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Application Note

Application of the Auto Synchronizer Function in the BE1-11*g*

The Basler Electric BE1-11*g* Generator Protection System contains an automatic synchronizer (25A) when ordered with style numbers GxxxxxxxSxxxxx or GxxxxxxxTxxxxx. Although the auto synchronizer operating mode can be set to phase-locked-loop (PLL) or anticipatory, this application note focuses on the anticipatory mode. A brief overview of synchronization and auto synchronizer basics is given. Then, instructions for programming the 25A element in BESTCOMS*Plus*® software and for using the 25A in BESTlogic™*Plus* are provided. Finally, additional considerations are reviewed and a brief summary is included.

Synchronization/Auto Synchronizer Overview

Before discussing synchronization and auto synchronizers, some important terms that are used throughout this application note are defined. See Figure 1.

- Circuit breaker: The generator or intertie circuit breaker that isolates and connects the generator output and the bus to which the generator is being synchronized.
- Generator bus: The three-phase electrical output of the generator up to the terminals of the generator circuit breaker.
- Synchronization bus: The three-phase ac system to which the generator is paralleled.
- Synchronization: In respect to this application note, the process required to parallel an ac generator to another ac system, whether it is a collection of generators on a grid or another single generator.

The BE1-11*g* accomplishes auto synchronization by continuously analyzing the synchronization parameters of the generator and the system to which it will be connected. The BE1-11*g* compares the voltages of the two systems by evaluating the three-phase generator bus voltage to the single-phase synchronization bus voltage. Because measuring phase rotation is not possible with the single-phase bus voltage, the phase rotation of both systems should be checked prior to connecting the VT inputs to the BE1-11*g*.

The BE1-11*g* sends control signals to the prime mover of the generator for speed/frequency adjustment and to the excitation system of the generator field for terminal

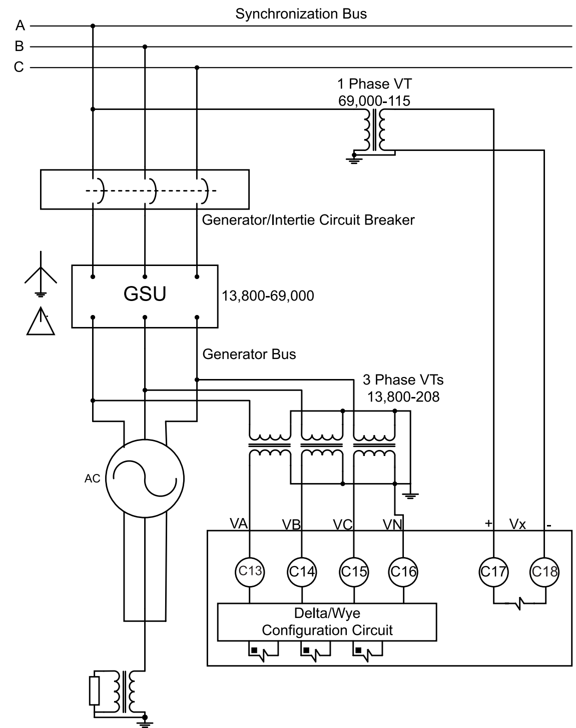


Figure 1 - System Reference Drawing

voltage adjustment. This is accomplished by the 25A auto synchronizer element and logic connections to the output relays. The physical outputs, the 25A element, and the logic are programmed with BESTCOMSPlus which is discussed in the following sections.

A PLL auto synchronizer generally makes rapid adjustments to bring a generator on line very quickly, but sacrifices some amount of precision. An anticipatory auto synchronizer sets and adjusts the synchronization parameters and issues a circuit breaker close signal in advance of synchronization. The advance close signal is determined by taking into account the slip frequency, the close output contact operate time, and the close time of the circuit breaker. By accounting for these parameters, the breaker main contacts parallel the two systems very close to 0 degrees. As a result, the electrical transients are reduced and the possibility of equipment damage is diminished.

BESTCOMS*Plus*: Programming the 25A Element

BESTCOMS*Plus*, the programming interface software for the BE1-11*g* Generator Protection System, is available for free download at www.basler.com/Downloads/. The BE1-11*g* instruction manual, also available at the above link, provides in-depth instructions for setting up and using BESTCOMS*Plus*. Thus, this application note provides instructions for use of the 25A element only.

The relay to be programmed must have a style number of GxxxxxxSxxxxx or GxxxxxxTxxxxx, which enables the use of the 25A control element. The same is true when developing a settings file in BESTCOMS*Plus* without a relay. The style number can be found in the General Settings tree of the Settings Explorer. See Figure 2.

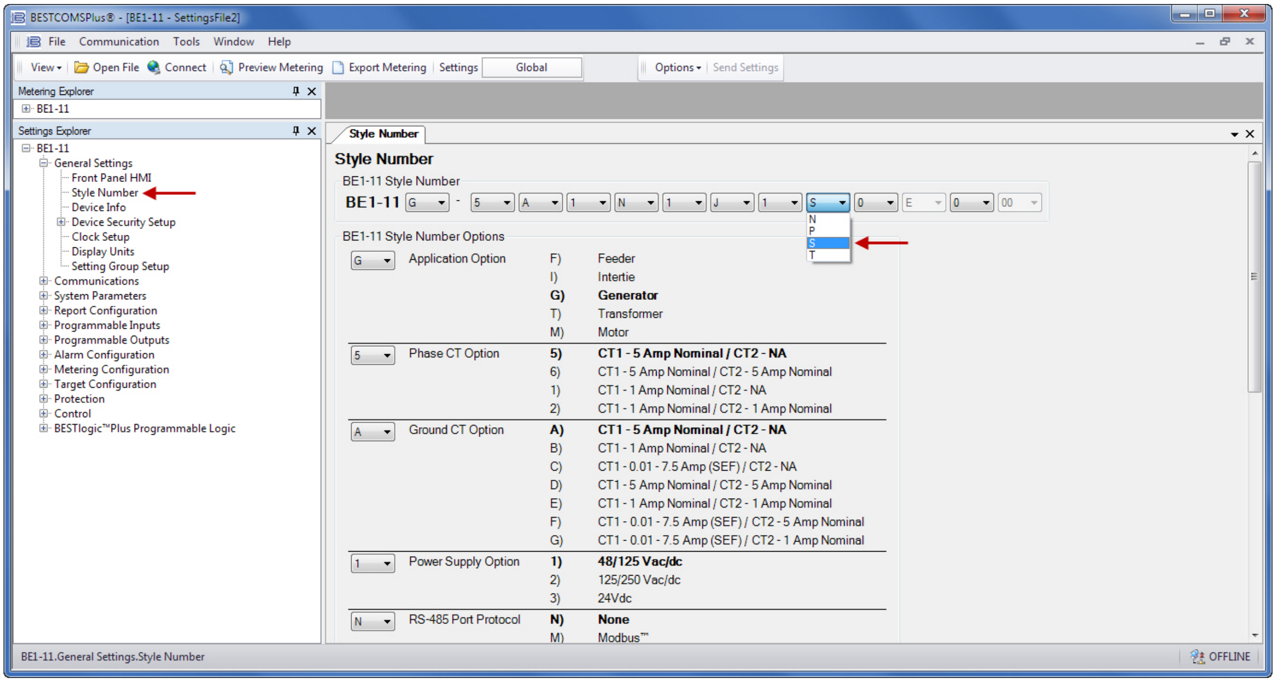


Figure 2 - Setting the Style Number

Using BESTCOMS*Plus* to Set the 25A

For the BE1-11*g* relay to properly evaluate the voltage magnitudes of the two systems to be synchronized, the proper quantities must be established. This is done in the “Nominal Settings” sub-tree under the “System Parameters” tree. See Figure 3. The values are input as phase to neutral. The generator bus voltage is input to the “Secondary Phase Voltage (V)” field. The example in Figure 1 shows the VT secondary voltage as 208 V_{L-L}, so the value entered in the “Secondary Phase Voltage (V)” field is 120. The synchronization bus VT shown in Figure 1 is rated for 69 kV/115 but is connected phase to ground. Therefore, the value entered in “Secondary Aux Voltage (V)” is 66.4. By following these steps, the secondary voltages of the VT sets have been per-unitized where 66.4 V and 120 V are 1 PU voltages.

Equally important for proper operation of the 25A element are the selections made in the “System Parameters” sub-trees “Phase VT Setup” and “Auxiliary VT Setup”. See Figure 4.

The VT connection types must be properly defined so that the 25A element makes the proper phase-angle references when performing calculations. In the “Phase VT Connection” field, select “4W-Y” to represent the wye-wye VT connection from the generator bus. The single phase VT as seen on the synchronization bus, is connected between phase A and ground; therefore, “AN” will be selected as the “Aux VT Connection”. In some cases it may be necessary for the 25A element to account for phase angle differences between the generator bus and synchronization bus created because of either VT connection types or power transformers in the synchronization zone or both. The steps to make such corrections are described later in this section.

Depending upon the overall application, the Fuse Loss (60FL) function may not be desirable. The 60FL element detects fuse loss and loss of potential by using voltage and current thresholds that are expressed as a percentage of the nominal voltage and current values.

Applications without any current measurements will typically disable the 60FL from blocking the 25A function. The 60FL settings screen is shown in Figure 5.

The Synchronizer (25A) function can be found in BESTCOMS*Plus* as a sub-tree under the "Control" heading. See Figure 6. As mentioned, "Mode" can be either "PLL" or "Anticipatory", the latter of which is selected because this example focuses on the anticipatory mode..

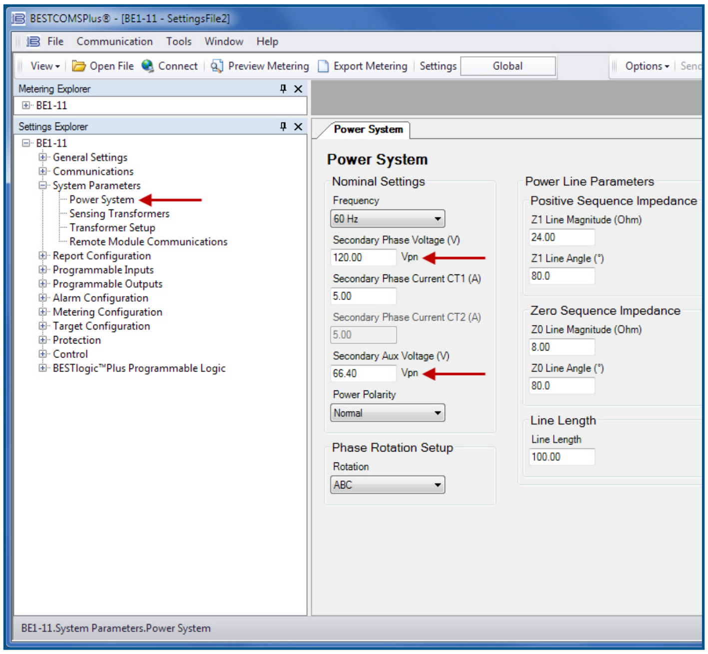


Figure 3 - Nominal Settings

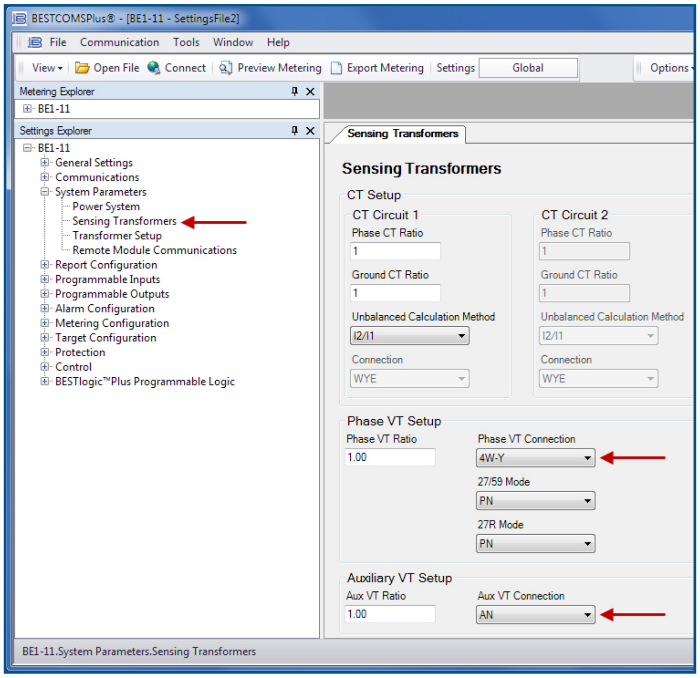


Figure 4 - Sensing Transformers

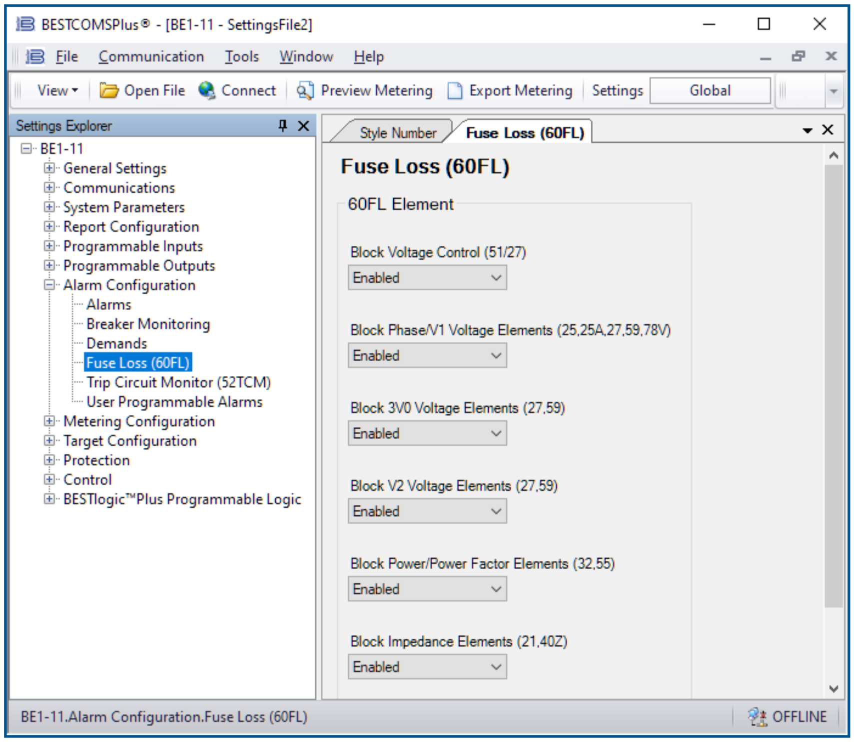


Figure 5 - 60FL Settings Screen

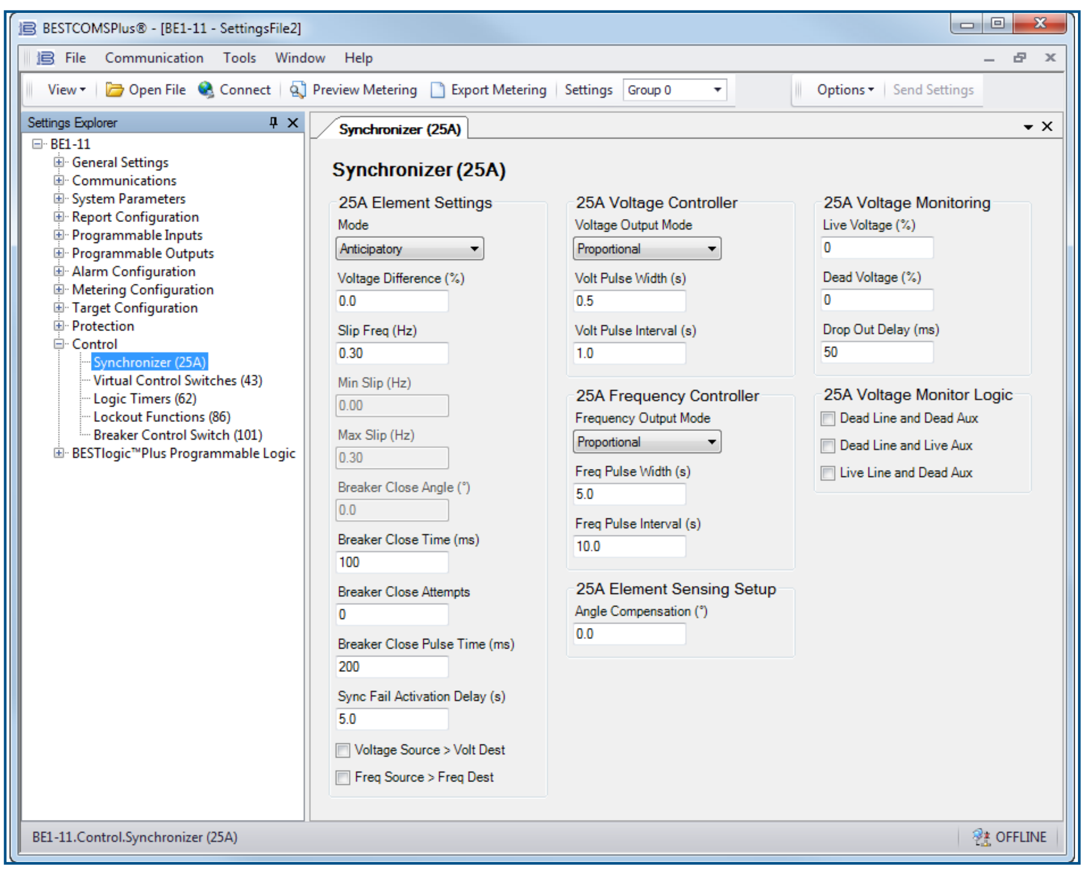


Figure 6 - 25A Element in BESTCOMS*Plus*

The “Voltage Difference (%)” setting defines the maximum allowable magnitude difference between the generator bus and the synchronization bus to be considered synchronized. The “Voltage Difference (%)” setting must be set above 0 for the auto synchronizer function to operate. In C37.102-2006, the IEEE recommends a voltage difference of no more than 5%.

It is common for applications to require the generator bus voltage be at or higher than the synchronization bus. Setting the generator bus voltage higher than the synchronization bus adds to “systems stability by insuring var flow into the system. Additionally, if the generator voltage is excessively lower than the grid when the breaker is closed, sensitively set reverse power relays may trip.” [IEEE C37.102-2006] If necessary, the BE1-11*g* can ensure that the generator output voltage is regulated above the bus to which it will be synchronized by checking the “Voltage Source > Volt Dest” box. When the “Voltage Source > Volt Dest” box is checked, the minimum allowable voltage difference is +0.5%.

The value input to the “Slip Frequency (Hz)” field delineates the difference in Hertz to which the BE1-11*g* auto synchronizer regulates the rotational speed of the generator versus the frequency of the voltage on the synchronization bus. This setting must be set above 0 for the auto synchronizer to operate. Properly setting the slip frequency should be based on the individual generator and prime mover characteristics but, in general, should be limited to no more than 0.067 Hz (IEEE C37.102-2006).

It may be desirable to ensure that the frequency of the generator is always slightly higher than the synchronization bus. This can prevent motoring of the generator and false operation of sensitively set reverse power relays. [IEEE C37-102-2006] To guarantee that the generator bus frequency is higher than the synchronization bus frequency at the time of parallelization, the “Freq Source > Freq Dest” box should be checked.

The actual or rated close time of the circuit breaker is input with the “Breaker Close Time (ms)” setting. The circuit breaker close time can be obtained from manufacturer’s literature or from field testing. The BE1-11*g* takes the input value and adds it to the internal relay computational time and the output relay contact closure time to achieve precision parallelization. It is important that the “Breaker Close Time (ms)” setting be accurate so that the advantages of the anticipatory type auto synchronizer are realized. This setting must be set above 0 for the auto synchronizer control element to operate.

The next two settings discussed are “Breaker Close Attempts” and “Sync Fail Activation Delay (s)”, both of which are supervisory settings for the 25A. These settings determine when a synchronization failure has occurred based on whether the circuit breaker has closed after a close signal is issued. The maximum number of circuit breaker close attempts allowed by the 25A element should be entered in the “Breaker Close Attempts” field. The default setting is 0 and needs to be changed to a value above 0 for the 25A to operate; the limit is 5. The “Sync Fail Activation Delay (s)” field defines the length of time the 25A element waits after issuing a breaker close command to receive a breaker status change. The default setting for “Sync Fail Activation Delay (s)” is 5 seconds and has a range of 0 to 600 seconds. Entering 0 in this field will result in no wait time for circuit breaker status feedback. This equates to a short pulse of the “Close Breaker” output and a close attempt is recorded. The 25A element immediately pulses the “Close Breaker” output again if the synchronization parameters are true and the “Breaker Close Attempts” have not been exceeded. If the number of “Breaker Close Attempts” has been reached, a synchronization failure occurs and the 25A element ceases to operate.

Some important considerations regarding how the “Breaker Close Attempts” and “Sync Fail Activation Delay (s)” are used in 25A operation are presented in the following example. Most anticipatory auto synchronizer applications require that the generator frequency be faster than the bus to which it will be synchronized. The operation can be illustrated by considering a synchroscope which is rotating clockwise through 12 o’clock. The breaker close signal is issued slightly in advance of 12 o’clock based on the “Breaker Close Time (ms)” setting. The circuit breaker close signal is a sustained signal as long as the synchronization parameters are true or until the circuit breaker status is reported as closed. However, in anticipatory mode, the close signal remains for only a short time because the synchronization parameters are true for only a short time as the synchroscope continues to rotate. If the breaker status has not changed and if multiple circuit breaker close attempts are allowed by the setting in the “Breaker Close Attempts”, the next circuit breaker close attempt does not occur until the synchroscope approaches 12 o’clock again. Otherwise, the synchronization is considered failed. Consideration for determining the

"Sync Fail Activation Delay (s)" setting should include the slip speed setting, circuit breaker close time, and the time to operate the circuit breaker auxiliary contact.

The "25A Voltage Controller" and "25A Frequency Controller" functions operate in a similar manner. The voltage and frequency controllers provide two output mode choices: "Proportional" or "Continuous". The type of frequency and voltage control used is generally based on the 25A mode. For anticipatory mode, Proportional control is most commonly used.

Proportional control administers the respective voltage and speed correction pulses for a given period of time based on the settings in "Volt Pulse Width (s)" and "Freq Pulse Width (s)". The time between pulses is based on the respective settings given for "Volt Pulse Interval (s)" and "Freq Pulse Interval (s)". The pulse widths and intervals are effectively maximum range settings because, as the voltage and frequency between the generator bus and synchronization bus become closer to equal, the BE1-11g reduces the width and interval of the correction pulses. This results in smooth and precise speed and voltage control because changes are made incrementally and checked by the BE1-11*g* after each change.

The "Angle Compensation" field provides a means to match phase differences between the three-phase and single-phase aux voltage inputs caused by either VT connection types or transformers in the synchronization zone or both. The BE1-11*g* instruction manual shows common VT connection types and the angle compensation required. The 13,800 V generator bus in Figure 1 is stepped up through a delta-wye generator step-up (GSU) transformer to 69 kV before it is connected to the circuit breaker. Therefore, this GSU is a part of the synchronization circuit and a phase shift needs to be accounted for as a result of the delta-wye winding. This phase shift is generally going to be 30 degrees leading on the high voltage side of the GSU. As a result, the VT phasor values, when compared by the BE1-11*g*, are offset by this quantity, preventing proper angular comparison between the generator bus and the synchronization bus.

Figure 1 shows that no compensation to correct the VT connections is required. Therefore, only the phase shift of the GSU windings should be considered for correction. However, if both a VT connection type requiring angular compensation and a transformer with a phase shift between the high and low windings are present in the synchronizing zone of the application, the sum of the angle differences is entered in the "Angle Compensation" setting field.

The phase angle difference that determines angular synchronization between the generator bus (phase VT) and synchronization bus (aux VT) is calculated within the BE1-11*g* as the difference between the phase VT and aux VT angles plus the value entered in the "Angle Compensation" field. See Calculation 1, which relates to the given application example. Note that leading is considered positive, lagging is considered negative, and 0 degrees is equivalent to 360 degrees.

Calculation 1

Angle Difference = phase VT angle – aux VT angle + "Angle Compensation"

Angle Compensation (Acomp) = unknown

Phase VT angle = 360

Aux VT angle = 30 leading

Solving for Acomp and a target Angle Difference of 360:

Acomp = –phase VT angle + aux VT angle + 360

Acomp = –360 +30 + 360

Acomp = 30 degrees

The "25A Voltage Monitoring" and the "25A Voltage Monitor Logic" provide a means to use the voltage quantities measured on the generator bus and the synchronization bus in logic based on the settings described below. The "Live Voltage (%)" setting determines the level at which either the phase voltage (generator bus, all three phases), or the auxiliary voltage (synchronization bus), is considered a live bus. The "Live Voltage (%)" conditions are met when the voltages are equal to or higher than the setting input. The "Dead Voltage (%)" setting determines the percentage at which either the phase voltage (generator bus, all three phases), or the auxiliary voltage (synchronization bus), is considered to be a dead bus. The "Dead Voltage (%)" parameters are met when the voltages are equal to or lower than the setting input. Both the "Live Voltage (%)" and "Dead Voltage (%)" quantities are based on the nominal values previously input. The "Dropout Delay (ms)" setting provides hysteresis in milliseconds for the "25A Voltage Monitoring" function. The buttons under "25A Voltage Monitor Logic" allow a selection of any or all of three possible conditions: Dead-Line and Dead-Aux, Dead-Line and Live Aux, or Live-Line and Dead Aux, where "Line" refers to the three-phase voltage input and "Aux" refers to the Vx single-phase input. The corresponding boxes should be checked to indicate under which conditions the "25A Voltage Monitor Logic" will be used. Figure 7 depicts how the "25A Voltage Monitor Logic" operates. Information on the usage of the "25A Voltage Monitor Logic" logic function is given in the next section.

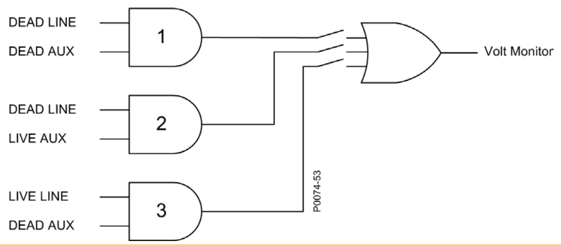
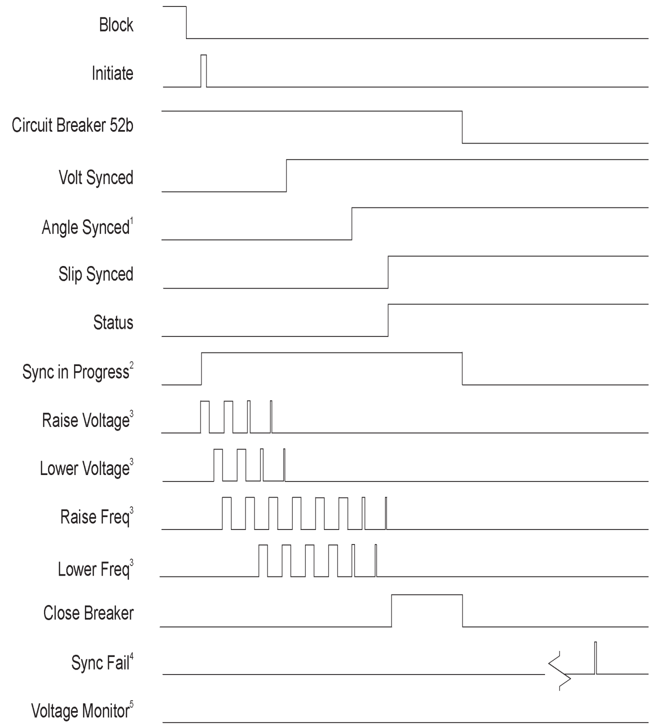


Figure 7 - Voltage Monitor Logic

Programming the 25A Element in BESTlogic™*Plus*

This section explains the operation of the 25A element and how to program it using BESTlogic*Plus*. For more details on BESTlogic*Plus*, refer to the BE1-11*g* instruction manual.

The 25A element can be found in the "Elements" tab near the lower left portion of the BESTlogic*Plus* programming screen. See Figure 8. Calculations based on the auto synchronizer settings are performed within the BE1-11*g*, and logical decisions are executed to operate the logical outputs of the 25A logic element. Then, logical outputs are coupled to other logic or physical outputs to interface with the generator speed and frequency control systems. The operation of the logical outputs during synchronization is depicted in Figure 9.



Notes:

1. Angle Synced in PLL mode is true when the oncoming source is within the window defined by the Breaker Close Angle setting.
In Anticipatory mode, Angle Synced is true when the calculated advance angle (including breaker close time) results in a zero-degree difference with the sync bus.
2. Sync in Progress is active as long as voltage is greater than 10 Vac secondary and frequency is greater than 15 Hz.
3. The 25A element pulses these outputs as needed to achieve synchronization.
4. Sync Fail pulses true after 1–5 attempts with no circuit breaker close (the setting is Breaker Close Attempts).
5. The Voltage Monitor is logical 1 and logical 0 per Dead Voltage/Live Voltage settings.

Figure 9 - 25A Timing Chart

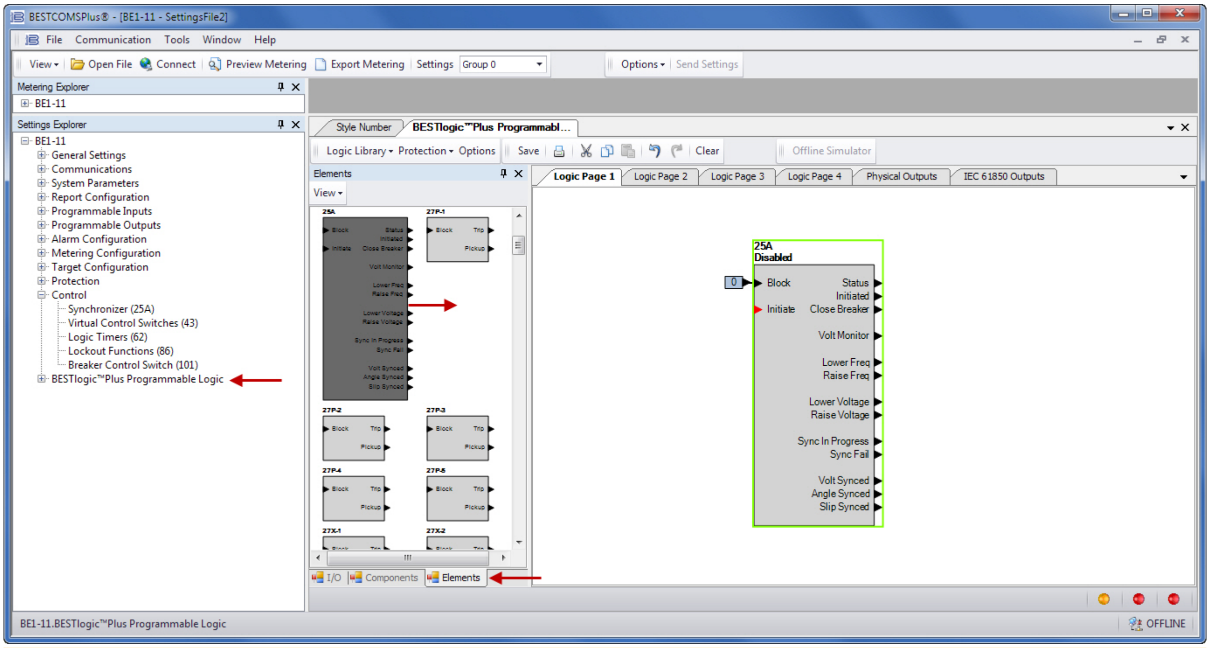


Figure 8 - 25A in BESTlogic*Plus*

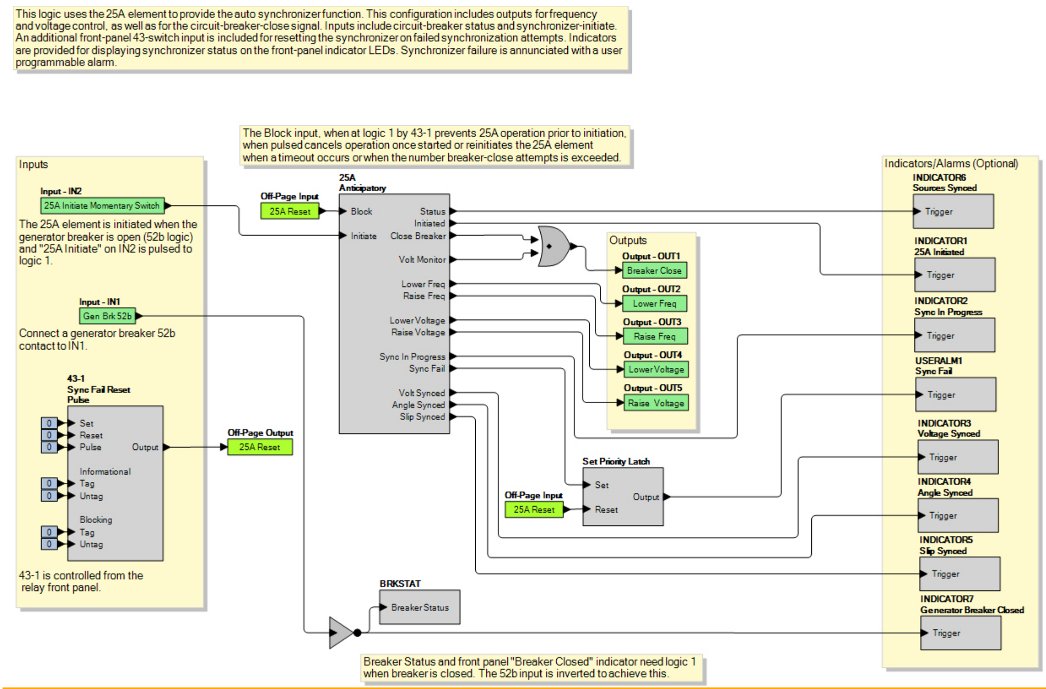


Figure 10 - 25A Logic Library File

The 25A logic element consists of 2 logical inputs and 13 logical outputs. The logical I/O is mapped to physical I/O by connecting logical wiring between the desired element I/O and the physical I/O objects. A BESTlogic*Plus* library file is used as an example throughout this section. See Figure 10.

Because most applications require the circuit breaker to be open before beginning auto synchronization and because the 25A element needs confirmation of the circuit-breaker close status after a close command has been issued, an element named "BRKSTAT" is provided to serve both purposes. "BRKSTAT" is also used in the breaker monitoring functions listed in the BE1-11*g* instruction manual and as a permissive in the 25A, 60FL, 50BF, and 52TCM elements. Though the connection to these logic elements is concealed and operates as a status input, the logical link between "BRKSTAT" and the other associated elements is a permanent digital input done through the BE1-11*g* firmware. As a result, no logical wired connections to the 25A, 60FL, 50BF, and 52TCM elements are required. However, a 52 contact from the circuit breaker must be logically connected to the "BRKSTAT" element to make it functional. A logical 1 on the input of "BRKSTAT" prevents the 25A from initializing. 52b contact input logic must be inverted for proper operation as seen in Figure 10. Failure to connect a 52 contact to "BRKSTAT" results in a 25A element that initiates regardless of the circuit breaker status. This causes a false synchronization failure because the 25A never receives confirmation of a successful circuit breaker state change after issuing a close signal.

The "Block" input of the 25A logic element, when at a logical 1, prevents the 25A element from being initiated and can be pulsed to either stop the 25A operation once started or reset the element for reinitialization in the event of a synchronization failure.

When switched or pulsed to logical 1, the input to the 25A logic element labeled "Initiate", starts the operation of the 25A but is dependent on the following factors:

- The "Block" input must be set at a logical 0.
- If configured, the "Fuse Loss 60FL" alarm must not be true (see BE1-11*g* instruction manual).
- "BRKSTAT" element must be set at a logical 0.
- "Breaker Close Attempts" in "25A Element Settings" must be set above 0.
- "Slip Frequency (Hz)" in "25A Element Settings" must be set above 0.
- "Voltage Difference (%)" in "25A Element Settings" must set above 0.
- "Breaker Close Time" in "25A Element Settings" must be set above 0.
- The 25A element was not previously stopped by "Sync Fail" without being reset by pulsing the "Block" input. This assumes that "Initiate" was not switched to logical 1 for the duration of the previous synchronization cycle. See explanation below.

For most applications, it is recommended that the "Initiate" input be connected in logic to a physical input that is wired to a momentary type contact. If a logical 1 remains on the "Intiate" input and a synchronization failure occurs, no reset is required by pulsing the "Block" input, and the 25A automatically reinitiates. If a momentary contact is desired but one is unavailable, a rising edge trigger may be used in logic to pulse a normally sustained contact. In this instance, the switch connected to the rising edge trigger needs to be switched to the "off" position before it can be switched to the "on" position to reinitialize the 25A element.

The following is an explanation of the 25A element logical outputs. The BESTlogic*Plus* programming example in Figure 10 shows some outputs connected to the BE1-11*g* physical outputs via logical wiring. These outputs provide a way to interface to the circuit breaker close coil, the prime mover's speed control, and to the generator excitation control system either directly or through an intermediary device such as a PLC, or programmable logic controller. However, any of the 25A element outputs could be used in logic for other functions as necessary to meet the requirements of a specific application. Other element outputs shown in the example are connected to indicators and a programmable alarm. The indicators are mapped to the front panel programmable indicators on the BE1-11*g*. Use of the indicators and programmable alarm is optional.

The "Status" output is a logical 1 when all of the synchronization parameters are met and the generator and synchronization bus voltages are stable. Refer to Figure 9 for clarification.

The "Initiated" output indicates when the 25A has been initiated but is not in an active synchronization status. The "Initiated" output becomes a logical 1 when the "Initiate" input is true and "Sync In Progress" is not true. See the "Sync In Progress" explanation, below. If the "Block" input is true, the circuit breaker is open, or a previous synchronization has failed but not been reset then the "Initiated" input will be logical 0.

Once the "Status" output has become a logical 1, the 25A element initiates a circuit breaker closure by making the "Close Breaker" output a logical 1. This output is sustained and remains a logical 1 until the "BRKSTAT" element goes true, the setting in "Sync Fail Activation Delay (s)" causes a failure, or the synchronization parameters are no longer true. The "Close Breaker" output operation depends on the following conditions:

- The voltages of the generator bus and synchronization bus must be stable.
- Frequency error between the generator and the synchronization bus is less than the "Slip Freq (Hz)" setting in "25A Element Settings".
- Voltage error between the generator and the synchronization bus is less than or equal to the "Voltage Difference (%)" setting in "25A Element Settings".

The "Volt Monitor" output of the 25A element will be logical 1 based on the settings given in "25A Voltage Monitoring" and the "25A Voltage Monitor Logic". See Figure 7. This output operates independently of the "Initiate" input but is logical 0 when the "Block" input is a logical 1. Figure 10 illustrates how to use the "Volt Monitor" output based on the criteria mentioned above in conjunction with the "Close Breaker" output that executes circuit breaker closure for live generator bus, live synchronization bus operation.

The "Lower Freq", "Raise Freq", "Lower Voltage", and "Raise Voltage" outputs operate in the same manner. These outputs toggle to logical 1 or 0 for use as control signals to the prime mover and excitation controls respectively. The state of these outputs is controlled via the 25A element and is a function of the user defined synchronization parameters and the monitored voltage inputs to the BE1-11*g*. Figure 10 depicts how these outputs are logically connected to the output relays of the BE1-11*g*.

"Sync In Progress" provides an output to monitor in logic when the 25A has been initiated and is not inhibited. The three-phase and single-phase voltage inputs connected to the respective generator bus and synchronization bus must sense greater than 15 Hz and 10 V or 25A operation will be inhibited and "Sync In Progess" will be logical 0. If the 25A has been initiated but is inhibited, it remains initialized unless the "Block" input goes to logical 1 or a synchronization failure occurs. The "Sync In Progress" output is logical 1 when the initiate logic is true and the inhibit parameters are false. Figure 10 shows that this output is connected to one of the BE1-11*g* front panel lights for visual confirmation that synchronization is in progress.

The "Sync Fail" logical output becomes logical 1 when the operation of the auto synchronizer is canceled by the 25A algorithm. When the "Sync Fail" output is at logical 1, all the remaining 25A element logic outputs are driven to logical 0. Synchronization is considered to be failed based on the parameters set for "Breaker Close Attempts" and "Sync Fail Activation Delay (s)" in "25A Element Settings" as described in the BESTCOMS*Plus*: Programming the 25A Element section. Figure 10 shows that this output is connected to one of the BE1-11*g* programmable alarms for visual indication on the relay LCD that the auto synchronizer has failed to parallel the generator bus and the synchronization bus, resulting in a failure of the 25A element.

The logical output of the 25A logic element labeled "Volt Synced" becomes logical 1 when the generator bus and the synchronization bus voltages are considered synchronized as defined by the "Voltage Difference %" setting in "25A Element Settings". If the "Voltage Source > Volt Dest" box is checked, the generator bus voltage must be at least +0.5% higher than the synchronization bus and within the range defined by the "Voltage Difference %" for the "Volt Synced" output to become logical 1.

The "Angle Synced" logical output is logical 1 when the calculated advance angle, including the setting entered in "Breaker Close Time (ms)" in "25A Element Settings" equals a zero degree phase angle difference between the generator bus and the synchronization bus.

The "Slip Synced" output is a logical 1 when the difference in frequency between the generator bus and the synchronization bus is within the settings entered in the "Slip Freq (Hz)" field in "25A Element Settings". The "Slip Synced" output also depends on the "Freq Source > Freq Dest" setting. If checked, the generator bus frequency is required to be higher than the synchronization bus frequency for the "Slip Synced" output to be logical 1.

Additional Considerations

It is common practice to supervise the 25A control element with a BE1-25 or other sync-check (25) device. The voltage and frequency settings for the 25 are generally set wider than the 25A. It is important to note that the recommended settings given above apply to the 25 device, if used. In such an application, the 25A is set with narrower parameters than those recommended maximums. Figure 11 shows a typical 25 and 25A parameter window.

Summary

The BE1-11*g* provides an economical solution for generator applications that require a fully functional auto synchronizer. The BE1-11*g* provides auto synchronization in two modes: anticipatory and phase-locked-loop (PLL).

For more information on setting the 25A to PLL mode, please refer to the BE1-11*g* instruction manual. In addition to the 25A, the BE1-11*g* also simultaneously provides voltage protection and current protection. Current differential protection can be implemented in addition to the 25A if the BE1-11*g* is ordered as style number GxxxxxxxTxxxxx. The added convenience and flexibility of programming the 25A function in BESTCOMS*Plus* and BESTlogic*Plus* make deployment of the 25A and other protective elements intuitive and simple.

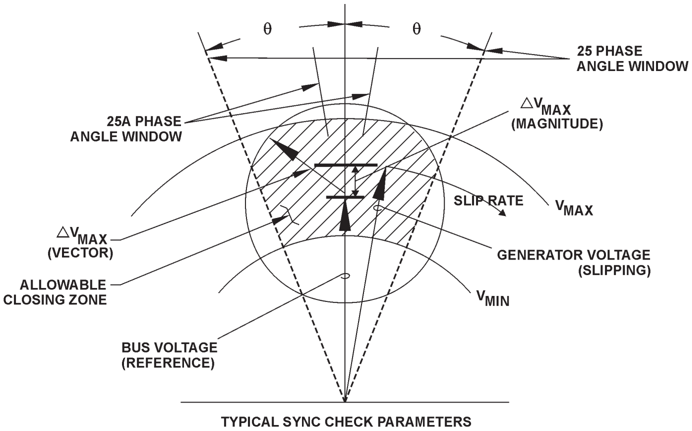


Figure 11 - Typical 25 and 25A Parameters

For more information

For additional information on BESTCOMS*Plus* software and the BE1-11 Protection System, including more application notes, product bulletins, and instruction manuals, go to www.basler.com, contact your Application Engineer, or contact Technical Support at 618-654-2341.

References

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