Selected Mode
- Start/stop on Initiate/Abort Mode

The start/stop on Breaker Selected Mode emulates analog technology where the synchronizer is turned on and it starts synchronizing immediately. The start/stop on Initiate/Abort Mode is typically used when integrated with the generator distributed control system (DCS). In this mode, the operator first selects the generator/breaker to be synchronized and then initiates the synchronizing process. This is a Global setting and the operator control logic must be configured as appropriate for the selected STMODE setting.

When synchronizing, only one generator and breaker combination can be selected at a time. An alarm function, SEL_ERR, is provided to alert operators if more than one selection input is asserted.

Three Conditions to Close

The A25A can close the selected breaker under three conditions. These are:

- Automatic synchronizing close (incoming and running voltage and frequency are healthy and slip is detected).
- Parallel close (incoming and running voltage and frequency are healthy and a zero-slip condition is detected).
- Dead close (live incoming and dead running, LIDR, or dead incoming and dead running, DIDR, can be enabled).

Synchronizing Close

The automatic synchronizing close function is the primary function of the A25A and is always enabled. There are two synchronizing close acceptance windows:

- Voltage difference
- Frequency difference (slip)

These permissive windows can be set to be either $\pm$ around zero or positive only. It is often desirable to synchronize with the incoming voltage high such that initial reactive power flow is positive and there is no concern that the generator will adversely affect the running voltage. It is often desirable to synchronize with the incoming frequency high such that initial active power flow is positive. Setting the permissive windows for positive only affects the correction pulse control characteristics as shown in *Figure 5–Figure 8*.

Parallel Close

The parallel close permissive is intended for dual breaker applications where the synchronizer must be able to close the second synchronizing breaker after the incoming system has already been synchronized to the running system. This permissive ensures that the voltage and frequency of the incoming and running systems are healthy and includes a $\pm$ angle window around zero degrees.

The parallel close permissive condition can be disabled when not needed.

Dead Close

The dead close permissive is used for black-start applications where the generator can be used to energize a dead power system. This permissive includes an undervoltage

threshold to declare the signal dead. The dead close permissive also requires an operator to confirm that a dead close is intended by asserting the dead close permissive logic input, DEINPUT. This feature is required to ensure that a blown VT fuse or tripped miniature circuit breaker does not falsely satisfy the permissive condition and cause an out-of-phase synchronization (OOPS).

An alarm function DEADERR is included to alert operators if a dead condition is detected and the operator dead close permissive logic, DEINPUT, is not asserted.

Two dead close conditions can be enabled. LIDR is the typical setting for black-start applications. DIDR is also supported. This option is used in applications where it is desirable to close the generator breaker to connect it to its step-up transformer before applying the field. The combined generator and step-up transformer can then be used to energize a dead system by using an upstream breaker. This sequence of starting significantly reduces the transformer inrush transient.

The dead close permissive condition can be disabled when not needed.

Operator Close Permissive

A robust synchronizing system includes multiple levels of supervision to allow a close command to the synchronizing breaker. A typical system will include two levels of supervision, a close command (either manual or automatic) and a synchronism-check relay. Both must agree that conditions are appropriate before the breaker close mechanism can be energized.

In some applications, it may be desirable to include a third level of supervision. The operator close permissive function can combine manual and automatic close into one integrated system. When this feature is enabled, both the A25A and the operator watching the synchronizing panel indications must agree that the synchronizing acceptance criteria are met. This, combined with the synchronism-check relay provides three-level close supervision.

The function requires that the operator assert logic input, OCINPUT, within a small window in advance of the slip-compensated advanced angle calculated by the A25A, as shown in *Figure 4*. *Figure 4* shows the operator close permissive window under conditions where the incoming frequency is higher than the running frequency (fast). The permissive window is mirrored on the opposite side of phase coincidence for the incoming frequency slow condition. This angle window in advance of phase coincidence is defined by the parallel close angle window.

The function includes logic to lock out the close process if the operator initiates a permissive contact when outside the operator close permissive window. The purpose of this logic is to prevent operators from taking themselves

out of the close process by holding the control switch closed and letting the other contacts initiate closing the breaker. The lockout condition automatically resets when the angle difference leaves the parallel close window to allow another attempt when the incoming angle again approaches phase coincidence.

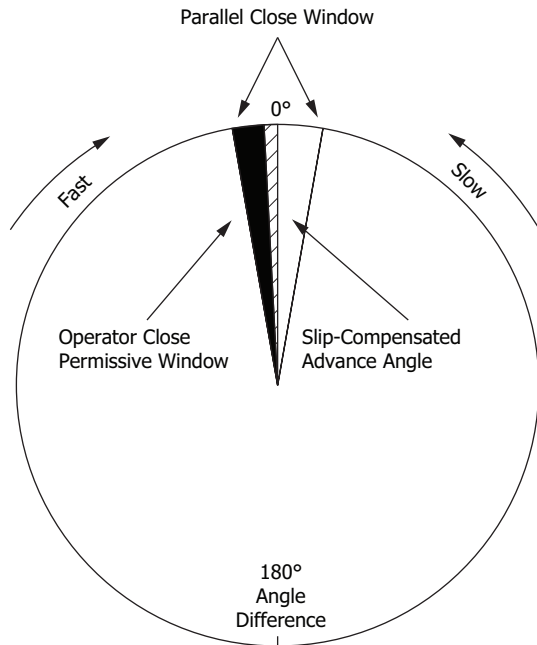


Figure 4 Operator Close Permissive Window With Incoming Frequency Fast

This permissive condition can be disabled when not needed.

Voltage and Frequency Matching Function

The A25A can be programmed to generate voltage correction pulses to adjust the incoming generator's automatic voltage regulator (AVR) to bring the voltage into the synchronism acceptance window.

The A25A can be programmed to generate frequency correction pulses to adjust the incoming generator's governor to bring the frequency into the synchronism acceptance window.

The voltage and frequency control functions can be separately enabled. In some applications, the generator control system may include control functions to match the incoming signal to the running signal. For example, the governor may include an internal function to match the frequency of the incoming system to the frequency of the running system. Similarly, the AVR may include an

internal function to match the voltage of the incoming system to the voltage of the running system. In general, if such functions exist in the generator control systems, they should be used because they will typically be able to bring the controlled parameter into the synchronism acceptance window faster than by using adjustment pulses.

Correction Pulse Characteristics

Each of the correction pulse control functions of the A25A can be set to one of three settings.

- N (off)
- F (fixed)
- P (proportional)

When set to N, that control function is not used. To bring the controlled parameter into the acceptance window, the synchronizing system may rely on operator manual control or other controls to match the incoming and running systems.

When set to F, the control function generates pulses with a fixed duration set in seconds. The period between the leading edge of pulses is set in seconds.

When set to P, the control function generates pulses with pulse duration proportional to how far the controlled parameter is from the center of the control deadband according to a slope setting in seconds per volts or seconds per Hz. The period between leading edge of pulses is set in seconds.

The correction deadband is inside the permissive window with a margin of 20 percent of the permissive window setting. This allows the control to continue to bring the controlled parameter closer to the center of the permissive band to improve the likelihood of a successful synchronizing close. The center of the control deadband is adjusted to the center of the permissive window which can be set for $\pm$ around zero or incoming signal high only.

Voltage Proportional Correction Pulse Characteristics

Figure 5 shows the voltage correction characteristic when the control function is set for P and the incoming voltage high permissive window setting, 25AIVHI, is set to N. Figure 6 shows the voltage correction characteristic when the control function is set for P and the incoming voltage high permissive window setting, 25AIVHI, is set to Y.

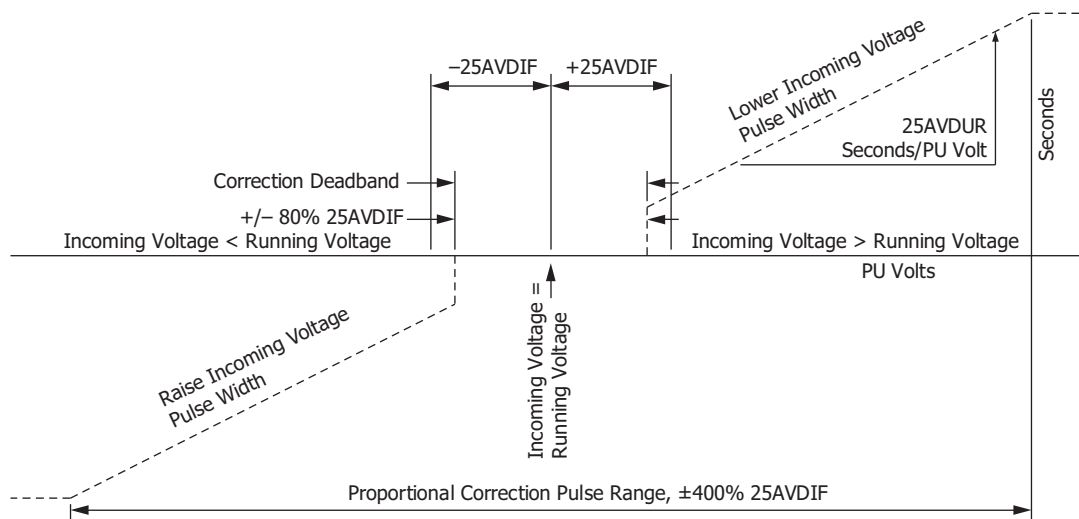


Figure 5 Voltage Proportional Pulse Characteristic, 25AIVHI = N

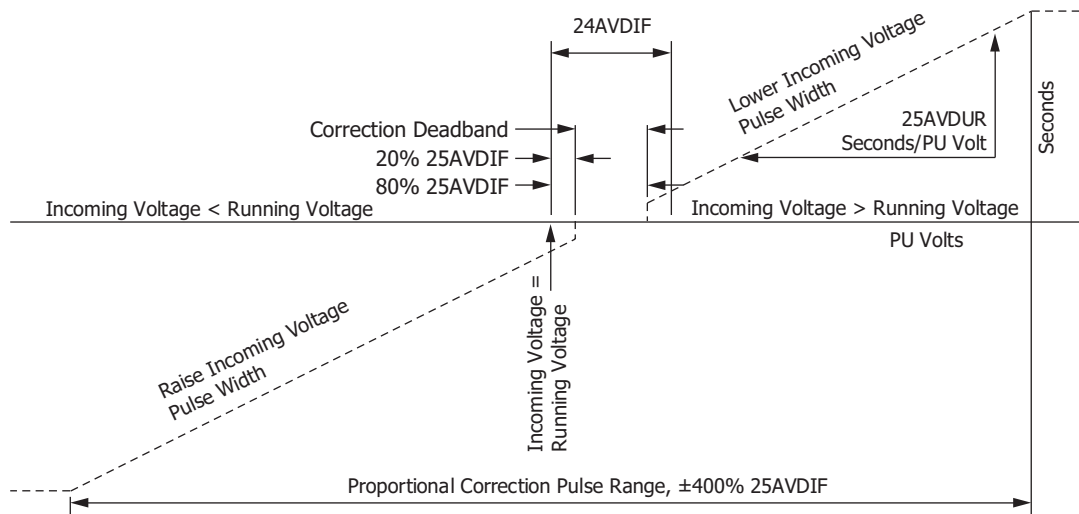


Figure 6 Voltage Proportional Pulse Characteristic, 25AIVHI = Y

Frequency Proportional Correction Pulse Characteristics

Figure 7 shows the frequency correction characteristic when the control function is set for P and the incoming frequency high permissive window setting, 25AIFHI, is

set to N. Figure 8 shows the frequency correction characteristic when the control function is set for P and the incoming frequency high permissive window setting, 25AIFHI, is set to Y.

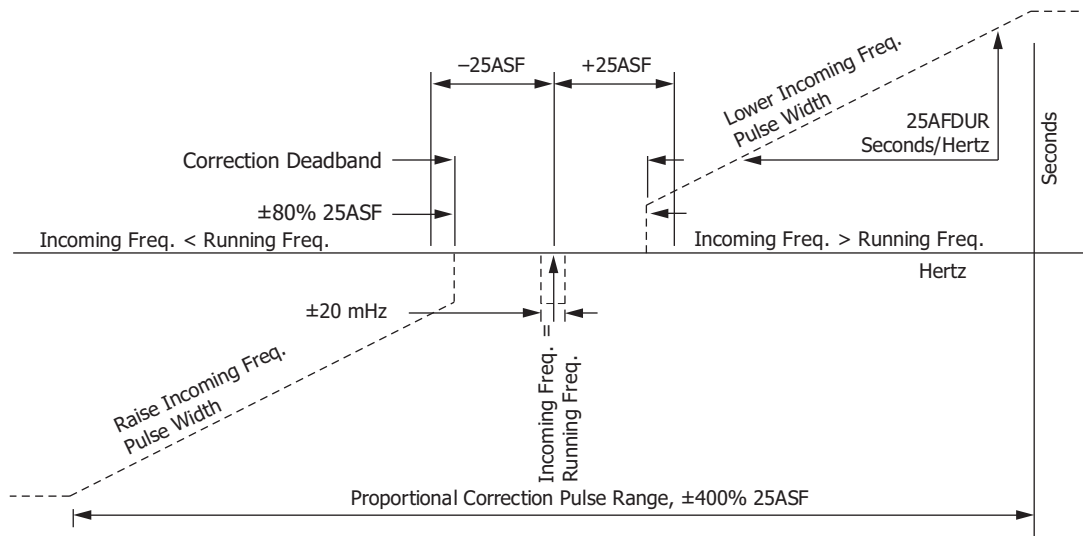


Figure 7 Proportional Pulse Characteristic, 25AIFHI = N

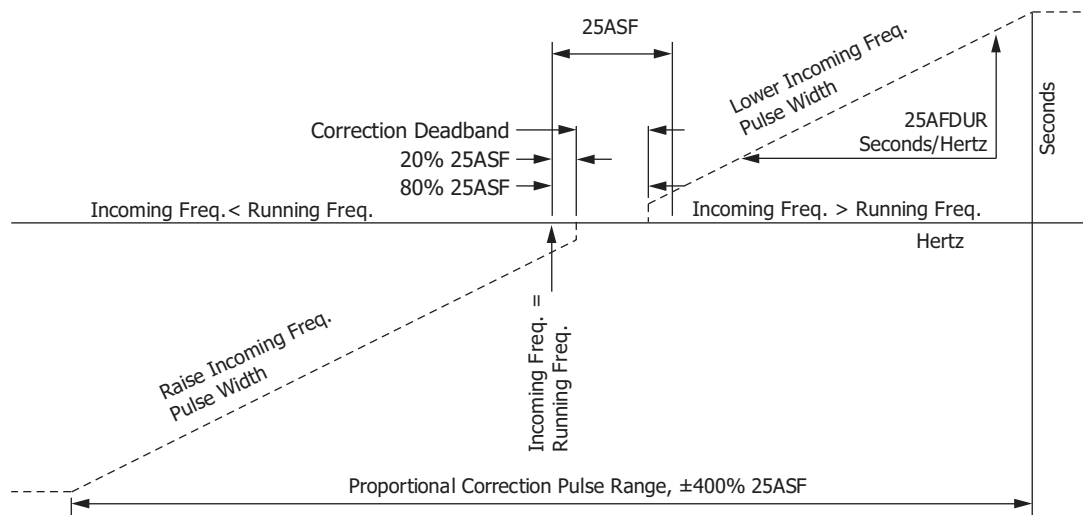


Figure 8 Proportional Pulse Characteristic, 25AIFHI = Y

Frequency correction requires an additional function that generates a raise pulse if the slip is near zero. This is called a dead scope condition. The frequency is in the dead scope band when the measured slip is between ± 20 mHz. When this occurs, it is necessary to raise the frequency of the incoming system so that the angle between the incoming and running signals can rotate into phase coincidence to allow a synchronizing close. This pulse is often called a kick pulse. Note the kick pulse characteristic in *Figure 7* where zero slip is within the control deadband.

- **Close Fail alarm.** Alert operators if the controlled circuit breaker fails to close within a user-configurable time and angle window when given a close command.
- **Close Lockout alarm.** Alert operators if the controlled circuit breaker opens within a user-configurable time after a close.
- **Too Much Time alarm.** Automatically stop the synchronizing process if a close does not occur within a maximum allowed time to synchronize. This function can be disabled.

Synchronizing Fail Alarm Functions

The A25A monitors the synchronizing process to alert operators if the synchronizing attempt is unsuccessful. Three alarm functions are included.

If the synchronizing process ends with the assertion of one of these alarms, the A25A function must be turned off (generator/breaker deselected) and the problem that caused the synchronizing process to fail must be found and corrected. The alarms must also be reset before another attempt to close the synchronizing breaker can be initiated.

User Indications

The A25A has a feature-rich user interface with user-programmable pushbuttons, LEDs, and LCD indications.

Figure 9 shows the default LED programming and default configurable labels for an SEL-451-5 ordered with the optional 12 pushbutton front panel. Figure 10 shows the default LED programming and default configurable labels for an SEL-451-5 ordered with the 8 pushbutton front panel. The user can reconfigure the front-panel programming and configurable labels as needed for the application.

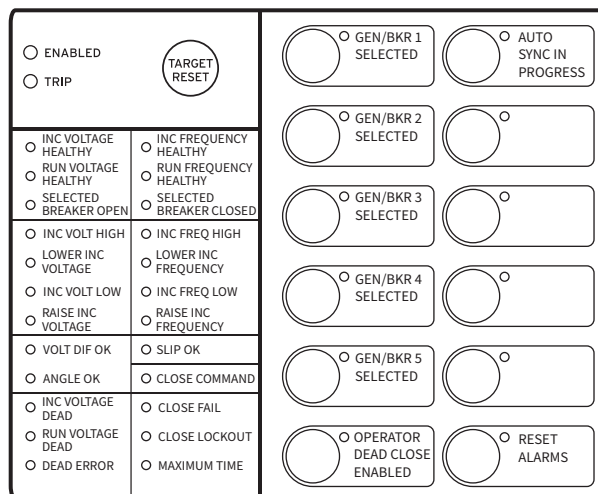


Figure 9 Default Front-Panel LED Functions and Configurable Labels, 12 Pushbutton Option

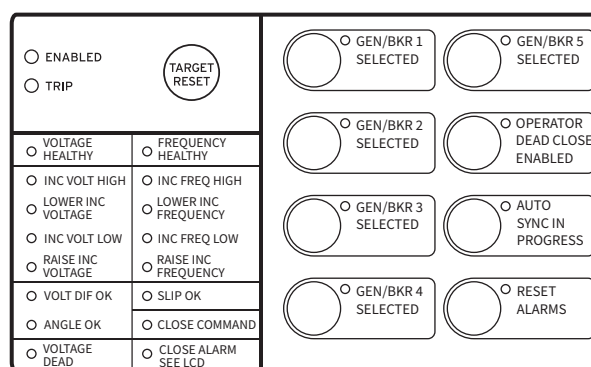


Figure 10 Default Front-Panel LED Functions and Configurable Labels, 8 Pushbutton Option

Figure 11 shows the default configuration for the first page of the rotating LCD display. This is the main page for monitoring the synchronizing process in real time. The user can reconfigure the display points as needed for the application.

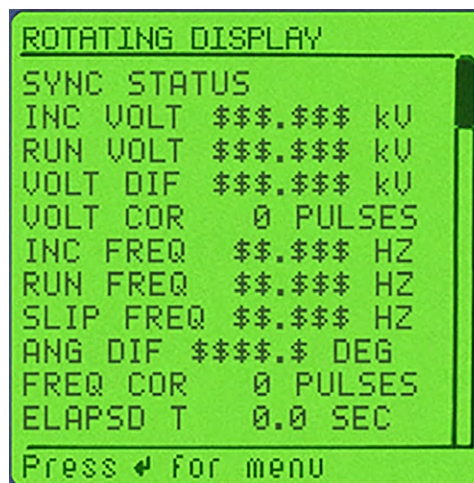


Figure 11 Default Front-Panel LCD Synchronizing Status Screen

Voltage Sensing Options

The nature of synchronizing requires accurate measurement of voltage signals at off-nominal frequencies. Thus, frequency tracking is critical for the A25A to function. The SEL-451-5 relay has the ability to switch between two different VT inputs for frequency tracking.

The SEL-451-5 has six VT inputs. These inputs are used differently for the two versions of the A25A Quickset Designer Template.

Single-Phase With Internal Signal Selection

The single-phase synchronizer version uses the six VT inputs as independent inputs. Figure 12 shows example connections for an application that spans the generator step-up transformer. Note that a V_{LL} phase is selected for the incoming signal that is in phase with a V_{LN} phase used for the running signal. This is recommended so that error prone angle compensation settings are not required and primary phasing tests are simplified. The magnitude difference between the signals is compensated in the settings.

Where one A25A is used for multiple generator and breaker combinations, the need for complex VT circuits with switching contacts and isolation transformers to isolate the VT signals from each other is often eliminated.

The user can designate one or two VT inputs as incoming signals for frequency tracking. Then, for each of the five generator and breaker combinations, the user indicates which of the designated incoming VT inputs to use and which of the six VT inputs to use for the running signal. *Figure 16, Figure 17, Figure 18, and Figure 19 in Application Examples on page 14 show examples of applications that eliminate external signal switching for generator and microgrid applications. Such examples can easily be integrated into a DCS to provide flexible synchronizing capability.*

In microgrid applications with multiple separation and synchronizing points for a single generator or group of generators, designation of one incoming signal and as many as five running signals is common. *Figure 16 and Figure 17 show microgrid applications with one incoming signal. Figure 18 and Figure 19 show generator synchronizing applications with one incoming and two possible running signals.*

In generator synchronizing applications, with multiple generators with multiple synchronizing breakers, designation of two incoming signals and as many as four running signals is common. *Figure 20 in Application Examples on page 14 shows an example where one A25A is used to synchronize two generators, each with dual breaker terminals.*

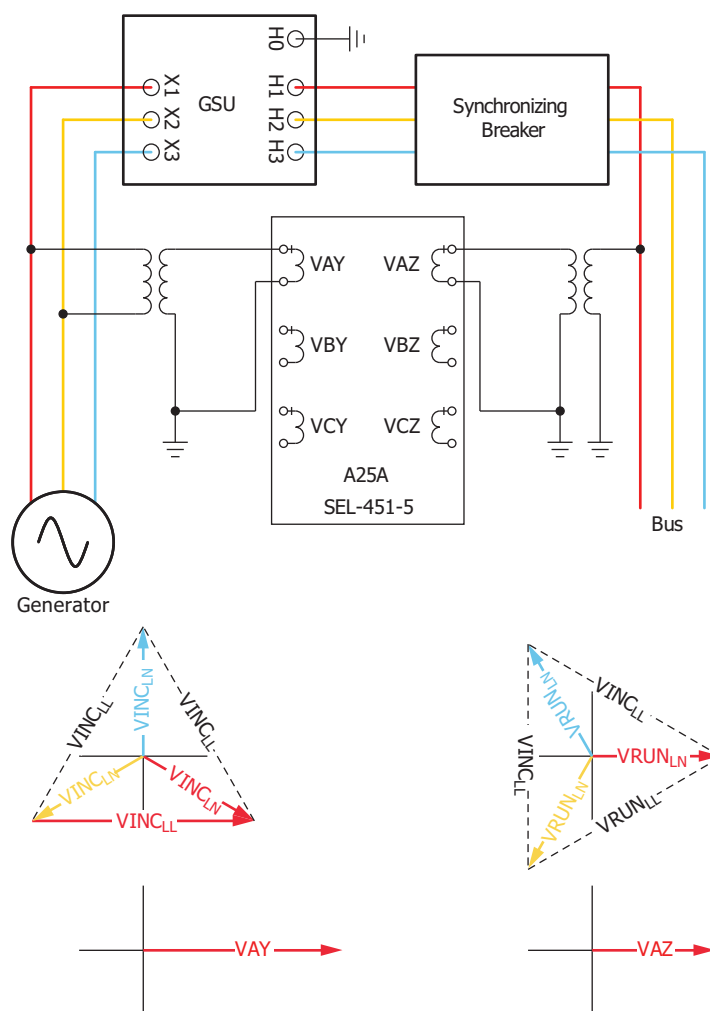


Figure 12 Example Single-Phase Synchronizer Application With the Incoming VT on the Generator Side of the GSU

Two Channel With Optional Three-Phase Sensing

For two channel and three-phase applications, using one A25A for multiple generator and breaker combinations requires external switching circuits to bring in all of the

VT signals required for each generator and breaker combination. Breaker status sensing inputs and close command outputs can be individually programmed if the SEL-451-5 is specified with sufficient I/O and do not need to be switched through the synchronizing switch circuits.

The two channel A25A can be set to one of three sensing settings. EN3PH can be set to:

- OFF
- 3PH
- OPDELTA

Two Channel Applications

In two channel applications, two sets of incoming and running VT signals, ideally from independent VT circuits, are wired to the A25A. Both channels must agree

that the synchronizing acceptance parameters are met before a slip-compensated advanced angle close command is issued.

For single-phase, two channel operation (EN3PH := OFF), the A25A uses VT inputs VAY and VAC for the two incoming signals and VT inputs VAZ and VCZ for the two running signals. See *Figure 13* for example connections.

An alarm function, C1C2ALM, is provided to alert operators when CH 1 and CH 2 are not in the same state.

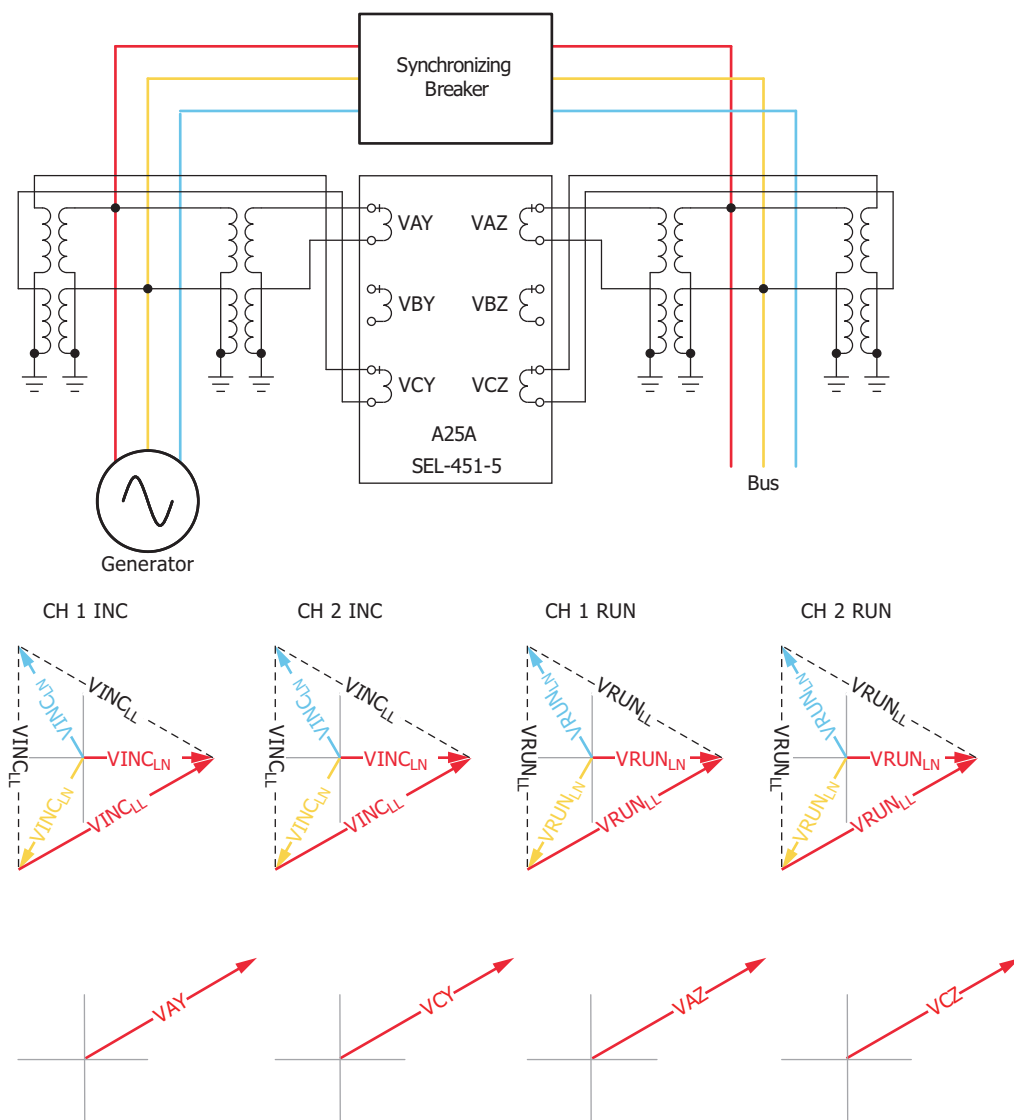


Figure 13 Example Two Channel Synchronizer Application With Two Sets of VTs Available, V_{LL} Sensing

Three-Phase Applications

For applications requiring three-phase sensing, the frequency, voltage, and angle windows are determined from the signals as described under *Two Channel Applications* on page 12.

Additionally, the A25A ensures that all three phases on the incoming and running sides of the CH 1 inputs are in the healthy windows and that the phase sequence is consistent between the incoming and running sides of the synchronizing breaker.

When EN3PH is set to 3PH, the A25A is wired to three-phase sets of VT signals. The two channel synchronizing function uses the A-phase and C-phase of the three-phase sets. See *Figure 14* for example connections.

An alarm function, 3PHALM, is provided to alert operators if the three-phase permissive conditions are not met.

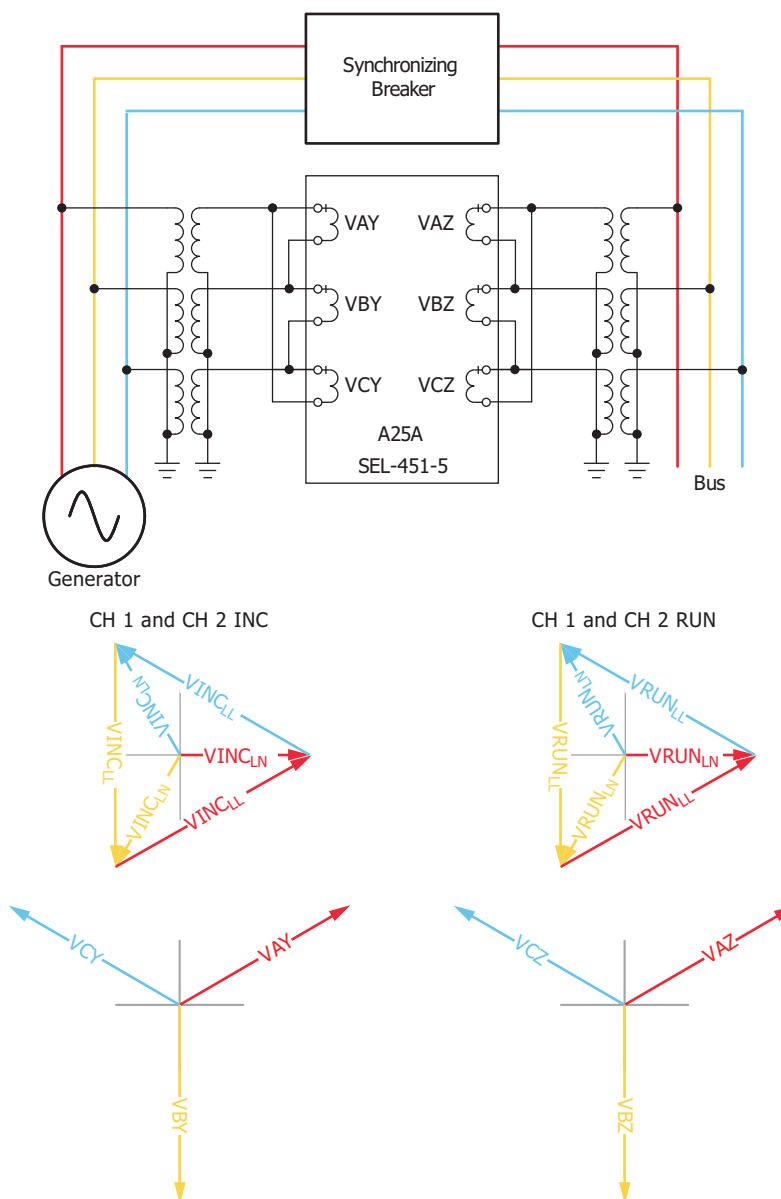


Figure 14 Example Two Channel, Three-Phase Synchronizer Application, EN3PH := 3PH, Four-Wire VTs, V_{LL} Sensing

For applications requiring three-phase sensing with the two channel function supplied by independent VT circuits, set EN3PH to OPDELTA. In this configuration, the three-phase sensing functions use the signals from VT

inputs VAY and VBY for incoming signals and VT inputs VAZ and VBZ for running signals, wired in an open delta configuration. See *Figure 15* for example connections.

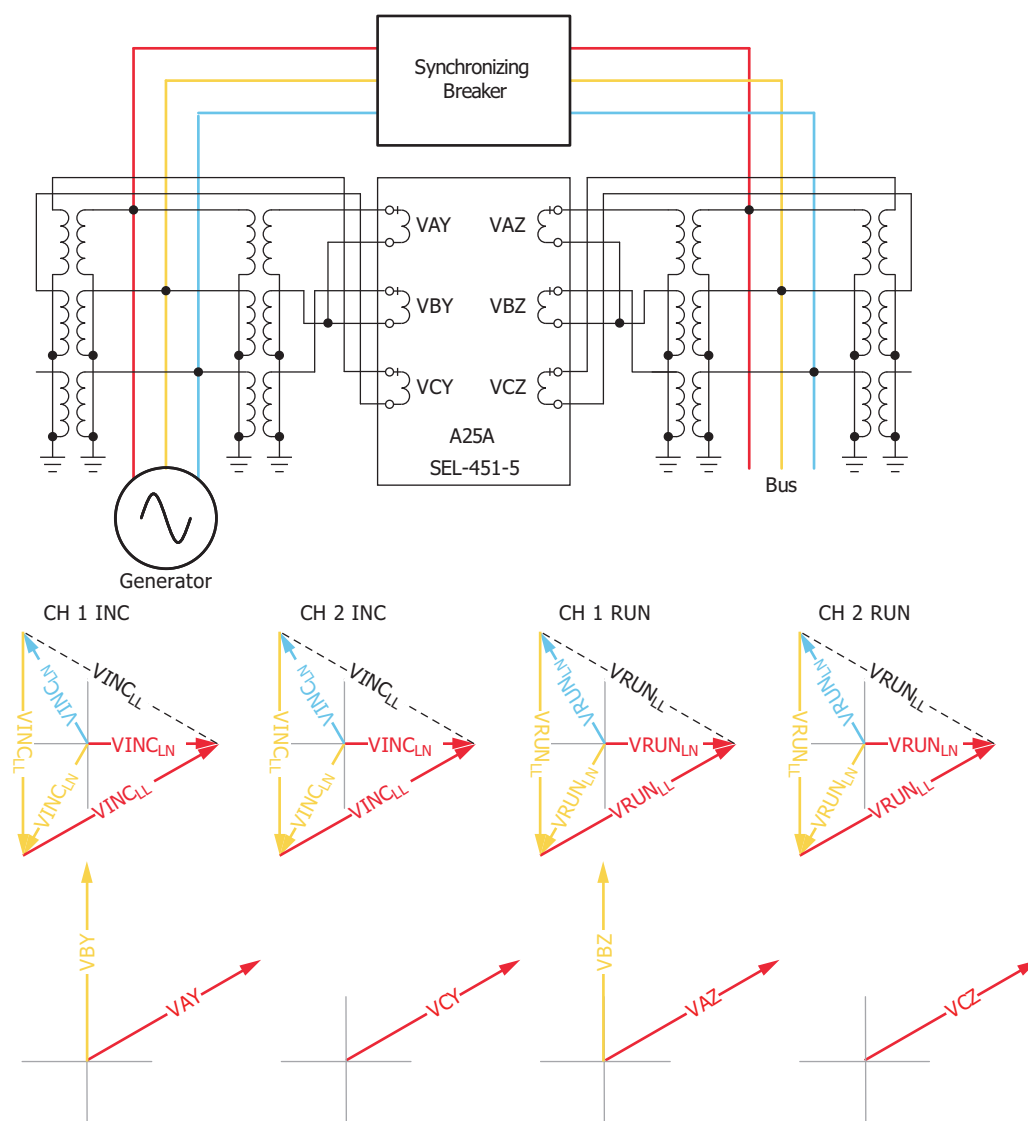


Figure 15 Example Two Channel, Three-Phase Synchronizer Application, EN3PH := OPDELTA, Two Sets of VTs Available, V_{LL} Sensing

Application Examples

The A25A can be used in many applications. The A25A has setting groups for as many as five generator and breaker combinations. In modernization applications that use one synchronizing visualization panel for multiple generators and/or synchronizing breakers, the A25A can be connected into the existing synchronizing selector switch circuits. Alternatively, the A25A can be directly

wired to the incoming and running VT circuits and bypass the synchronizing selector switch circuits, as shown in these examples.

The simplest configuration is to specify one A25A per generator. Two application examples show this configuration.

Synchronizer Application for an Offshore Platform Emergency Microgrid

Figure 16 shows an example application for an emergency generator feeding a critical load microgrid on an offshore production platform with five separation and synchronizing points. For more information, see [6].

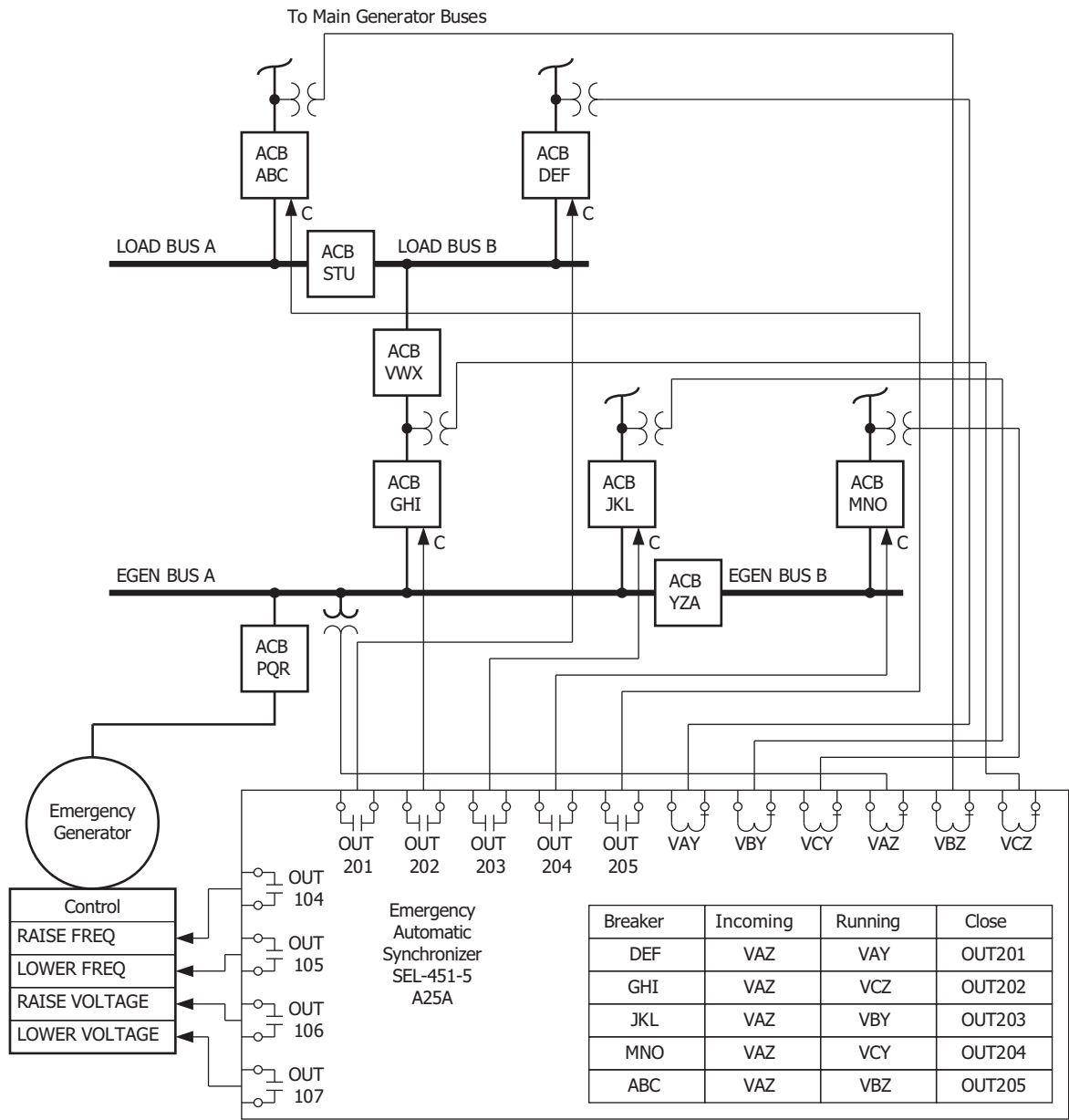


Figure 16 Example Single-Phase A25A Applied for a Complex Emergency Microgrid Synchronizing Application

Synchronizer Application for a University Microgrid With Remote CHP Plant

Figure 17 shows an example application for a university campus microgrid with two utility tie breakers and three intermediate synchronizing points. In this application, the combined heat and power (CHP) plant is located a significant distance from the substation that connects the campus to the utility power grid.

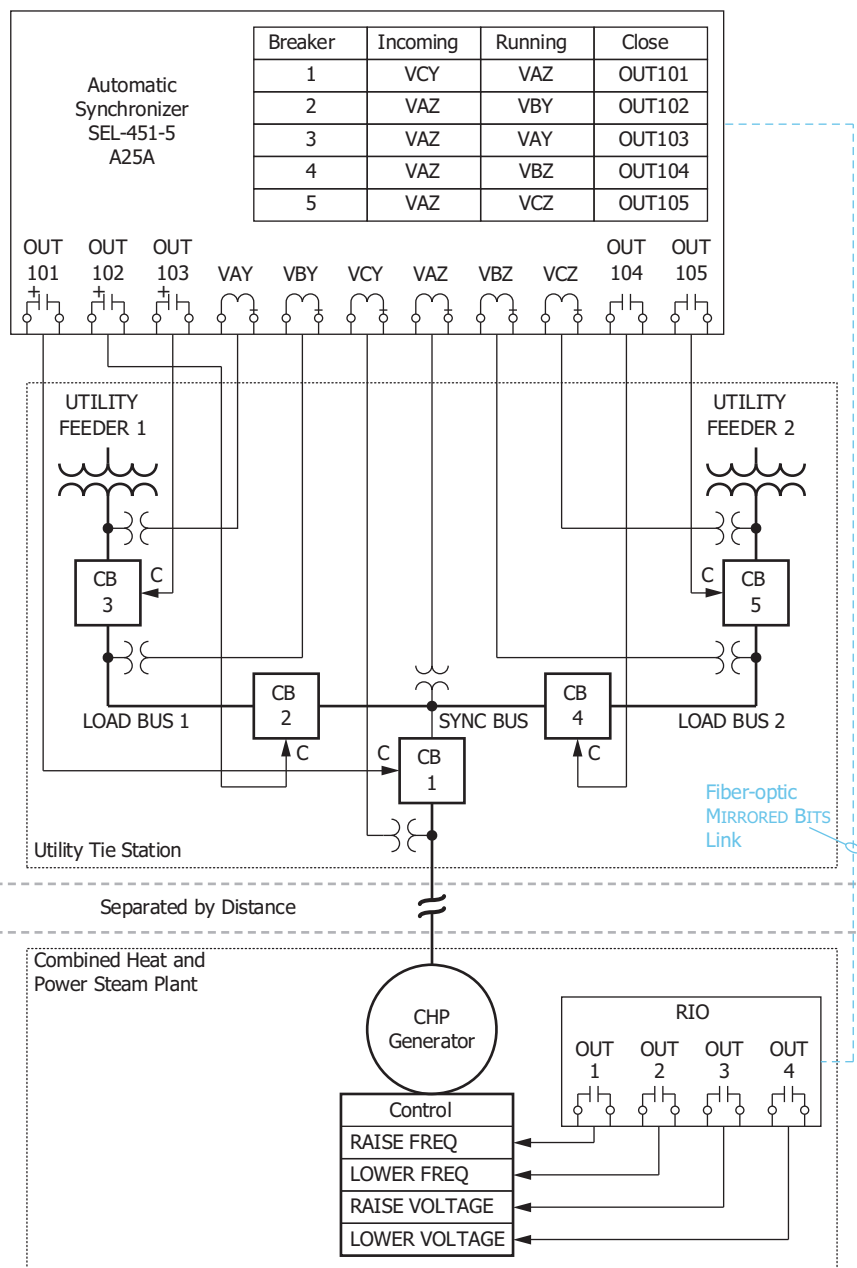


Figure 17 Example Synchronizing Application With a Single-Phase A25A Applied for a University Microgrid With a Remote CHP Plant

Synchronizer Application for a Generator With Single Breaker/Double Bus Station Arrangement

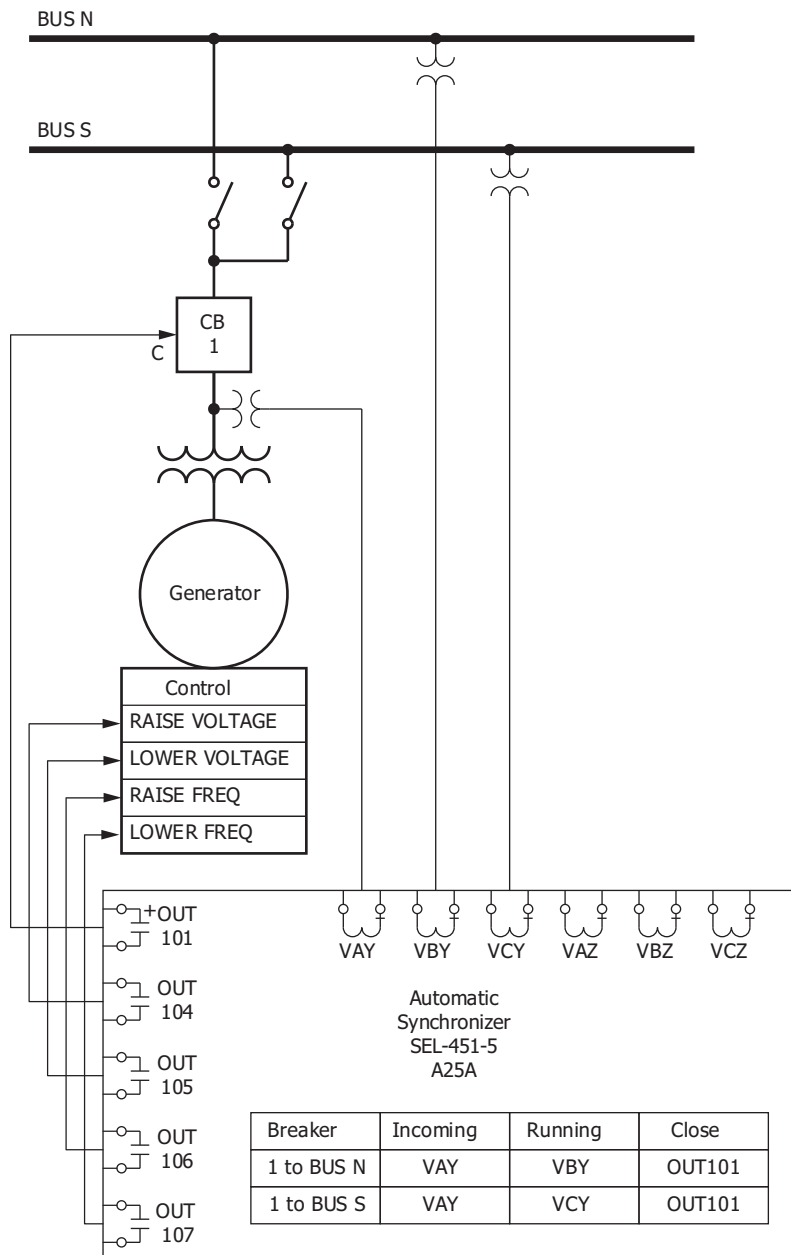


Figure 18 Example Single-Phase A25A Applied for Single Breaker, Double Bus Application

Synchronizer Application for a Generator With Isolation Between the Substation and the Power Plant

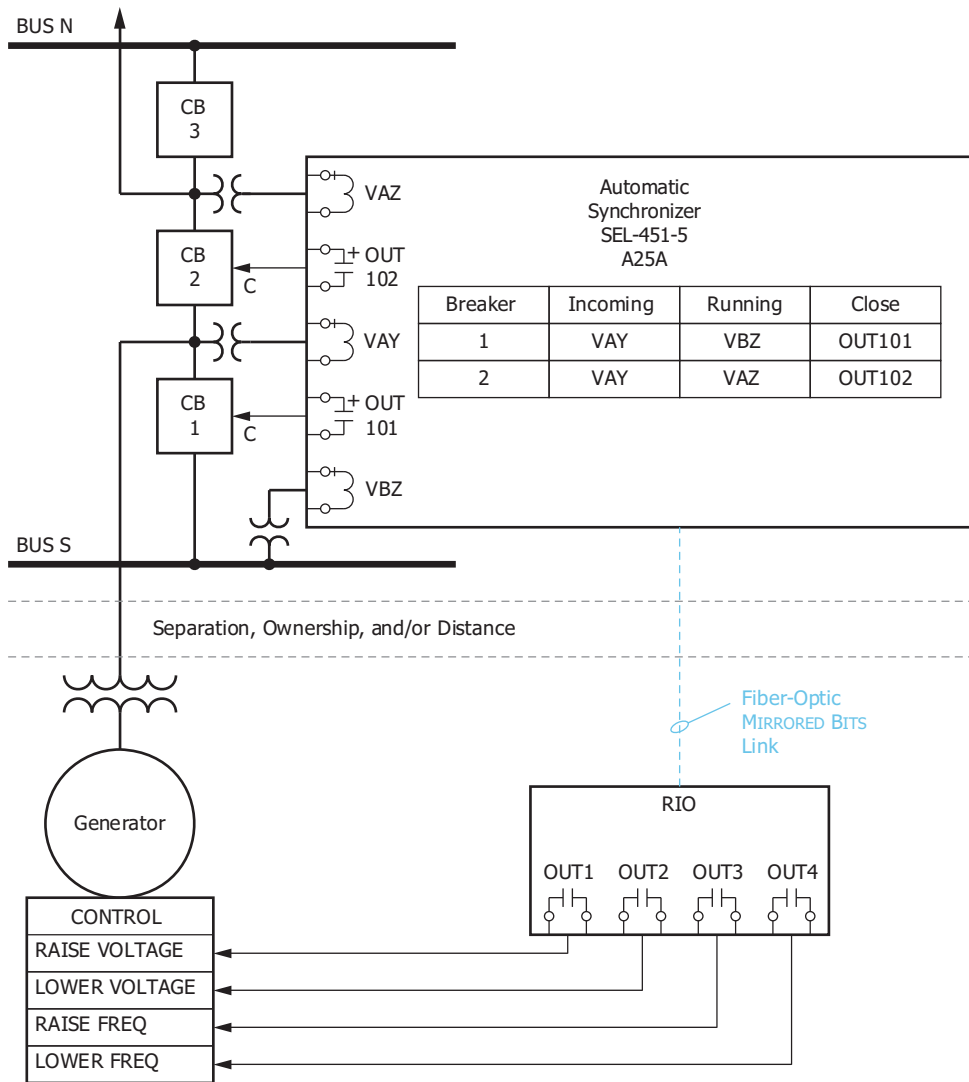


Figure 19 Example Use of Fiber-Optic MIRRORED BITS Link to Eliminate Long VT Secondary Circuits

Synchronizer Application for Two Generators With Two Synchronizing Breakers Each

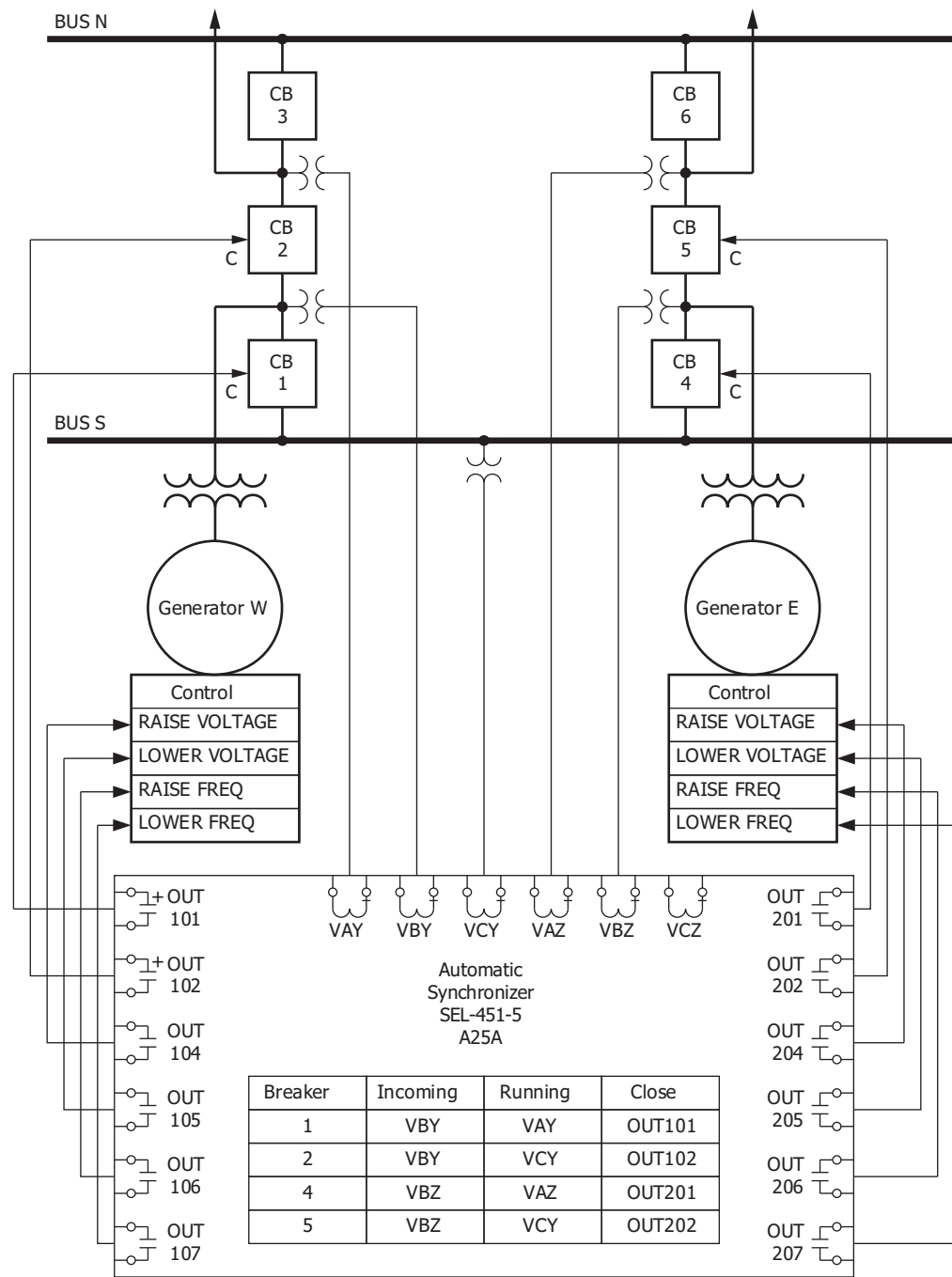


Figure 20 Example Single-Phase A25A Applied for Multiple Generators With Multiple Synchronizing Breakers Application

Diagrams and Dimensions

Please refer to the product data sheet for the SEL-451-5 Feeder Protection Relay for front-panel and rear-panel diagrams, relay dimensions, and additional specifications.

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 Input (Secondary Circuits)

Note: Current transformers are Measurement Category II.

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

1 A Nominal: 18.2 A

5 A Nominal: 91 A

Continuous Thermal Rating

1 A Nominal: 3 A
4 A (+55°C)

5 A Nominal: 15 A
20 A (+55°C)

Saturation Current (Linear) Rating

1 A Nominal: 20 A

5 A Nominal: 100 A

A/D Current Limit

1 A Nominal: 49.5 A

5 A Nominal: 247.5 A

Note: Signal clipping may occur beyond this limit.

One-Second Thermal Rating

1 A Nominal: 100 A

5 A Nominal: 500 A

One-Cycle Thermal Rating

1 A Nominal: 250 A peak

5 A Nominal: 1250 A peak

Burden Rating

1 A Nominal: ≤ 0.1 VA @ 1 A

5 A Nominal: ≤ 0.5 VA @ 5 A

AC Voltage Inputs

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

Rated Voltage Range: 55–250 V_{LN}

Operational Voltage Range: 0–300 V_{LN}

A/D Voltage Limit (Peak): 490 V_{LN}

Note: Signal clipping can occur beyond this limit.

Ten-Second Thermal Rating: 600 Vac

Burden: ≤ 0.1 VA @ 125 V

LEA Voltage Inputs

Rated Voltage Range: 4 V_{LN}

Operational Voltage Range: 0–8 V_{LN}

Ten-Second Thermal Rating: 300 Vac

Input Impedance: 1 MΩ

Common Mode Voltage

Operation: 50 Vac

Without Damage: 300 Vac

Frequency and Rotation

Nominal Frequency Rating: 50 ± 5 Hz
60 ± 5 Hz

Phase Rotation: ABC or ACB

Frequency Tracking Range: 40–65 Hz
< 40 Hz = 40 Hz
> 65 Hz = 65 Hz

Default Slew Rate: 15 Hz/s

Power Supply

24–48 Vdc

Rated Voltage: 24–48 Vdc

Operational Voltage Range: 18–60 Vdc

Vdc Input Ripple: 15% per IEC 60255-26:2013

Interruption: 20 ms at 24 Vdc, 100 ms at 48 Vdc per IEC 60255-26:2013

Burden: < 35 W

48–125 Vdc or 110–120 Vac

Rated Voltage: 48–125 Vdc, 110–120 Vac

Operational Voltage Range: 38–140 Vdc
85–140 Vac

Rated Frequency: 50/60 Hz

Operational Frequency Range: 30–120 Hz

Vdc Input Ripple: 15% per IEC 60255-26:2013

Interruption: 14 ms at 48 Vdc, 160 ms at 125 Vdc per IEC 60255-26:2013

Burden: < 35 W, < 90 VA

125–250 Vdc or 110–240 Vac

Rated Voltage: 125–250 Vdc, 110–240 Vac

Operational Voltage Range: 85–300 Vdc
85–264 Vac

Rated Frequency: 50/60 Hz

Operational Frequency Range: 30–120 Hz

Vdc Input Ripple:	15% per IEC 60255-26:2013
Interruption:	46 ms at 125 Vdc, 250 ms at 250 Vdc per IEC 60255-26:2013
Burden:	< 35 W, < 90 VA

Control Outputs

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

Update Rate:	1/8 cycle
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. These outputs are polarity-dependent.

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

Direct Coupled (Use With DC Signals)

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

Optoisolated (Use With AC or DC Signals)

Main Board:	5 inputs with no shared terminals 2 inputs with shared terminals
INT2, INT7, and INT8 Interface Boards:	8 inputs with no shared terminals
INT3 and INT4 Interface Boards:	6 inputs with no shared terminals 18 inputs with shared terminals (2 groups of 9 inputs, with each group sharing one terminal)
Voltage Options:	24 V standard 48, 110, 125, 220, 250 V level sensitive
Current Drawn:	< 5 mA at nominal voltage < 8 mA for 110 V option
Sampling Rate:	2 kHz

DC Thresholds

(Dropout thresholds indicate level-sensitive option.)

24 Vdc:	Pickup 19.2–30.0 Vdc Dropout < 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)

24 Vac:	Pickup 16.4–30.0 Vac rms Dropout < 14.4 Vdc
48 Vac:	Pickup 32.8–60.0 Vac rms; Dropout < 20.3 Vac rms
110 Vac:	Pickup 75.1–132.0 Vac rms; Dropout < 46.6 Vac rms
125 Vac:	Pickup 89.6–150.0 Vac rms; Dropout < 53.0 Vac rms
220 Vac:	Pickup 150.3–264 Vac rms; Dropout < 93.2 Vac rms
250 Vac:	Pickup 170.6–300 Vac rms; Dropout < 106 Vac rms

Communications Ports

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

Communications Card Slot for Optional Ethernet Card

Ordering Options:	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

Communications Ports for Optional TiDL (EtherCAT) Interface

EtherCAT Fiber-Optic Ports:	8
Data Rate:	Automatic
Connector Type:	LC fiber
Protocols:	Dedicated EtherCAT
Class 1 LASER/LED	
Wavelength:	1300 nm
Fiber Type:	Multimode
Link Budget:	11 dB
Min. TX Power:	–20 dBm
Min. RX Sensitivity:	–31 dBm
Fiber Size:	50–200 μ m
Approximate Range:	2 km
Data Rate:	100 Mbps
Typical Fiber Attenuation:	–2 dB/km

Time Inputs

IRIG Input–Serial Port 1

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

IRIG-B Input–BNC Connector

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

PTP–Ethernet Port 5A, 5B

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)

3U Rack Unit:	8.0 kg (17.7 lb)
4U Rack Unit:	9.8 kg (21.6 lb)
5U Rack Unit:	11.6 kg (25.6 lb)
8U Rack Unit:	14.0 kg (32.8 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)

Reporting Functions

High-Resolution Data

Rate:	8000 samples/second 4000 samples/second 2000 samples/second 1000 samples/second
-------	--

Output Format: Binary COMTRADE

Note: Per IEEE C37.111-1999 and IEEE C37.111-2013, *IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems*.

Event Reports

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

Event Summary

Storage: 100 summaries

Breaker History

Storage: 128 histories

Sequential Events Recorder

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

Processing Specifications

AC Voltage and Current Inputs

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

Digital Filtering

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

Protection and Control Processing

Eight times per power system cycle

Control Points

64 remote bits
64 local control bits

SELogIC Variables

Single-Phase A25A

Protection Variables:	64 Math Variables (17 used by A25A) 64 Boolean Variables (46 used by A25A) 32 Control Timers (15 used by A25A) 32 Sequencing Timers (1 used by A25A) 32 Latch Bits (25 used by A25A)
Automation Variables:	256 Math Variables (173 used by A25A) 256 Boolean Variables (139 used by A25A) 32 Control Timers (0 used by A25A) 32 Sequencing Timers (1 used by A25A) 32 Latch Bits (0 used by A25A)

Two Channel/Three-Phase A25A

Protection Variables:	64 Math Variables (28 used by A25A) 64 Boolean Variables (47 used by A25A) 32 Control Timers (15 used by A25A) 32 Sequencing Timers (1 used by A25A) 32 Latch Bits (25 used by A25A)
Automation Variables:	256 Math Variables (192 used by A25A) 256 Boolean Variables (158 used by A25A) 32 Control Timers (0 used by A25A) 32 Sequencing Timers (1 used by A25A) 32 Latch Bits (0 used by A25A)

Functional Ranges

Sensing

VT Ratios:	1.0–10000.0
Nominal Voltage:	20.00–300.00 V
Enable Three-Phase (Two Channel A25A Only):	OFF (Single-Phase, Two Channel) 3PH (Three-Phase, Two Channel) OPDELTA (Three-Phase, Two Independent Channel)

Signals Healthy

Voltage Healthy:	0.80–1.20 PU
Voltage Dead:	0.05–0.50 PU
Frequency Healthy:	45.000–65.000 Hz

Synchronizing Close Windows

Voltage Difference:	±0.010–0.500 PU or +0.010–0.500 PU
Slip:	±0.025–0.0500 Hz or +0.025–0.0500 Hz
Slip Accuracy:	±0.0025 Hz plus ± 2% of setting
Parallel Close Window:	±3.0–80.0°
Angle Accuracy:	±3.0° plus ± 5% of setting

Control

Enable Voltage Correction:	N (Not enabled) F (Fixed Pulse) P (Proportional Pulse)
Period:	1.00–30.00 s
Duration:	0.01–100.00 s (Fixed) 0.01–100.00 s/V PU (Proportional)
Enable Frequency Correction:	N (Not enabled) F (Fixed Pulse) P (Proportional Pulse)
Period:	1.00–30.00 s
Duration:	0.01–100.00 s (Fixed) 0.01–100.00 s/Hz (Proportional)

Breaker

Breaker Close Time: 1.00–30.00 cycles

Close Alarms

Close Fail Delay:	0.10–60.00 s
Close Fail Angle:	3.0–80.0°
Close Lockout Delay:	0.50–60.00 s
Max Time Allowed:	1–120 m

Station DC Battery System Monitor Specifications

Rated Voltage:	24–250 Vdc
Operational Voltage Range:	0–300 Vdc
Sampling Rate:	DC1: 2 kHz DC2: 1 kHz
Processing Rate:	1/8 cycle
Operating Time:	<1.5 cycles (all elements except ac ripple) <1.5 seconds (ac ripple element)

Setting Range

DC Settings:	1 Vdc steps (OFF, 15–300 Vdc)
AC Ripple Setting:	1 Vac steps (1–300 Vac)
Pickup Accuracy:	$\pm 3\%$ ± 2 Vdc (all elements except ac ripple) $\pm 10\%$ ± 2 Vac (ac ripple element)

Metering Accuracy

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

Currents

Phase Current Magnitude

5 A Model:	$\pm 0.2\%$ plus ± 4 mA (2.5–15 A sec)
1 A Model:	$\pm 0.2\%$ plus ± 0.8 mA (0.5–3 A sec)

Phase Current Angle

All Models:	$\pm 0.2^\circ$ in the current range $0.5 \cdot I_{NOM}$ to $3.0 \cdot I_{NOM}$
-------------	---

Sequence Currents Magnitude

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

Sequence Current Angle

All Models:	$\pm 0.3^\circ$ in the current range $0.5 \cdot I_{NOM}$ to $3.0 \cdot I_{NOM}$
-------------	---

Voltages

300 V Maximum Inputs

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

8 V LEA Maximum Inputs

Phase and Phase-to-Phase Voltage Magnitude:	$\pm 0.3\%$ (0.2–0.6 V) $\pm 0.1\%$ (0.6–8.0 V)
Phase and Phase-to-Phase Angle:	$\pm 0.5^\circ$ (0.2–8.00 V)
Sequence Voltage Magnitude (V1, V2, 3V0):	$\pm 0.3\%$ (0.2–0.6 V) $\pm 0.1\%$ (0.6–8.0 V)
Sequence Voltage Angle (V1, V2, 3V0):	$\pm 0.5^\circ$ (0.2–8.00 V)

Frequency (Input 40–65 Hz)

Accuracy:	± 0.01 Hz
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Power

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

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

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

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

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

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

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

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

Energy

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

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

Synchrophasors

Number of Synchrophasor

Data Streams:	5
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Number of Synchrophasors for Each Stream:

15 Phase Synchrophasors (6 Voltage and 9 Currents)
5 Positive-Sequence Synchrophasors (2 Voltage and 3 currents)

Number of User Analogs for

Each Stream:	16 (any analog quantity)
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Number of User Digitals for

Each Stream:	64 (any Relay Word bit)
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Synchrophasor Protocol:

IEEE C37.118-2005, SEL Fast Message (Legacy)

Synchrophasor Data Rate:

As many as 60 messages per second

Synchrophasor Accuracy

Voltage Accuracy:	$\pm 1\%$ Total Vector Error (TVE) Range 30–150 V, $f_{NOM} \pm 5$ Hz
Current Accuracy:	$\pm 1\%$ Total Vector Error (TVE) Range (0.1–2.0) $\cdot I_{NOM}$ A, $f_{NOM} \pm 5$ Hz

Synchrophasor Data

Recording:	Records as much as 120 s IEEE C37.232-2011, File Naming Convention
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Technical Support

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Notes

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