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GENERATOR-SYSTEM AUTOSYNC. CONFIGURATION WITH REX640 RELAY

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Generaattorin synkronointi verkkoon on monen muuttujan prosessi, jossa moni asia voi epäonnistua. Tämän lopputyön aiheena on tehdä tekninen ohje, jossa kerrotaan, miten ABB:n REX640 releen synkronointilohkot konfiguroidaan ja miten ne voidaan toisiokoestaa Omicron-koestuslaitteella.

Työn teoriaosassa selitetään, mitä synkronointi on ja mitä siihen tarvitaan. Seuraavaksi käydään läpi, miten rele ohjaa generaattorin jännitettä ja taajuutta. Lisäksi on kerrottu releen synkronointilohkojen toiminnallisuutta ja käyttöä. Myös koestuksessa käytetyt työkalut on esitelty.

Työssä on tarkasteltu olemassa olevia reledokumentaatioita, joiden pohjalta luotiin, dokumentointiin ja koestettiin kahdelle releelle konfiguraatio.

Työn tuloksena muodostui tekninen ohjeistus, jossa käydään läpi ASGCSYN, ASNSCSYN ja ASGAPC synkronointilohkojen konfiguroinnissa ja koestamisessa tarvittavat vaiheet. Kommunikaatio releiden välillä toteutetaan GOOSE-protokollan avulla, minkä koestamisen helpottamiseksi tekniseen ohjeistukseen lisättiin tulkintataulukko.

Avainsanat suojarele, synkronointi, konfigurointi, toisiokoestus

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ABSTRACT

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Synchronising of the generator to the network is multi variable process where many things can fail. The subject of this thesis is to provide a technical guide on how the ABB REX640 relay synchronization functions are configured and can be secondary tested using an Omicron tester.

The theoretical part of the thesis explains what synchronisation is and what is needed for it. Next, it is also discussed how the relay controls the generator voltage and frequency. Then, functionality and usage of the relay autosynchronous function blocks are described.

In the thesis, existing relay documentation is revised, and based on that, the configurations for two relays were created, documented and tested.

The result of this thesis is a technical document that goes through the necessary steps to configure and test the autosynchronization functions. The communication between the relays is done using the GOOSE protocol. To assist the testing of the communication, an interpretation table was included in the technical document.

Keywords protection relay, synchronizing, configuration, secondary test

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ABBREVIATIONS

+ΔUmax Setting Voltage Diff Ov Ex

-ΔUmax Setting Voltage Diff Un Ex

AVR Automatic Voltage Regulator

CB Circuit Breaker

DC Disconnector

ds/dt Frequency slip acceleration

ES Earth Switch

f Frequency

fBus Measured bus side frequency

fBusA Bus A side frequency

fBusB Bus B side frequency

fGen Measured generator side frequency

fn Nominal Frequency

GOOSE Generic Object Oriented Substation Events

Hz Hertz

IED Intelligent Electronic Device

ms Millisecond

NSCB Non-Source Circuit Breaker

PCM Protection and Control IED Manager

s Frequency slip

SCB Source Circuit Breaker

SLD Single Line Diagram

TCB Setting for closing time of CB

UBus Measure bus side voltage

UBusA Measured bus A side voltage

UBusB Measured bus B side voltage

UGen Measured generator side voltage

VT Voltage Transformer

ΔU Measured voltage difference across the CB to be synchronized

dU/dt Setting voltage rate of change

∠UBus Measured bus side phase voltage

∠UGen Measured gen side voltage phase angle

1 INTRODUCTION

Majority of the electrical power is produced by the means of synchronous generators. Before the generator can be connected to the power network it must first be run in sync with the network. This is done by a synchronizer device.

Protection relays are used in the power network to detect failures or abnormalities in the system and quickly isolate the defective element before excessive damage or possible power system collapse occur. Modern relays contain a variety of protection, measurement and control functionalities. The ABB relay type REX640 also contains an autosynchronizer functions. **Figure 1** shows two hardware variants of the REX640.

Figure 1. REX640 relays (ABB, 2025).

Prior this thesis, creating an autosynchronizer configuration for REX640 has been challenging due to the lack of easy-to-follow guidelines and examples. The purpose of this thesis is to make a working and tested autosynchronizer configuration and to document this process as a Technical Note. This purpose is to be achieved through the following objectives:

- First, to give an understanding of the REX640 autosynchronizer functionality with the available REX640 technical, application and engineering manuals.
- Next, to describe in brief how the autosynchronizer works in REX640, and the needed inputs and outputs for the autosynchronizer functions.
- Next, to introduce the used tools in this thesis.
- Then, to create a working and tested autosynchronizer configuration example for the REX640 relay.
- The last goal of this thesis is to write a technical guide for configuring and verifying autosynchronizer applications, see Appendix 1.

1.1 Overview of the Generator Network Systems

Synchronization ensures the safe and reliable connection of a generator to the power grid. The generator requires an AVR (automatic voltage regulator) to control its voltage output and a governor to regulate its frequency.

Figure 2 illustrates a generator with its controlling devices. The purpose of the generator is to convert mechanical power produced by a prime mover (e.g. diesel machine, steam or water turbine) to electrical power. The governor controls the speed of the prime mover and thus the frequency of the generator. For converting electrical power, the synchronous generator requires magnetization (also known as excitation) which controls the voltage output of the generator. In this thesis the generator synchronization unit is a REX640 relay.

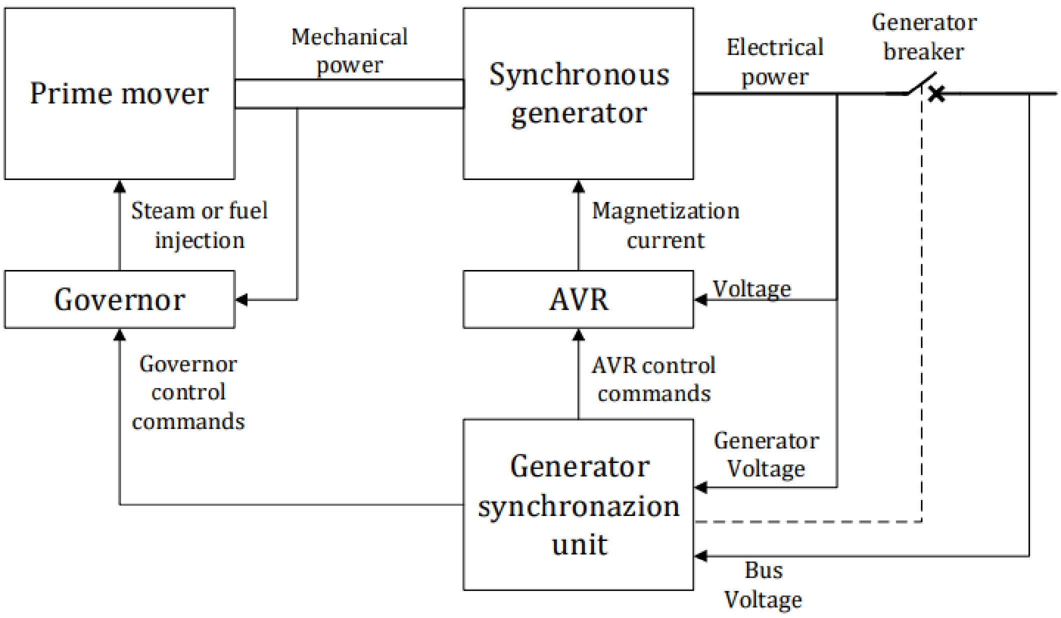


Figure 2. Generator and control systems (Internal source REX640 Autosynchronizer Theory, 2022).

The REX640 relies on VTs (voltage transformers) to measure the generator and network voltages. VTs reduce the high primary voltage to a lower, measurable level for the relay (Glover et al., 2016, p. 614). Using these measurements, the relay can also calculate the phase angle, a critical factor for synchronization.

When synchronizing a generator to the grid, the following three conditions must be fulfilled:

1. The phase angle between the grid and generator must align.
2. The voltage of the grid and generator must closely match.
3. The generator and grid frequency must also be closely matched.

Once these conditions are fulfilled, REX640’s synchronization control function sends signals indicating that synchronization is in order. Then, a close command is initiated to close the generator circuit breaker (GCB), also known as a source circuit breaker (SCB). If any of the conditions are not met within a specified time window from the beginning of the synchronization, the relay will cancel the synchronization process and will give an alarm (ABB, 2024).

REX640 synchronization function can be applied to various types of networks. A simple one generator network typically has just one SCB to connect the generator to the grid. REX640 also has another synchronizer function for closing of a non-generator circuit breaker (non-source breaker, NSCB) such as a bus sectionalizer, a bus coupler or an incoming feeder (ABB, 2024).

A network where multiple generators are operated in parallel is more complex. Each generator must be synchronized to the grid individually, which requires a separate relay for each generator.

Networks usually include a disconnector (DC) after the CB, which is used to isolate parts of the network, and earth switch (ES) for earthing purposes (e.g. during the generator maintenance).

1.2 A One Generator Network

Figure 3 illustrates an example of a one generator connected to a network (busbar). Generator and bus voltages are measured by the means of the VTs. This kind of system is usually used to give more power to the grid in times of power shortage. Additionally, should generator and network have different voltage levels, a step-up transformer (not shown in the figure) is used. Then voltage and angle differences must be considered.

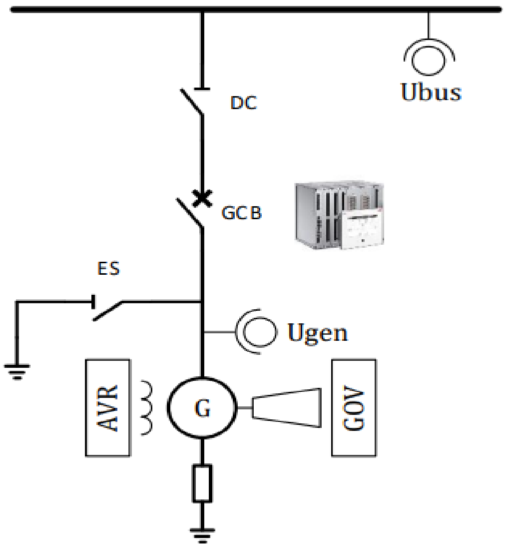


Figure 3. Basic Network (Internal source REX640 Autosynchronizer Theory, 2022).

1.3 Parallel Running Multiple Generator System

In parallel networks generators are typically used to distribute the load of the electrical power system between the generators. The advantages of operating multiple generators in parallel include increased reliability, expandability, flexibility, serviceability, and efficiency (Ranchagoda et al., 2015). When one of the generators fails, other generators pick up the load from the failed one. A parallel network is challenging to control because of the various generators and circuit breaker and needs a coordinator to take care of the controlling. In this kind of network, it is possible to have multiple SCBs for generators and NSCBs for sectionalizers, as seen in **Figure 4**.

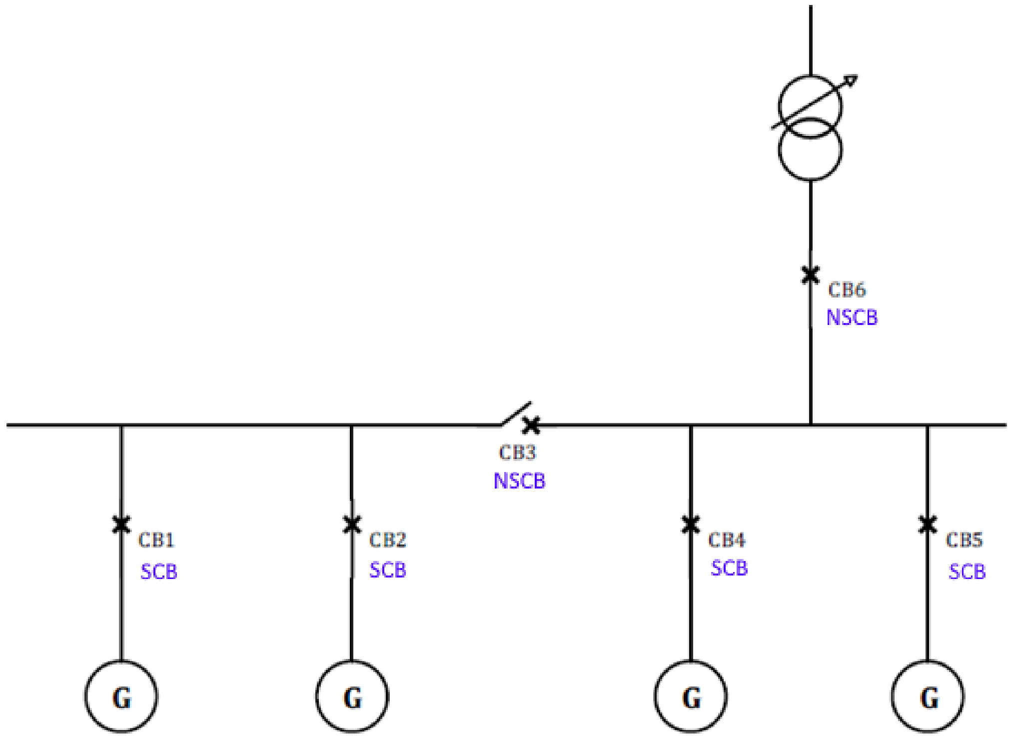


Figure 4. Parallel generators (Internal source REX640 Autosynchronizer Theory, 2022).

2 BASICS OF AUTOSYNCHRONIZING

In this chapter, we will cover the dangers associated with faulty synchronization as well as the benefits and needs of autosynchronization. Next to clarify the difference between Synchro check and Energizing check functionalities.

2.1 Significance of Synchronizing of the Generator

According to Thompson (2012) synchronizing a generator to the network must be done carefully. The speed (frequency) and voltage of the generator must be closely matched, and the rotor angle must be close to the network's phase angle.

Poor or incorrect synchronizing can cause the following problems:

- Damage the generator and the prime mover because of mechanical stresses caused by rapid acceleration or deceleration, bringing the rotating masses into synchronism (Thompson, 2012).
- Damage to the generator and step-up transformer windings caused by high currents as results of too high voltage or angle difference (Thompson, 2012).
- Disturbs to the power system such as power oscillations and voltage deviations from nominal (Thompson, 2012).
- Prevents the generator from staying online and picking up load when protective relay elements interpret the condition as an abnormal operating condition and trip the generator (Thompson, 2012).
- Results in a high current surge which can damage or reduce the life of generator and transformer windings (Thompson, 2012).
- Over stresses the circuit breakers (CB) main contacts.

- Closing a generator breaker with an excessive phase angle across the synchronizing breaker just prior to the closing action tends to cause an-out-of-step or so-called power swing condition (Ibrahim, 2011, p. 381).

When synchronizing, the phase angle must be as close as possible to zero. The other thing to consider when synchronizing is that the CB has a closing delay, which REX640 also anticipates. **Figure 5** illustrates the generator angle movement near CB closing time.

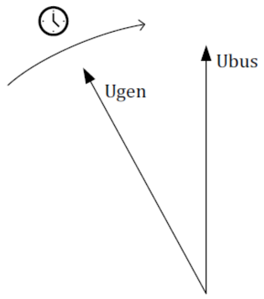


Figure 5. Closing CB time (Internal source REX640 Autosynchronizer Theory, 2022).

Frequency and phase difference between generator and network are related such that angle is changing (rotating). If there is frequency difference and angle is stationary then frequency difference is zero. To illustrate this **Figure 6** and **Figure 7** show an example of a one phase voltage at 5 Hz, and 0,5 Hz frequency difference, respectively. For example, in **Figure 7**, if CB closing time is 60 ms and frequency difference is 0,5 Hz then in this time phase angle rotates (50 Hz – 49,5 Hz) * 0,06 s * 360° = 10,8°.

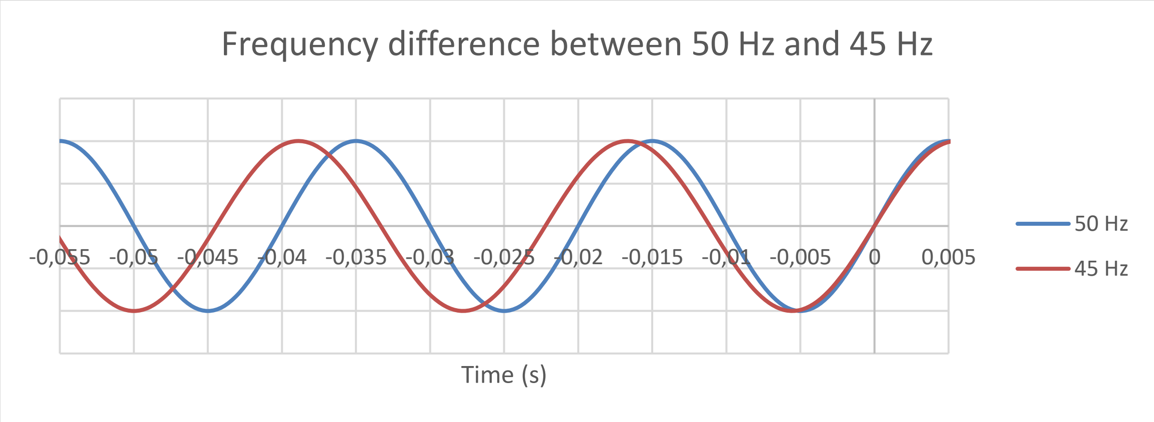


Figure 6. Difference of 50 Hz and 45 Hz.

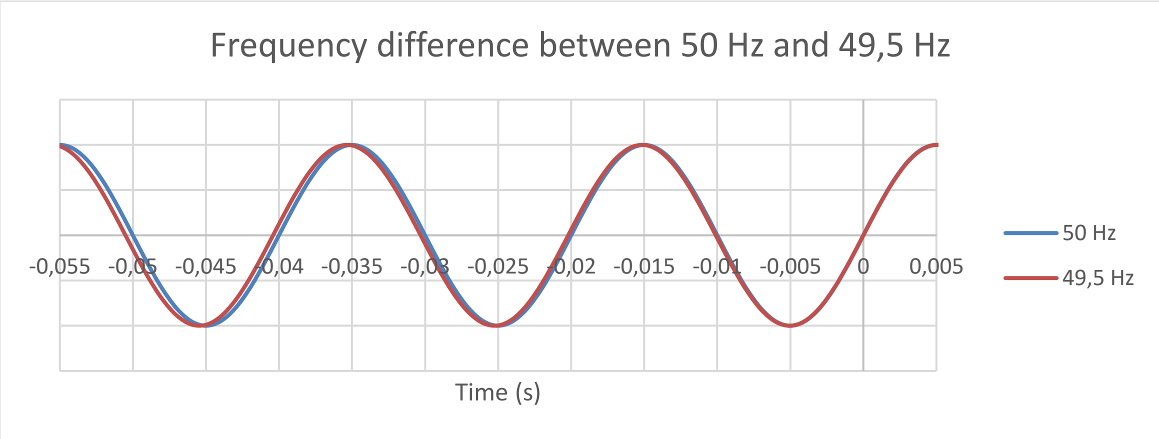


Figure 7. Difference of 50 Hz and 49,5 Hz.

2.2 Benefits of Autosynchronizer

Autosynchronization is more accurate and reliable than manual synchronization in making phase, voltage, and frequency adjustments. This accuracy minimizes issues during CB closing such as power surges, transient spikes, and mechanical stress on the generator. Autosynchronization is also faster than manual synchronization, which is useful when a backup generator is needed, or a generator needs to come online during a peak load time.

In the case of a synchronization error, the relay autosynchronizer function notices it and cancels the synchronization. Autosynchronizer also eliminates human errors and gives more precise and less stressing CB closing to the network (ABB, 2024).

2.3 Synchro Check vs Energizing Check

Synchro check functionality is used to check that both voltage, frequency and phase angle are within allowed range for CB closing. This means that both voltages must be live.

An energizing check is used when either or both sides are dead. For example, CB can be allowed to be closed when generator is live, and bus is dead. Here only voltage amplitudes are checked. Dead and live voltages mean that voltage is below or over set parameters, respectively. **Figure 8** shows an energizing check different setting from ASGCSYN function.

Live dead mode	Description
Off	Live dead mode setting is in off status
Both Dead	Both bus and generator de-energized
Live G, Dead B	Bus de-energized and generator energized
Dead B, G Any	Bus de-energized and generator energized or de-energized

Figure 8. Energizing check settings in ASGCSYN function (ABB, 2024).

3 CONTROLLING GENERATOR VOLTAGE AND SPEED (FREQUENCY)

In this chapter, we will discuss briefly how automatic voltage regulators AVR, and governor operate and how they are used in autosynchronization.

3.1 AVR (Automatic Voltage Regulator)

Generator AVRs are the most important means of voltage control in power systems. With AVR the excitation level of the generator is controlled, which in turn affects the generator output voltage (Kundur, 1994, p. 967).

From a synchronizing unit (in this case REX640) voltage `raise` and `lower` pulse commands are issued to the AVR that changes the generators excitation by controlling the amount of current given to the generator field winding (Machowski, 2008, p. 22).

Higher excitation gives higher voltage output from the generator and lower excitation gives lower voltage output from the generator. When synchronizing, the voltage is controlled to be within the allowed voltage difference. That is the voltage difference between the generator and the grid. Closing the CB with a higher generator voltage results generator to feed higher reactive power than needed towards the network. Lower voltage results generator to absorb reactive power from the network (Internal source REX640 Autosynchronizer Theory, 2022).

3.2 Governor (Frequency)

A governor is a system that is used to maintain the speed of an engine or turbine (prime mover) within certain limits, under varying load conditions. For example, if an increase in frequency is desired, the fuel valve is opened by the governor, resulting in an increase in speed.

From a synchronizing unit (in this case REX640) frequency `raise` and `lower` pulse commands are issued to the governor for matching the rotation speed (frequency). Increasing the speed raises the generator frequency and decreasing the speed lowers the frequency (ABB, 2025)

4 REX640 RELAY AUTOSYNCHRONIZER FUNCTIONALITIES

In this chapter we describe the necessary functions required in REX640 autosynchronizer configuration. ABB protection relay REX640 has an advantage for having a built-in autosynchronizer, which allows customization for different kinds of networks. The most important functions for this thesis are:

- Autosynchronizer for generator breaker ASGCSYN
- Autosynchronizer for Network Breaker ASNSCSYN
- Autosynchronizer co-ordinator ASCGAPC

We will review the information from the REX640 technical and application manuals, making it easier to understand while highlighting the most important parts related to autosynchronizer functions.

4.1 Autosynchronizer for Generator Breaker ASGCSYN

The autosynchronizer for a generator breaker (ASGCSYN) takes care of synchronizing the generator to the bus, by giving instructions to the AVR and governor to raise or lower the voltage or frequency, respectively. When all the conditions are met, ASGCSYN permits the CB to close (ABB, 2024). **Figure 9** shows the module diagram of the ASGCSYN function. All the input signals are shown on the left-hand side and output signals on the right-hand side.

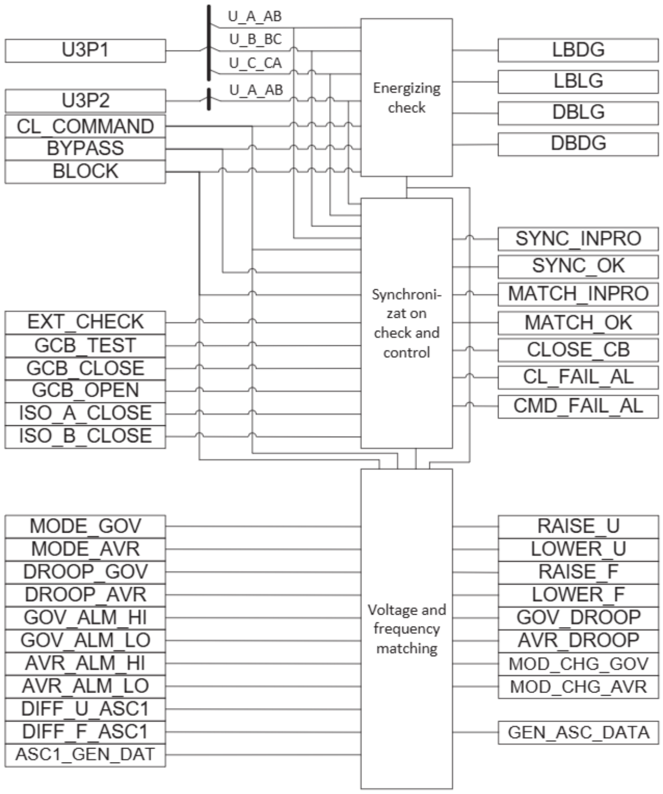


Figure 9. ASGCSYN module diagram (ABB, 2024).

Figure 10 shows ASGCSYN function block as seen in relay configuration.

Figure 10. ASGCSYN function block.

For synchronizing a generator breaker to the network, the relay needs preferably 3-phase voltage measurements both from the generator and bus sides (ABB, 2024). Single-phase measurement is also possible, but it is usually used only in testing the configuration. Relay gives the control commands to the AVR, the governor, and the generator breaker. **Figure 11** shows the voltage measurements and control commands. DC is shown in the figure, but it is usually closed before connecting the generator to the network, and ES is closed only when doing maintenance to the generator or the circuit breaker.

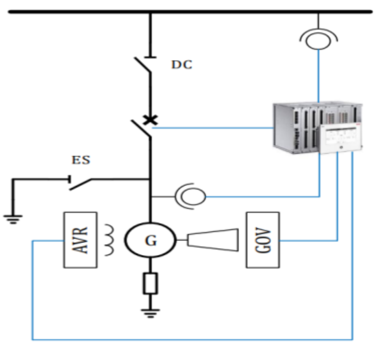


Figure 11. Measurements and controls for ASGCSYN. (Internal source REX640 Autosynchronizer Theory, 2022).

4.1.1 ASGCSYN Energization Check

ASGCSYN's energization check module checks whether both sides of CB voltages are considered Live or Dead. In case of either or both sides are dead, the CB closing can be allowed with the energizing direction setting `live-dead mode` (ABB, 2024). **Figure 12** shows how the closing of the CB can be allowed with energization check.

Live dead mode	Description
Off	Live dead mode setting is in off status
Both Dead	Both bus and generator de-energized
Live G, Dead B	Bus de-energized and generator energized
Dead B, G Any	Bus de-energized and generator energized or de-energized

Figure 12. ASGCSYNC energization check modes (ABB, 2024).

4.1.2 ASGCSYN Synchronization Check and Control

The synchronization check and control module checks if the measured voltages, frequencies and phase angles on both sides of the breaker are within the set matching limits to give a closing command to the breaker (ABB, 2024). If the measured values differ from set values, this module gives control commands to the AVR and to the Governor to raise or lower the voltage and frequency, respectively.

For the synchronization the following criteria are first checked:

- The measured bus and generator voltages are higher than the set value of *Live voltage value* (`ENERG_STATE` equals **Both Live**) (ABB, 2024).
- The measured bus and generator frequencies are both within the range of 95 to 105 % of the nominal frequency (f_n) (ABB, 2024).
- The measured bus and generator voltages are lower than the set value of *Maximum voltage* (ABB, 2024).

Figure 13 shows the additional conditions in synchro check. ASGCSYN `synchrocheck mode` is **Asynchronous**.

Measurements	Synchrocheck mode "Asynchronous"
U_DIFF_MEAS	< Voltage Diff Ov Ex and > -Voltage Diff Un Ex
PH_DIFF_MEAS	< Angle Diff positive and > - Angle Diff negative
FR_DIFF_MEAS	< Freq Diff OV Synch and > -Freq Diff sub Synch
Closing angle	< Angle Diff positive and >- Angle Diff negative

Figure 13. Asynchronous conditions (ABB, 2024).

In REX640, the module calculates the voltage, frequency and voltage phase angle difference based on the equations seen below.

Voltage difference is calculated in Equation (1).

$$\text{U\_DIFF\_MEAS} = U_{Gen} - U_{Bus} - Voltage\ offset \quad (1)$$

where

U_{Bus} = Measured bus side voltage

U_{Gen} = Measured generator side voltage

Voltage offset = Setting for voltage offset

Frequency difference is calculated in equation (2).

$$\text{F\_DIFF\_MEAS} = f_{Gen} - f_{Bus} - \mathit{Frequency\ offset} \quad (2)$$

where

f_{Gen} = Measured generator side frequency

f_{Bus} = Measured bus side frequency

Frequency offset = Setting for frequency offset

Voltage phase difference is measured in equation (3).

$$\text{PHASE\_DIFF\_MEAS} = \angle U_{Gen} - \angle U_{Bus} - \mathit{Phase\ shift} \quad (3)$$

where

$\angle U_{Gen}$ = Measured gen side voltage phase angle

$\angle U_{Bus}$ = Measured bus side phase voltage

Phase shift = Setting for Phase shift

4.1.3 ASGCSYN Closing CB Conditions

Depending on the circuit breaker and the closing system, the delay between the closing command and the circuit breaker actual closing is about 50 to 250 milliseconds. When the frequency, phase angle, and voltage conditions are fulfilled, the relay also checks that these conditions remain fulfilled for the set CB closing time (ABB, 2024).

The set closing time of CB informs the function of how long the conditions must persist. The value covers both circuit breaker closing delay and output type-dependent delay. The synchro check function compensates the measured frequency difference and the circuit breaker closing delay (ABB, 2024).

The closing angle is calculated as seen in Equation (4).

$$\text{Closing angle} = \left|(\angle U_{Gen} - \angle U_{Bus})° + ((f_{Gen} - f_{Bus}) \times (\frac{TCB}{1000}) \times 360°)\right| \tag{4}$$

where

$\angle U_{Gen}$ = Measured generator voltage phase angle

$\angle U_{Bus}$ = Measured bus voltage phase angle

TCB = Setting for closing time of CB, time in ms

When `Synchrocheck mode` is set to **Asynchronous,** the close command is given as explained below.

First, the frequency slip (s), which is given in reference to bus frequency, is calculated in equation (5).

$$\textit{Frequency slip } (s) = \frac{(f_{BusA} - f_{BusB})}{f_{BusA}} \tag{5}$$

Where

f_{BusA} = Bus A side frequency

f_{BusB} = Bus B side frequency

From the acceleration (ds/dt), the bus frequency `FR_BUS_MEAS` (f_{Bus}) and the set closing time of CB, the function calculates the necessary lead angle (αLead) by which the close CB command is given forward in time so that the main contacts close on phase coincidence (ABB, 2024). The αLead is calculated as seen in equation (6).

$$\alpha_{Lead} = \left(360 \times f_{BusA} \times \left(s + \frac{\frac{TCB}{2} \times \frac{ds}{dt}}{1000}\right) \times \frac{TCB}{1000}\right) \tag{6}$$

where

f_{BusA}	= Bus A side frequency
s	= Frequency slip
ds/dt	= Frequency slip acceleration
TCB	= Setting for closing time of CB, in ms

If the closing conditions remain fulfilled during a permitted check time set with `Maximum Syn time`, ASGCSYN gives synchro check permission (`SYNC_OK`) and closing signal (`CLOSE_CB`) to the breaker control function block CBXCBR, which gives the CB closing command signal (`EXE_CL`). See **Figure 14**.

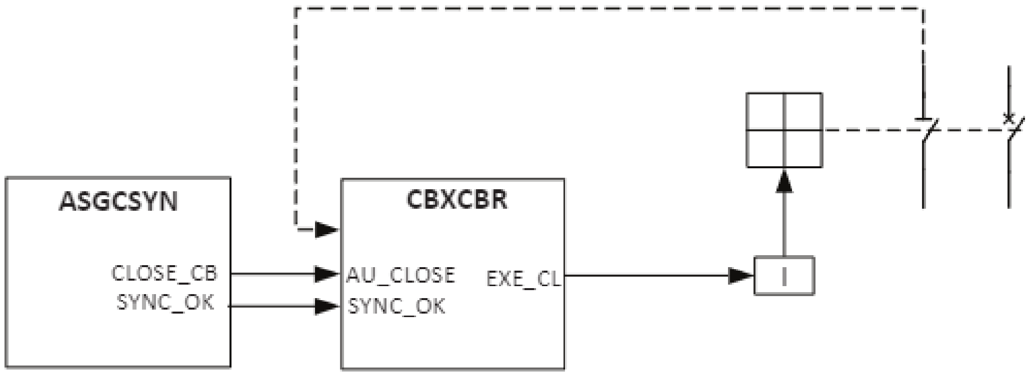


Figure 14. Simplified presentation of relay configuration with CB connections for closing circuit (ABB, 2024).

4.2 Autosynchronizer for Network Breaker ASNSCSYN

ASNSCSYN can be used for synchronized closing of non-generator circuit breakers, such as a bus sectionalizer, bus coupler, or incoming feeder. ASNSCSYN preferably requires 3-phase voltages from both sides of the breaker to be synchronized. (ABB, 2024). **Figure 15** shows an example of a network with one generator and one incomer feeder connection.

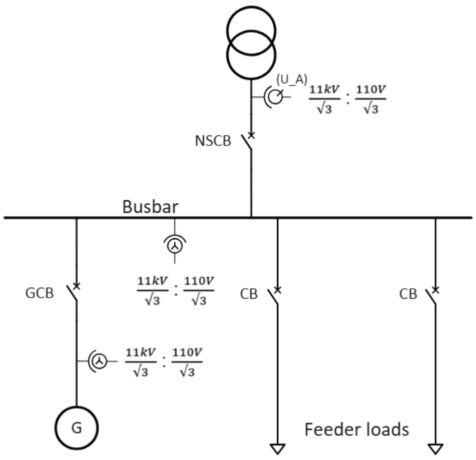


Figure 15. Example where ASNSCSYN is used for NSCB breaker (Internal source REX640 Autosynchronizer Theory, 2022).

In the case of ASNSCSYN is set to `synchronous mode`, the closing command is issued after considering the function modes, essential checks, CB closing time, and parallel conditions. In the case of ASNSCSYN is set to `asynchronous mode`, the function initiates the matching of voltage and frequency with the help of available generators through Autosynchronizer co-ordinator ASCGAPC (ABB, 2024).

When all the conditions are met, ASNSCSYN gives permission to close the CB. **Figure 16** shows the module diagram of ASNSCSYN function and all the input signals are shown on the left-hand side and output signals on the right-hand side.

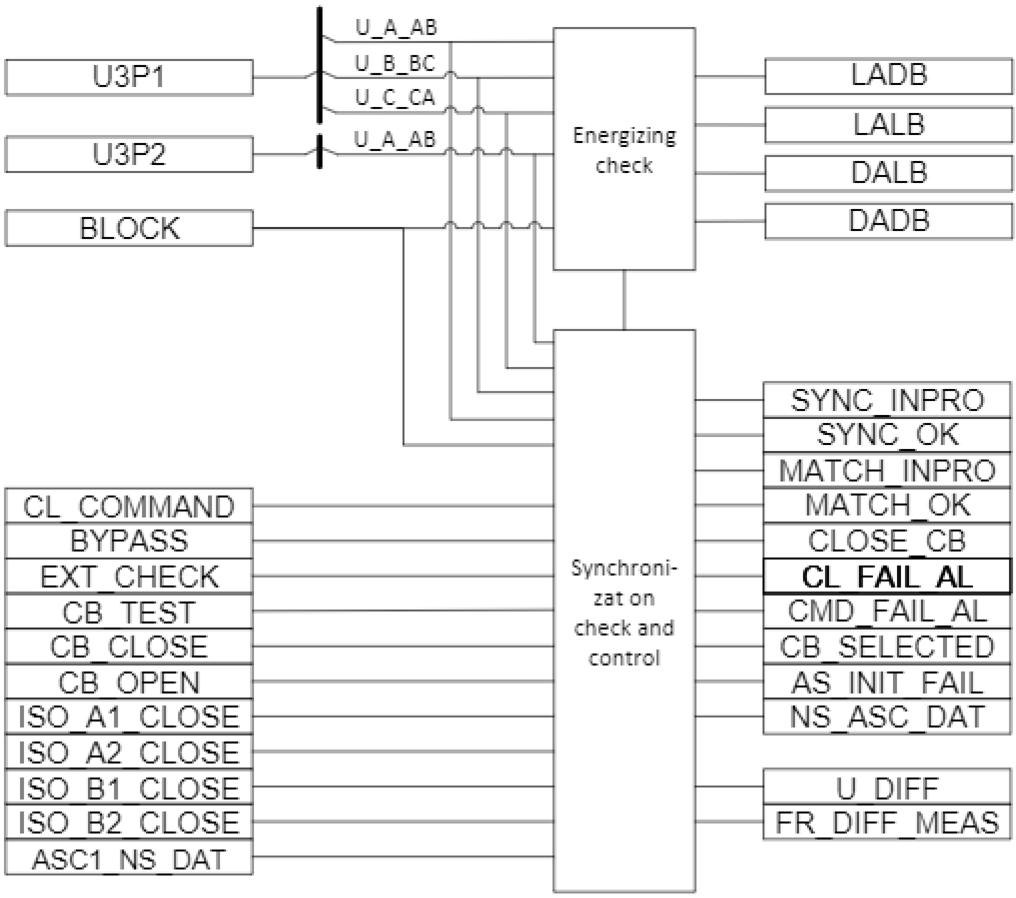


Figure 16. ASNSCSYN module diagram (ABB, 2024)

4.2.1 ASNSCSYN Energization Check

The `Live dead mode` setting is used to set the energized condition of the bus section across the CB, that is, whether the bus section across the CB is Live or Dead as seen in **Figure 17** (ABB, 2024).

Live dead mode	Description
Command	The *Live dead mode* setting uses *Live dead mode Ctl* control command.
Off	*Live dead mode* is set to "Off".
Both Dead	Both Bus A and Bus B de-energized
Live B, Dead A	Bus B energized and Bus A de-energized
Dead B, Live A	Bus B de-energized and Bus A energized
Dead A , B Any	Bus A de-energized and Bus B energized or deenergized
Dead B, A Any	Bus B de-energized and Bus A energized or deenergized
One Live, Dead	Bus A de-energized and Bus B energized or Bus B de-energized and Bus A energized
Not Both Live	Both Bus A and B de-energized or Bus A deenergized and Bus B energized or Bus B deenergized and Bus A energized

Figure 17. ASNSCSYN Energizing check modes (ABB, 2024).

4.2.2 ASNSCSYN Synchronization Check and Control

When synchro check setting is **off**, synchro check is not active, and no control commands will be given. When synchro check setting is **asynchronous**, matching criteria are based on settings for allowed voltage, frequency, and phase differences. As for **synchronous**, the matching criteria are fixed (ABB, 2024).

In the synchronous and asynchronous mode, the following criteria are first checked:

- The measured bus A and bus B voltages are higher than the set value of Live bus voltage (ENERG_STATE is **Both Live**) (ABB, 2024).
- The measured bus A and bus B frequencies are both within the range of 95% to 105 % of the value of the nominal frequency (f_n) (ABB, 2024).
- The measured bus A and bus B voltages are lower than the set value of Max energizing V (voltage) (ABB, 2024).

Additionally, depending on the set mode, the criteria shown in **Figure 18** are checked.

Measurements	Synchrocheck mode	
	"Synchronous"	"Asynchronous"
U_DIFF_MEAS	< 0.01 x Nominal voltage (U_n)	< Difference voltage
PH_DIFF_MEAS	< 5 degree	< Difference angle
FR_DIFF_MEAS	< 0.001 x Nominal frequency (f_n)	< Frequency difference
Estimated closing angle	N/A	< Difference angle

Figure 18. Additional conditions in Synchronous and Asynchronous modes (ABB, 2024).

Voltage difference is calculated as seen in equation (7).

$$\text{U\_DIFF\_MEAS} = U_{BusA} - U_{BusB} + Voltage\ offset \tag{7}$$

where

U_{BusA} = Measured bus A side voltage

U_{BusB} = Measured bus B side voltage

Voltage offset = Setting for voltage offset

Figure 19 shows visual representation of the voltage difference between two sources.

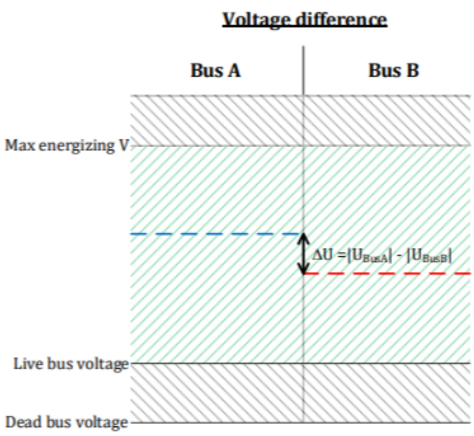


Figure 19. ASNSCSYN Voltage difference (Internal source REX640 Autosynchronizer Theory, 2022).

Frequency difference is calculated as seen in equation (8).

$$\text{F\_DIFF\_MEAS} = f_{BusA} - f_{BusB} + \textit{Frequency offset} \tag{8}$$

where

f_{BusA}	= Measured bus A side frequency
f_{BusB}	= Measured bus B side frequency
Frequency offset	= Setting for frequency offset

Phase difference is calculated as seen in equation (9).

$$\text{PH\_DIFF\_MEAS} = \angle U_{BusA} - \angle U_{BusB} + \textit{Phase shift} \tag{9}$$

where

$\angle U_{BusA}$	= Measured bus A side voltage phase angle
$\angle U_{BusB}$	= Measured bus B side voltage phase angle
Phase shift	= Setting for phase shift

Figure 20 shows visual representation of phase difference between two sources, where the *diff angle* is the set allowed angle difference.

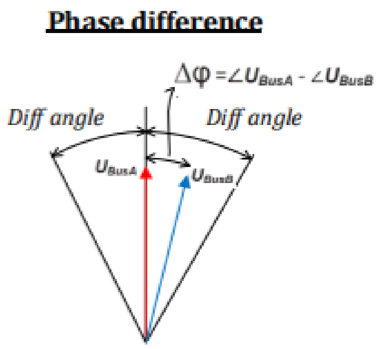


Figure 20. ASNSCSYN Phase difference (Internal source REX640 Autosynchronizer Theory, 2022).

4.2.3 ASNSCSYN Close CB Conditions

ASNSCSYN has the same close conditions as ASGCSYN when `Synchrocheck mode` is **Asynchronous**. When the `Synchrocheck mode` is **Synchronous**, a zero-passage of the phase-angle difference is not needed, and CB closing is permitted as soon as all the Synchrocheck conditions are fulfilled (ABB, 2024). **Figure 21** shows the closing configuration of ASNSCSYN.

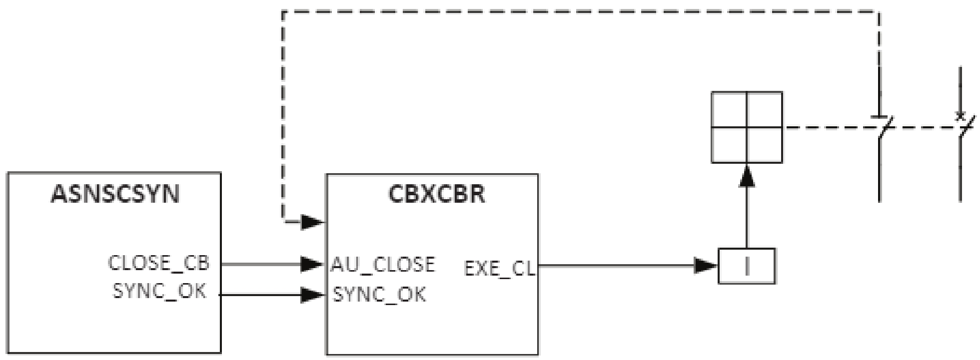


Figure 21. Simplified presentation of relay configuration with CB connections for closing circuit (ABB, 2024).

4.3 Autosynchronizer Co-ordinator ASCGAPC

Autosynchronizer co-ordinator (ASCGAPC) takes care of which parts of the network are eligible for synchronization, i.e. which parts of the network in which sequence can be energized (ABB, 2024). ASCGAPC module diagram is shown in **Figure 22**. All the input signals are shown on the left-hand side and output signals on the right-hand side.

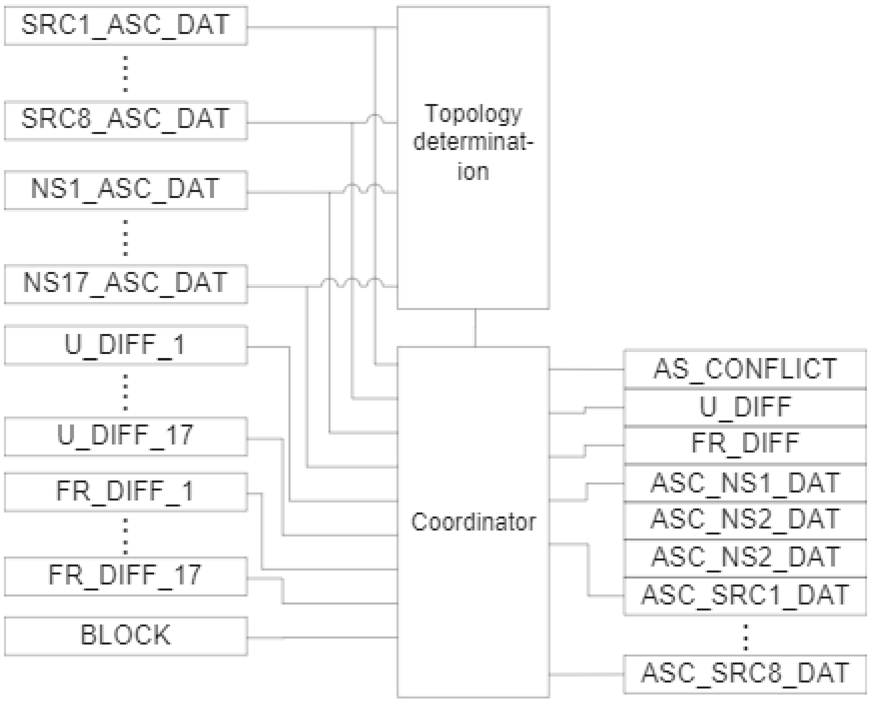


Figure 22. ASCGAPC module diagram (ABB, 2024).

Compared to the synchronization of the generator breaker, the synchronization of the network breaker does not include the matching functionality.

The autosynchronizer co-ordinator function ASCGAPC is used as a coordinator for the synchronization of any bus coupler or grid incomer breakers in the power network (ABB, 2024). The co-ordinator function ASCGAPC checks which generators are connected to the bus and transfers control commands from ASNSCSYN to the connected generators.

It is so that ASGCSYN can help synchronize the other bus where non-source breaker resides so that ASNSCSYN can close the breaker between the busbars.

ASCGAPC must always be present on the relay configuration together with the ASGCSYN or ASNSCSYN autosynchronization functions (ABB, 2024). ASCGAPC performs the network topology determination to identify the subnetworks within the whole network.

ASCGAPC routes the voltage and frequency difference values from the synchronizing CB to all the generator sources. It also identifies the sources which are allowed to participate in matching the voltage and frequency difference (ABB, 2024). ASCGAPC allows select sources for synchronization and permits matching the selected sources after essential checks (ABB, 2024).

ASCGAPC allows autosynchronization of only one non-source circuit breaker at a time. It also provides voltage and frequency matching status for the synchronization in progress (ABB, 2024). **Figure 23** illustrates the responsibilities of ASCGAPC.

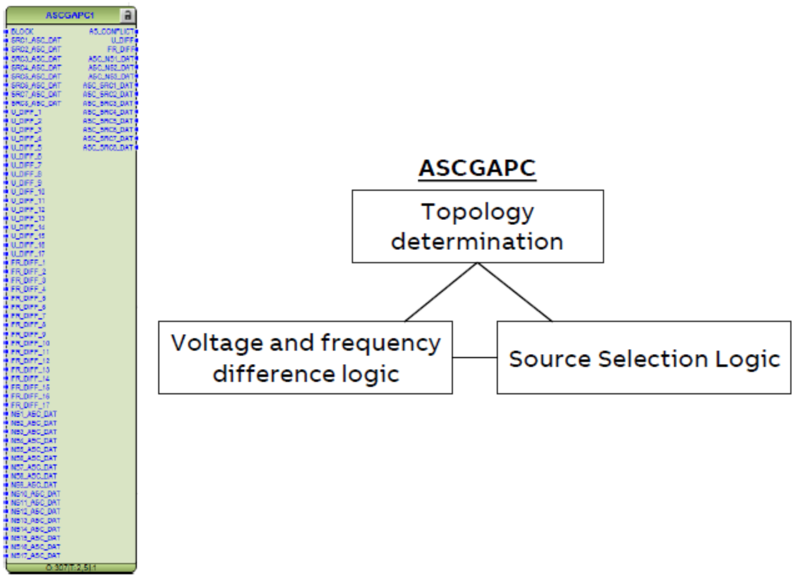


Figure 23. ASCGAPC function block (Internal source REX640 Autosynchronizer Theory, 2022).

4.3.1 ASCGAPC Source Selection Logic

The source selection logic is responsible for selecting and coordinating the sources for voltage and frequency matching. Source selection for non-source works only if the autosynchronizer function in NSCB (non-source circuit breaker) is set as `Semiautomatic` or `Automatic mode`.

The generator is ready for network CB matching only when the generator CB is closed, the REX40 relay is in remote mode and the generator is requested for matching from non-source function (ABB, 2024). **Figure 24** shows all the sources in the network that are divided up to nine partition groups.

Source participation group	Description
Group 1	All the sources which are unavailable for participation, are electrically connected to the grid or are not part of either subnetwork which must be synchronized by the selected CB.
Group 2	The sources which do not belong to Group 1 and are part of the subnetwork which includes the lower-number busbar of the two busbars connected across the selected CB.
Group 3	The sources which do not belong to Group 1 and are part of the other subnetwork, which includes the higher-number busbar.
Group 4	The sources in Group 2 which are not ready for participation in matching.
Group 5	The sources which are part of Group 3, but not ready for participation in matching.
Group 6	The sources which are part of Group 2 or Group 3, but the network is internally connected and setting *Synchrocheck mode* in ASNSCSYN is "Synchronous"
Group 7	The sources which are part of Group 2 or Group 3, but the network is internally connected and the setting *Synchrocheck mode* in ASNSCSYN is "Asynchronous".
Group 8	The sources which are part of Group 2 or Group 3, but the network is internally asynchronous and setting *Synchrocheck mode* in ASNSCSYN is "Synchronous".
Group 9	The sources which are part of Group 2 or Group 3, but setting *Synchrocheck mode* in ASNSCSYN is "Off".

Figure 24. ASCGAPC source selection grouping (ABB, 2024).

After receiving the reply from ASGCSYN, the autosynchronizer coordinator function ASCGAPC gives permission to participate in the voltage and frequency matching across the CB to be synchronized in the network. ASCGAPC also shares the information about how many generators participate in the voltage matching and frequency matching. Depending on the number of participating generators, the voltage and frequency difference is divided among the generators (ABB, 2024).

4.3.2 ASCGAPC Selection

It is not possible to synchronize any bus coupler or tie feeder if the voltage and frequency differences are outside the allowed limits across the circuit breaker. In this case, ASCGAPC is used to select and coordinate the sources. The coordinator assists in voltage and frequency matching for bus coupler or tie feeder CB to be synchronized by participating sources selection based on network topology (ABB, 2024). **Figure 25** shows an example where every relay is controlling its own circuit breaker, and every relay has ASCGAPC. In the figure Source 1 is selected as the tuning source in helping to synchronize NSCB2. The communication is done by IEC61850 communication standard using GOOSE protocol. GOOSE sends voltage differences, phase differences and condition status data between the relays.

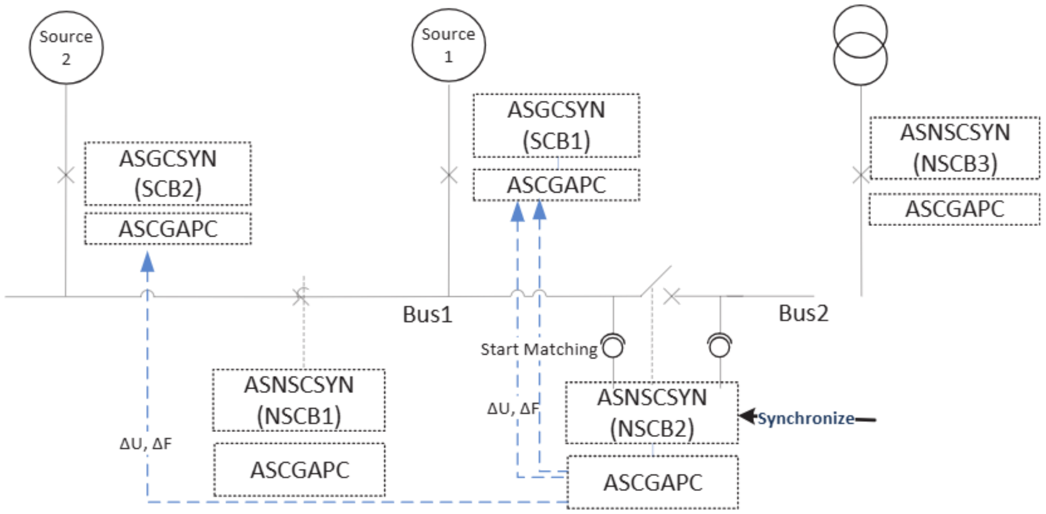


Figure 25. ASCGAPC coordination (ABB, 2024).

5 SYNCHRONIZATION PROCESS

The autosynchronizer can be initialized either remotely or from HMI. There are three possible autosynchronizing modes:

- When `Auto Syn mode` is set to `Manual mode`, voltage and frequency `RAISE` or `LOWER` command pulses are generated manually from the function's user commands (ABB, 2024).
- When `Auto Syn mode` is set to either `Semi-automatic synchronizing mode` or `Automatic synchronizing mode`, the voltage raise, or lower command pulses are generated from the function based on the voltage difference across the breaker and AVR response characteristics. Also, the frequency raise or lower command pulses are generated from the function based on the frequency difference across the CB and governor response characteristics (ABB, 2024).

Appendix 3 contains information on how the synchronization is done in manual, semi-automatic and automatic modes.

5.1 Voltage Matcher

Figure 26 illustrates the working ranges of the voltage matcher. If the bus voltage U_BUS is between settings Minimum voltage and Maximum voltage and the generator voltage U_GEN is greater than the setting Dead voltage value, the adjusting commands are released. The direction of the adjusting commands depends on the polarity of ΔU. As an additional condition, both frequencies must be in the range f_n = ±5 Hz (ABB, 2024).

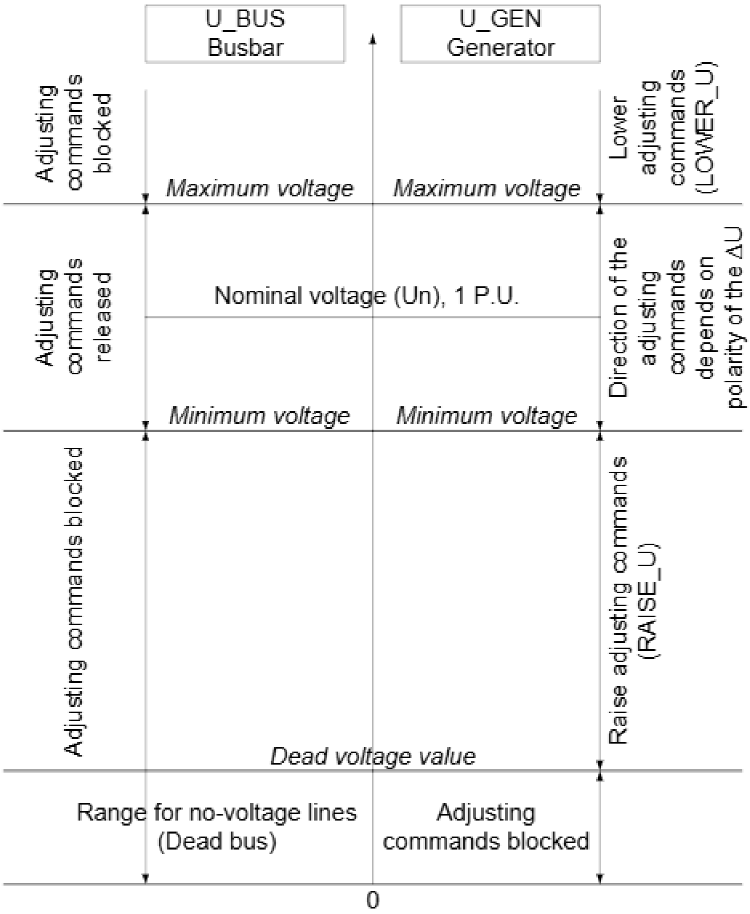


Figure 26. Working range of the voltage matcher (ABB, 2024).

5.2 Voltage Command Pulse Length Modes

When the operator wants to increase the voltage, it gives out `RAISE_U` command pulse, in a similar way `LOWER_U` pulse is given for lowering the voltage. There are two command pulse lengths in voltage matching `Variable Pulse` and `Variable Interval` (ABB, 2024).

The voltage matcher gives commands with a length that is proportional to the voltage difference. `Voltage rate of change` (dU/dt) can be adapted to the voltage regulator (ABB, 2024).

When the setting `Voltage match mode` is set to `Variable Pulse`, the length of the pulse (Volt pulse Min Dur, tpU) is calculated as shown in equation (10).

$$tpU = \frac{\Delta U - \left(\frac{+\Delta Umax - |-\Delta Umax|}{2}\right)}{\frac{dU}{dt}} \qquad (10)$$

where

ΔU	= Measured voltage difference across the CB to be synchronized
$+\Delta U_{max}$	= Setting Voltage Diff Ov Ex
$-\Delta U_{max}$	= Setting Voltage Diff Un Ex
dU/dt	= Setting voltage rate of change

When the setting *`Voltage`* `match mode` is set to `Variable Interval`, the voltage matching is done with variable command pulse off intervals (tsU). The voltage match command pulses are now the same length, but the intervals are inversely proportional to the voltage difference (ABB, 2024).

The pulse off interval (tsU) can be adjustable with the setting `Volt pulse off Intv`, and dependent on settings `Voltage Diff Ov Ex` and Voltage Diff Un Ex. Equation (11) shows how `Pulse interval` is calculated.

$$tsU = \text{Volt pulse off Intv} \times \left(1 - 0.325 \times \left(\Delta U - \frac{(+\Delta Umax + |-\Delta Umax|)}{2}\right)\right) \geq 0 \qquad (11)$$

where

ΔU	= Measured voltage difference across the CB to be synchronized

$+\Delta U_{max}$ = Setting Voltage Diff Ov Ex

$-\Delta U_{max}$ = Setting Voltage Diff Un Ex

5.3 Manual Voltage Matching of ASGCSYN

When the control command parameter `Tune V` and `F match is` set to `Volt match rate`, the function calculates the generator voltage matching rate (dU/dt). The calculated voltage matching rate is stored to the non-volatile memory output `VOLT_CHG_RTE` and is available in the Monitored data view. Once stored, the value from the output `VOLT_CHG_RTE` is used to set the setting `Volt rate of change` (dU/dt) (ABB, 2024).

The voltage matching rate (dU/dt) is calculated with equation (12). Voltage matching is done as follows:

- Generator voltage is adjusted until it reaches 95 to 97 % of the line voltage, then the pulse that is adjusting the voltage is stopped.
- When ten seconds have passed after a pulse, voltage difference ΔU_0 is measured, then a voltage raise command `RAISE_U` is given that lasts five seconds. When ten seconds have passed after end of the pulse, voltage difference is ΔU is measured and du/dt is calculated.

$$\frac{dU}{dt} = \frac{\Delta U - \Delta U_0}{5} \qquad (12)$$

5.4 Frequency Matcher

Figure 27 illustrates frequency matching limits. To close the CB, the frequency difference must be at least 1/3 of the frequency difference setting. For example, in a 50 Hz system with a frequency difference setting of 0,04 xFn, frequency difference of 1/3 of 0,04 is needed, which equals 0,0133 xFn. Therefore, the minimum frequency difference required to close the CB is 50 x 0,0133 = 0,67 Hz. In other words, the starting range for frequency matching is from 48 Hz to 49,33 Hz.

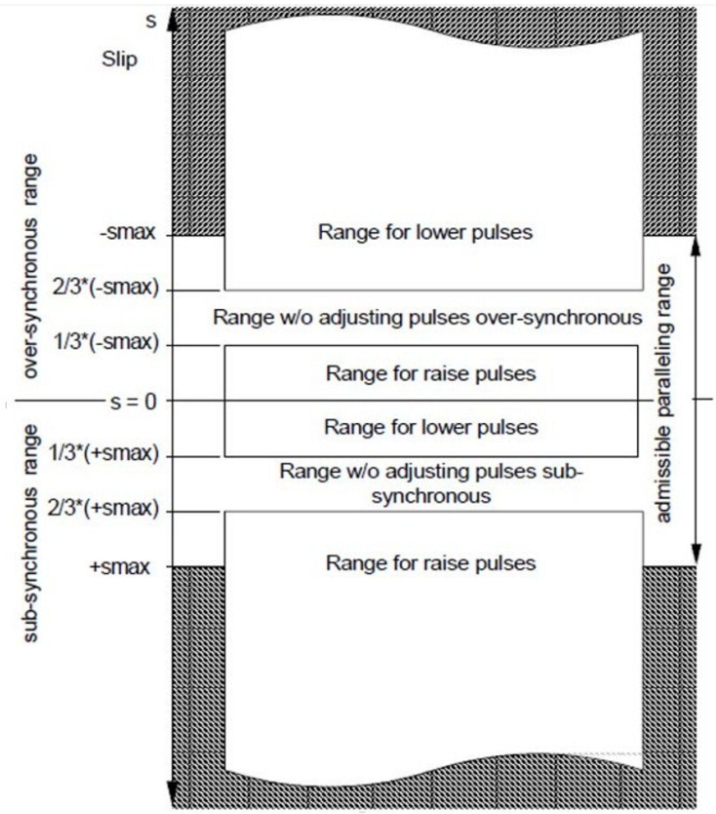


Figure 27. Working range of the frequency matcher (ABB, 2024).

5.5 Frequency Command Pulse Length Modes

If the operator gives a frequency raise command, the function gives out `RAISE_F` pulse. In a similar way, the function gives `LOWER_F` pulse when the operator gives a lower command (ABB, 2024).

When setting `Frequency match mode` is set to `Variable pulse` frequency matching is done with the variable command pulse length. The frequency matchers command length is proportional to the present slip.

The frequency matcher tries to steer the value in centrally between the slip limit and zero (ABB, 2024). Equation (13) shows how the frequency command pulse length (tpf) is calculated.

$$tpf = \frac{|\pm s| - \frac{|\pm smax|}{2}}{\frac{df}{dt}} \tag{13}$$

where

s	= Measured frequency slip across the CB to be synchronized
$+s_{max}$	= Setting Freq Diff Ov Synch
$-s_{max}$	= Setting Freq Diff sub Synch
df/dt	= Setting for Freq rate of change

When setting `Frequency match mode` is set to `Variable Interval`. The matching is done with command pulse off intervals. The command pulses are now the same length, but the intervals are inversely proportional to the frequency difference (ABB, 2024). Equation (14) shows how the Pulse off interval (tsf) is calculated.

$$tsf = \frac{1}{f_{Gen} - f_{Bus}} = \frac{1}{f_{Gen} \times |s|} \leq 30\ [Sec] \tag{14}$$

where

s	= Measured frequency slip across the CB to be synchronized
f_{Gen}	= Measured generator side frequency

f_{Bus} = Measured bus side frequency

5.6 Manual Frequency Matching of ASGCSYN

When the control command parameter `Tune V` *and* `F match` is set to `Freq match rate`, the function calculates the generator frequency matching rate (df/dt). The calculated frequency matching rate is stored to the non-volatile memory output FREQ_CHG_RTE and is available in the Monitored data view. Once stored, the value from FREQ_CHG_RTE can be used to set the setting `Freq rate of change` (ABB, 2024).

The frequency matching rate (df/dt) is calculated with equation (15). Frequency matching is done as follows:

- The slip is adjusted until it lies in the range of +1 to +3 %, then the adjusting pulse is stopped.
- Ten seconds after the first adjusting pulse, the slip s_0 is measured. Then a frequency raise command `RAISE_F` lasting 3 seconds is issued. Ten seconds after the end of the pulse, the slip s is measured and df/dt is calculated.

$$\frac{df}{dt} = \frac{s - s0}{3\ \text{sec}} \tag{15}$$

6 INTRODUCTION OF THE TOOLS USED IN THIS THESIS

6.1 Omicron CMC 356 and Test Universe

CMC 356 was used in this thesis to simulate the grid and generator voltages during the testing of autosynchronization. CMC 356 is a testing solution used for testing protection relays by mimicking the secondary values of the voltage and current transformers. **Figure 28** shows the inputs and outputs of the device. In this thesis four voltage outputs, auxiliary DC supply, and five binary inputs were used.

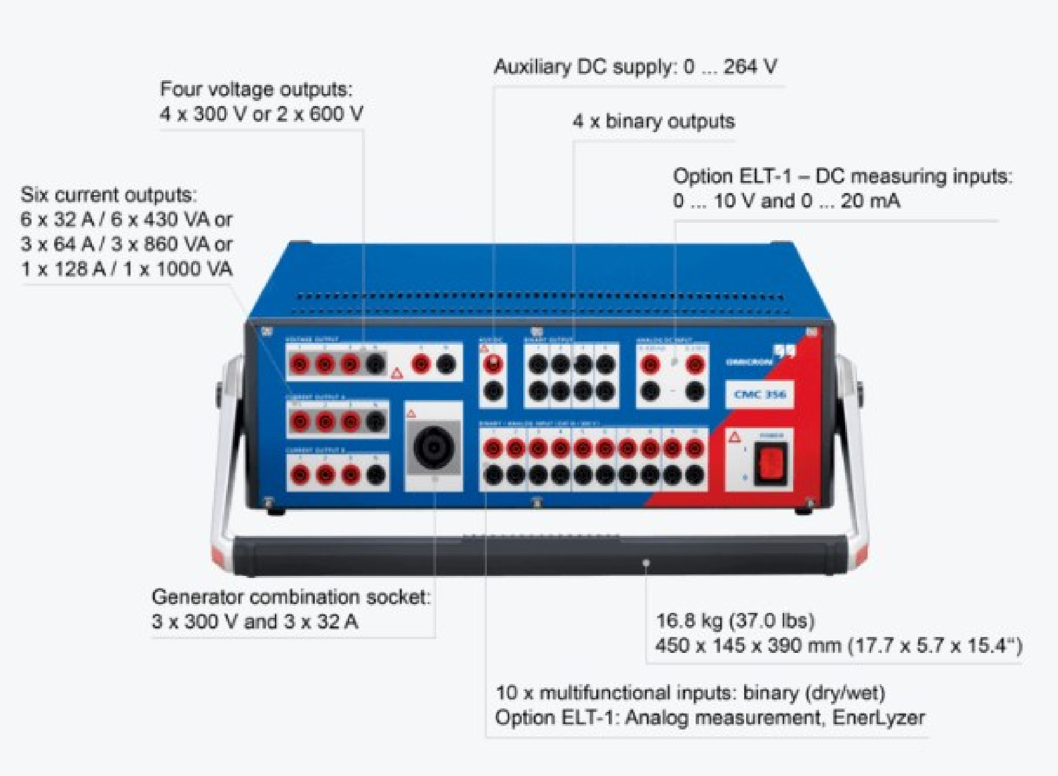


Figure 28. Omicron CMC 356 (Omicron, 2024).

Test Universe is a PC program that is used to control CMC 356 device, which generates output voltages for the REX640 relays. Commands can be given from the relay to Omicron to raise or lower voltage and frequency.

We will use synchronizer module for testing the relays' autosynchronizer configuration, see **Figure 29**.

Figure 29. Omicron module to be used this thesis.

Figure 30 shows the view when opening the synchronizer module. In the view you can see system 1 and system 2. System 1 is used to give the busbar its voltage and frequency. System 2 is used to give the generator its voltage and frequency, and the difference to the wanted values from where the synchronization is started.

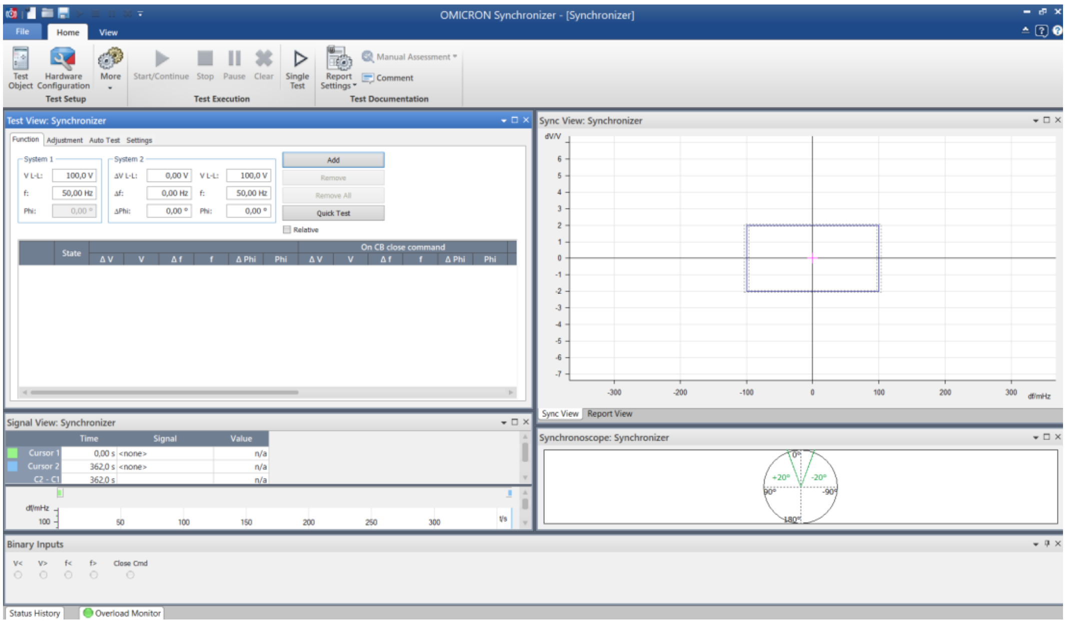
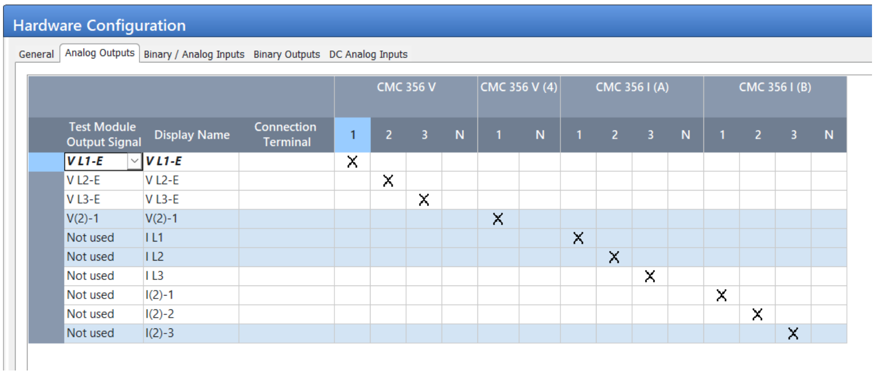


Figure 30. Omicron Synchronizer module view.

Figure 31 shows the analog outputs from Omicron. Only the four voltages are set to being used.



Hardware Configuration

General | Analog Outputs | Binary / Analog Inputs | Binary Outputs | DC Analog Inputs

Test Module Output Signal	Display Name	Connection Terminal	CMC 356 V 1	2	3	N	CMC 356 V (4) 1	N	CMC 356 I (A) 1	2	3	N	CMC 356 I (B) 1	2	3	N
V L1-E	V L1-E		X													
V L2-E	V L2-E			X												
V L3-E	V L3-E				X											
V(2)-1	V(2)-1						X									
Not used	I L1								X							
Not used	I L2									X						
Not used	I L3										X					
Not used	I(2)-1												X			
Not used	I(2)-2													X		
Not used	I(2)-3														X	

Figure 31. Omicron analog outputs.

Figure 32 shows the binary inputs to Omicron, where the relay gives raise and lower commands to frequency and voltage.

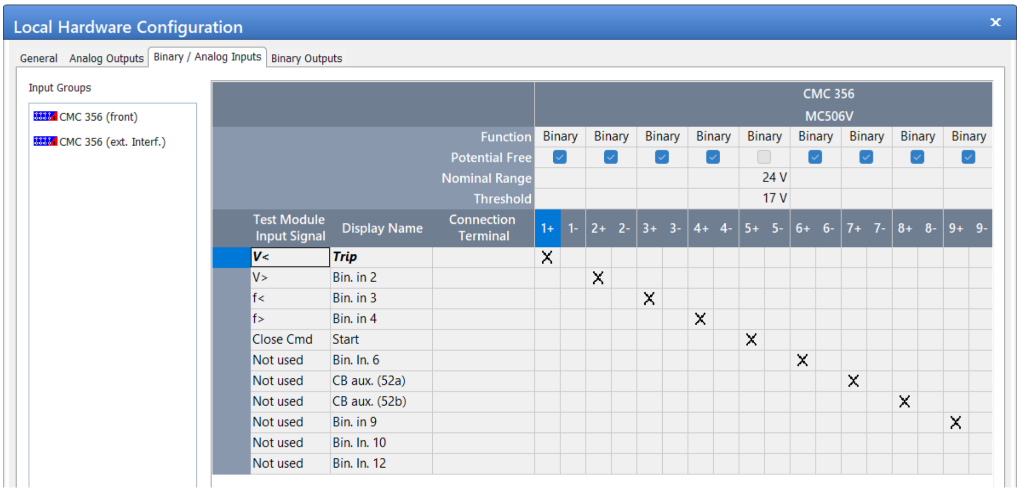


Figure 32. Omicron binary inputs.

Figure 33 shows an adjustment window, in system 2 the initial generator values (before synchronization) are given for voltage, frequency and phase angle. With the Add-button a test parameter is created, and the test can be done following those parameters. Different situations of synchronization could be added, but the problem is, that Omicron does the tests in sequence without any delay between the tests.

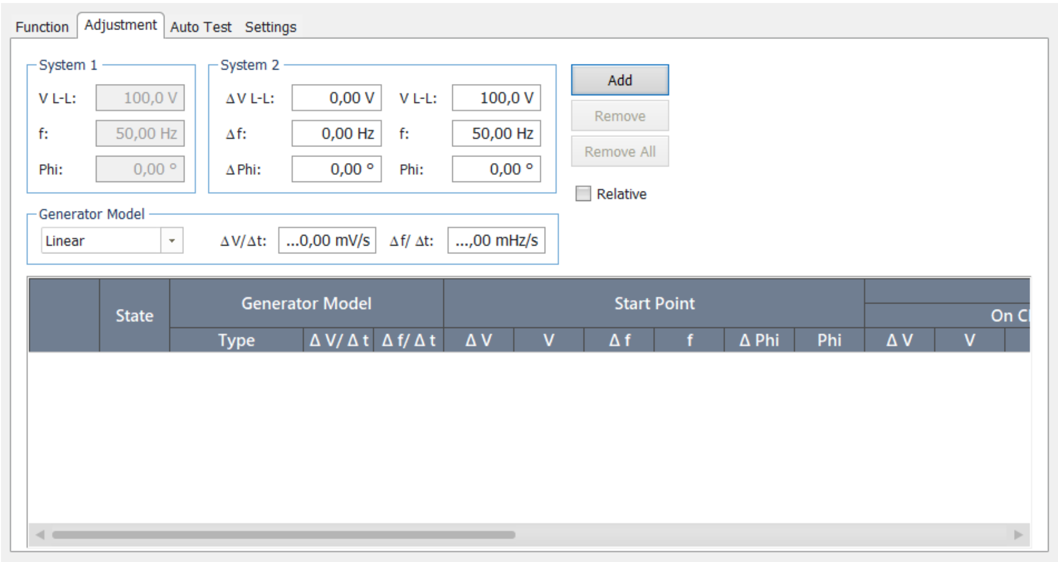


Figure 33. Synchronizer adjustment window.

Figure 34 shows a sync view whereby clicking the field you can change the starting values of the generator and see the wanted synchronization areas in blue. In the sync view, the left-hand side area is under-synchronous and the right-hand side area is over-synchronous.

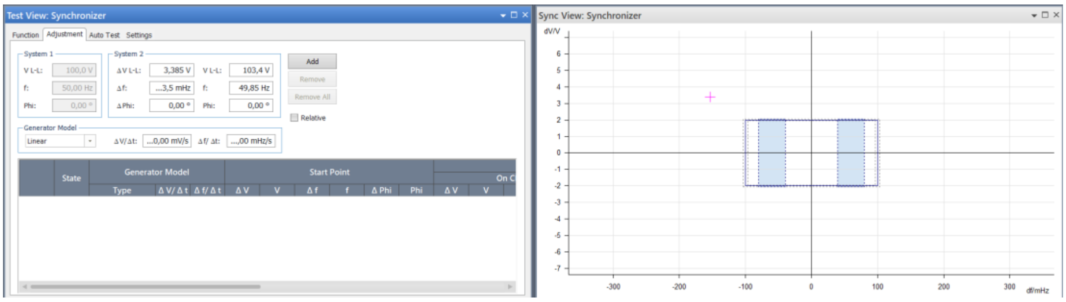


Figure 34. Sync view.

Another way to test the configuration is with QuickCMC as seen in **Figure 35**. ASNSCSYN is tested with QuickCMC, because Synchronizer module can't be used. The testing is done by manually raising or lowering the voltage, frequency and phase angle values.

Figure 35. Omicron QuickCMC.

Figure 36 shows the test view of the QuickCMC. You can give voltage and frequency values to present a generator and bus, by manually changing the values of voltage and its frequency. The figure shows four voltage analog outputs, which are given to the relay to mimic bus and generator.

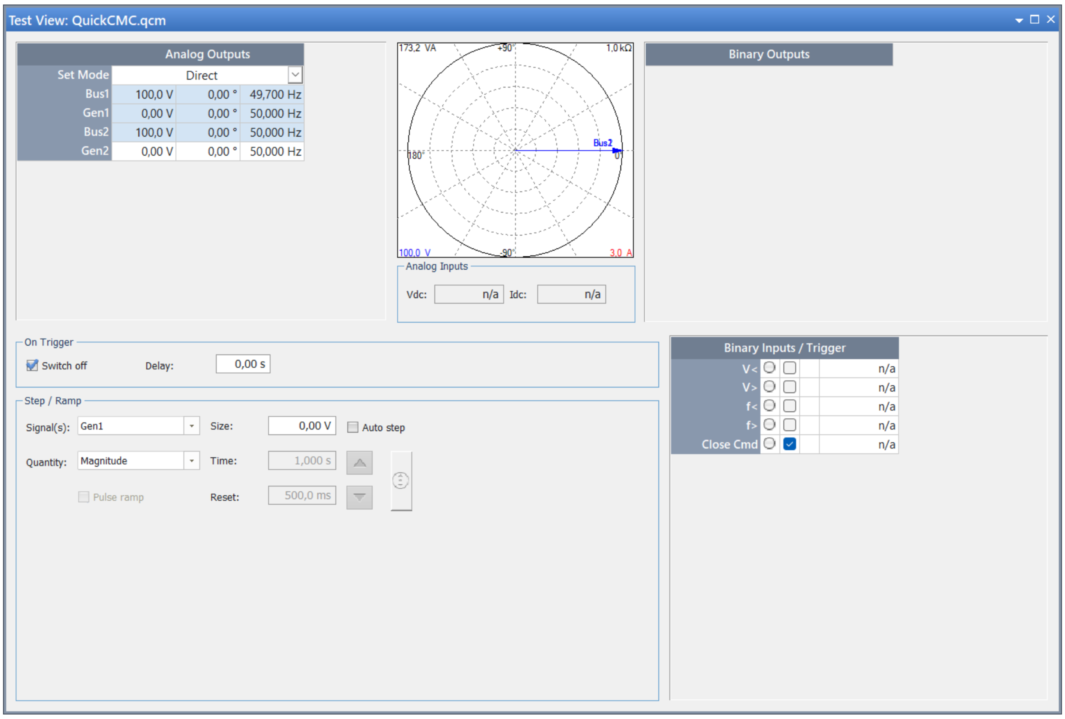


Figure 36. QuickCMC test view.

6.2 PCM600

PCM600 (protection and control IED manager) is a program that is used for parametrization and configuration of ABB protection relays. In this thesis, PCM600 will be used in making the working configuration of the autosynchronizer.

The autosynchronizer can be configured on multiple relays using PCM600's built-in configuration wizard. This wizard automatically configures all necessary functions (ASGCSYN, ASNSCSYN, and ASCGAPC) based on the desired network structure specified by the user.

The Autosynchronizer wizard can be started in PCM600 by adding the relays to the project and making sure that they are at the same voltage level as shown in **Figure 37**. The relays are named according to which sources circuit breaker it controls.

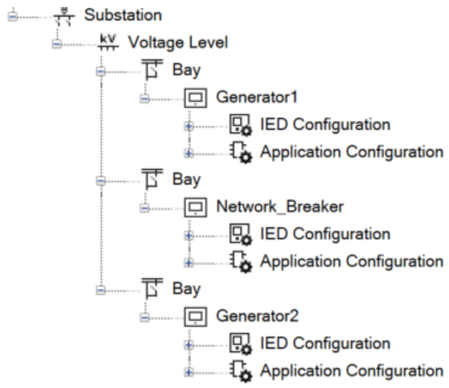


Figure 37. Example of project tree for configuration.

6.3 ABB Circuit Breaker Simulator

The circuit breaker simulator is used as its name implies, to simulate up to eight (8) circuit breakers or disconnectors. This device is used in this thesis to visualize that the CB closes and opens, and to give information to Omicron when the CB is closed. **Figure 38** shows front panel connections and **Table 1** explains the numbers in the figure. In the tests the CB closing time is set to 60 ms.

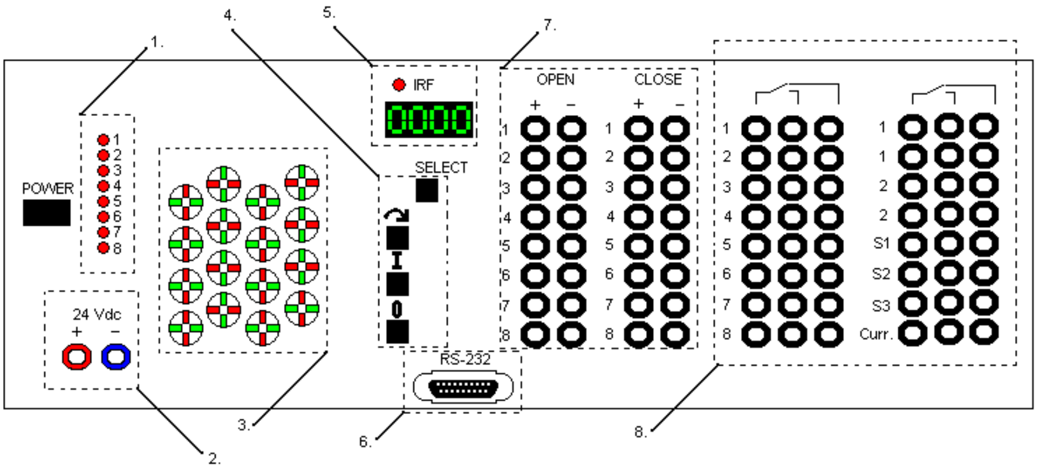


Figure 38. Circuit breaker simulator (ABB, 2025).

Table 1. Circuit simulator front panel list.

	Explanation
1	Eight programmable LEDs.
2	DC-voltage 24V output.
3	Position indication screen for switches.
4	Function keys.
5	Numerical display and fault (IRF)-led.
6	RS-232 (serial bus) is not used in this thesis.
7	Inputs for open and close commands. (up to 8 CB/DC)
8	Output contacts for CB/DC position.

7 CREATING AUTOSYNCHRONIZER CONFIGURATIONS FOR SELECTED SYSTEM

In this chapter we go through available documentation on autosynchronization. Next, advantages and limitations of application manual examples are discussed. After that, next step is creating an autosynchronization example with the PCM600 wizard tool which makes a configuration setup based on the wanted network with multiple REX640 relays and generators. After that when autosynchronizer wizard is completed, configuration is manually finalized. This aims to provide more accessible documentation on the partially available material in relay manuals. Available documents are shown in **Table 2**.

Table 2. Autosynchronizer available documentation.

Document name	**Available information**
REX640 technical manual	Function block descriptions, and technical data.
REX640 application manual	Configuration example for ASGCSYN and ASNSCSYN.
REX640 engineering manual	Guidelines for wizard configuration.

7.1 Advantages and Limitations of Manual Examples

Appendix 4 presents examples of autosynchronization configurations given in REX640 application manual. In manual examples PCM600 autosynchronizer wizard tool is not utilized.

The examples in application manual have the following advantages:

- Good information for basic applications where you have only one generator or one generator with one network breaker.
- Good basis on understanding the autosynchronizer function.

The limitation is as follows:

- Examples do not give understanding on how to use the wizard, and without that the risk of errors in GOOSE and co-ordinator settings increased considerably. Wizard speeds up configuration and engineering. Wizard also creates a GOOSE communication automatically.

7.2 Introduction of the Selected System

A larger system typically means more generators and more breakers. In the system selected for this thesis, we have two generators in parallel and non-source circuit breaker in between them as seen in **Figure 39**. Each breaker has its own relay, named in this thesis as Generator 1, Network breaker and Generator 2 relay.

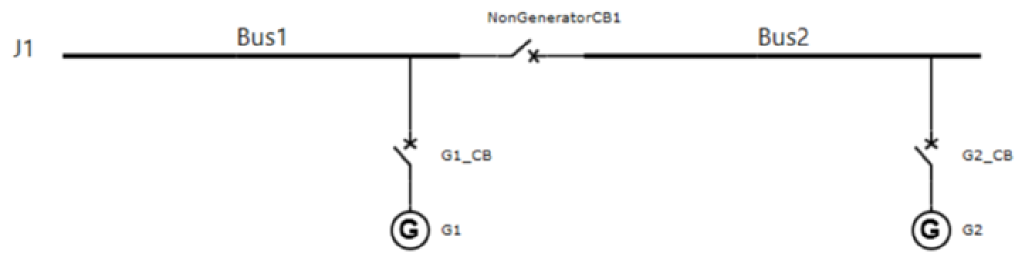


Figure 39. Selected system.

7.3 REX640 Hardware and Connections

For this application we are using three REX640 narrow hardware variant relays. **Figure 40** shows the different hardware placements and **Table 3** shows the list of modules used in this thesis.

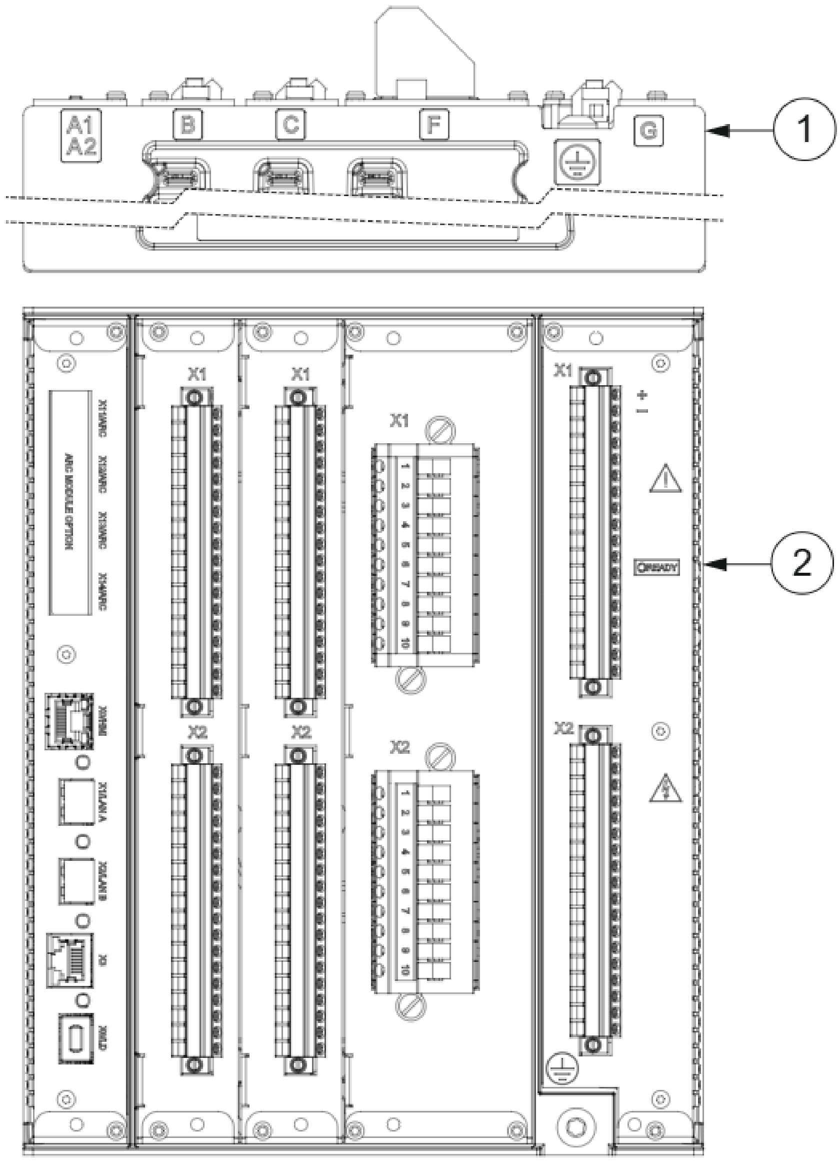


Figure 40. REX640 narrow hardware drawing.

Table 3. REX640 modules as used in this thesis.

Slot	**Card type**	**Description**
A1-A2	COM0001	Communication card
B	BIO1001	Binary input/output module
C	BIO1001	Binary input/output module
F	AIM1001	Analog input module
G	PSM1002	Power supply module

Figure 41 shows connections from the CB simulator to the relay and from relay to the Omicron. The left-hand side shows the inputs of CB position indications from the circuit breaker simulator and `Start_Sync` button where the synchronization can be started from. On the right-hand side are the relay outputs to Omicron to raise or lower voltage or frequency.

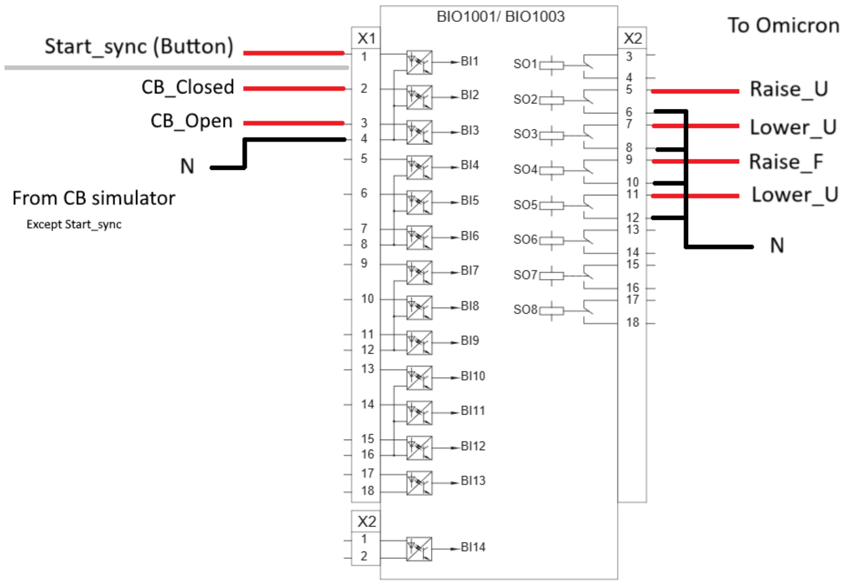


Figure 41. BIO1001 inputs and outputs in Generator 1 relay.

Figure 42 illustrates how BIO is connected to CB simulator and Omicron.

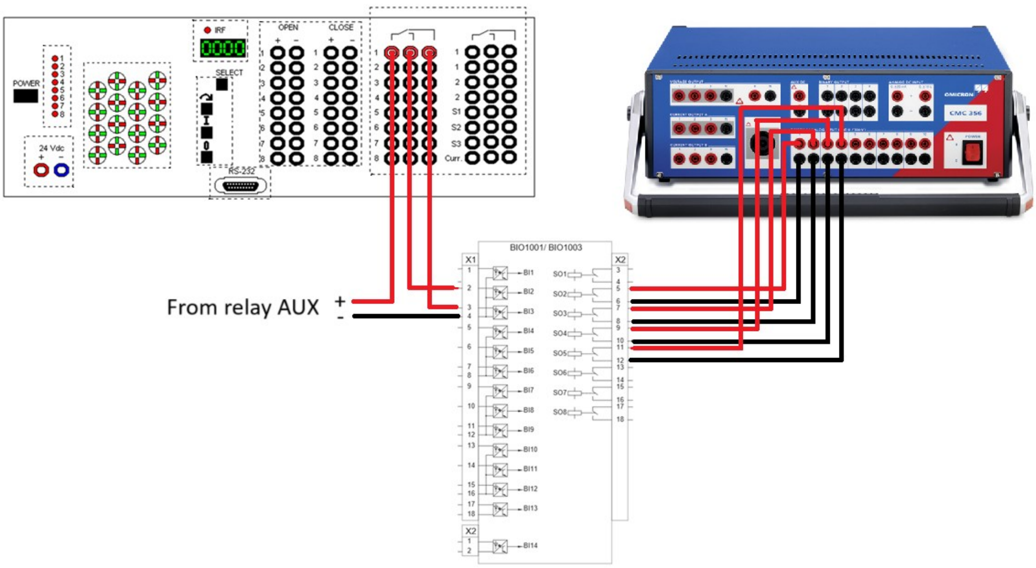


Figure 42. BIO connections in Generator 1 relay.

Figure 43 illustrates the voltage measurements for relay, that controls generator 1. The voltage measurements are coming from Omicron.

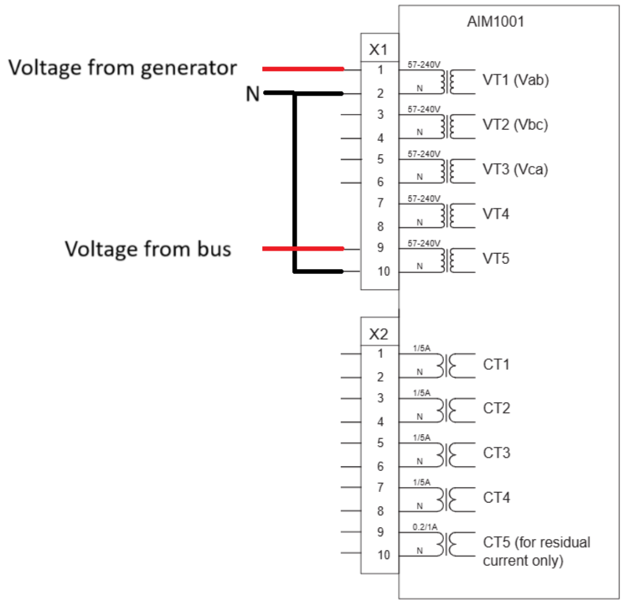


Figure 43. AIM1001 connections in Generator 1 and 2 relays.

Figure 44 illustrates how Omicron is connected to the AIM modules. The non-source breaker relay takes the voltage measurements from bus A and bus B, which can be chained from the other two relays.

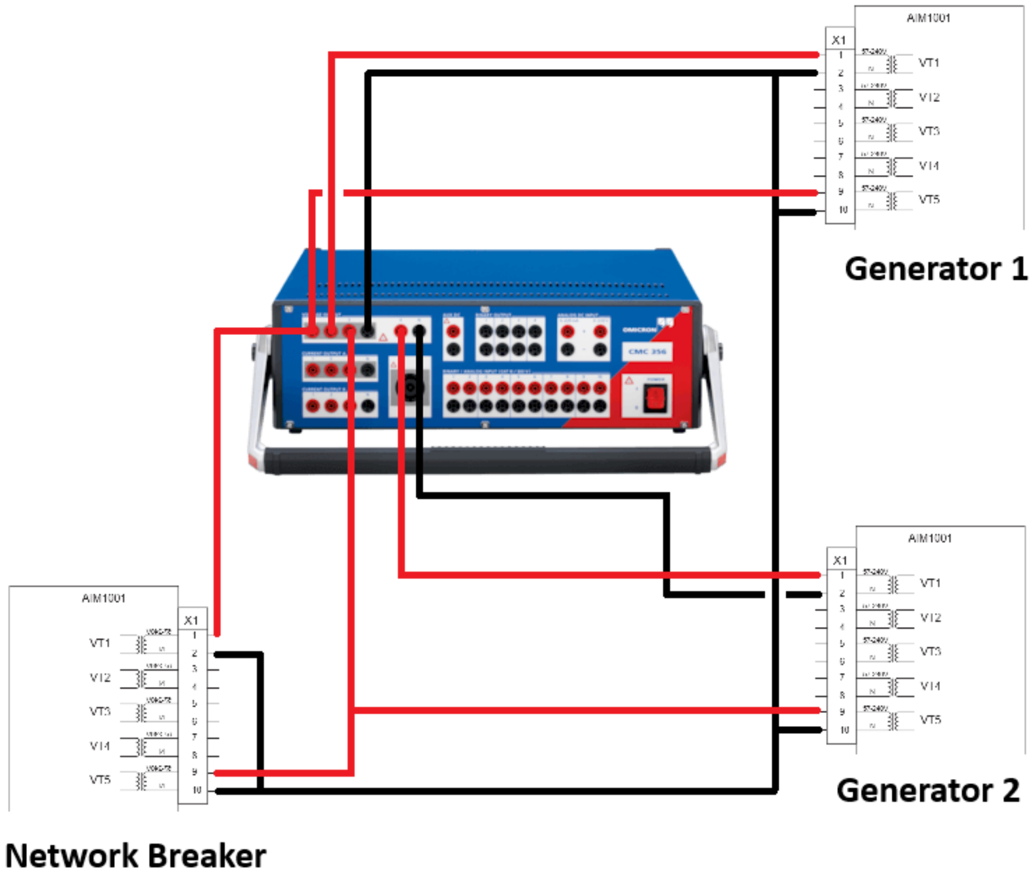


Figure 44. AIM connections in all the relay.

Figure 45 illustrates the outputs of the PSM-module, and the auxiliary voltage from external power supply. The outputs S01 and S02 get their auxiliary voltage from circuit breaker simulators auxiliary voltage output.

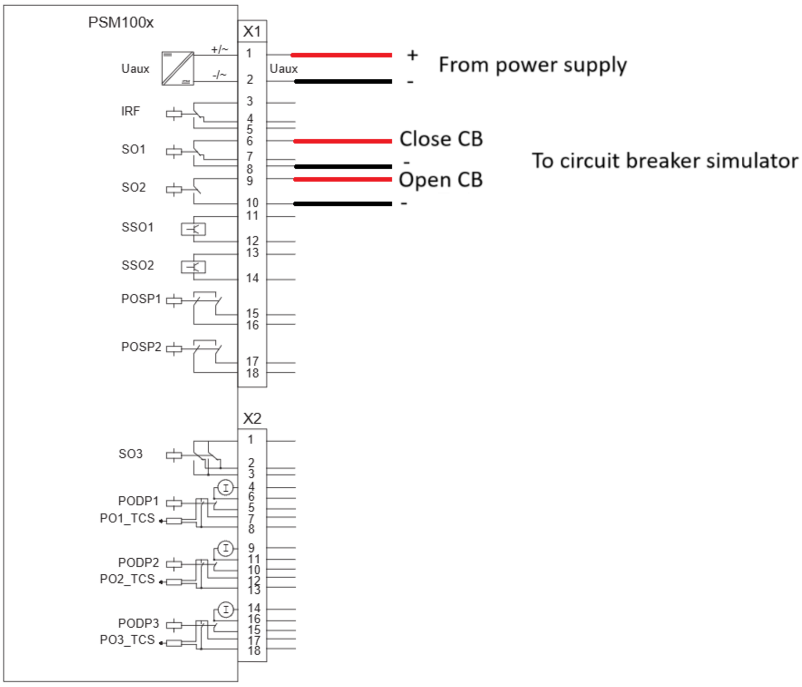


Figure 45. PSM outputs in all three relays.

Figure 46 illustrates the connection between PSM, Omicron and CB simulator.

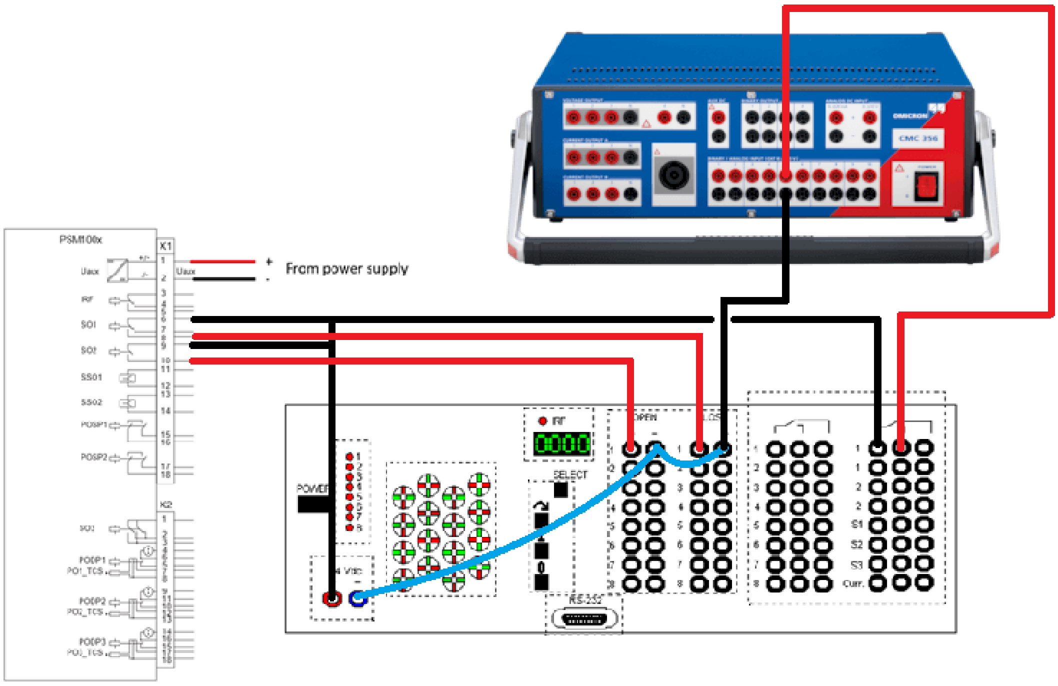


Figure 46. PSM connections in Generator 1 relay.

PSM connection in Generator and Network breaker relays are similar as in Generator 1 except that in CB simulator own breakers are used for those. **Table 4** shows the used signals in Omicron.

Table 4. Omicron signals used in testing.

Voltage output	**Binary inputs**
1, 2, 3, 4, N	1,2,3,4,5
1 = Voltage of bus 1 2 = Voltage of generator 1 3 = Voltage of bus 2 4 = Voltage of generator 2	1 = Raise_U 2 = Lower_U 3 = Raise_F 4 = Lower_F 5 = CB_Closed position

Figure 47 illustrates how the relays are connected to the Omicron. Omicron gives voltage measurements to the relay and the relay gives the Omicron information to raise and lower either voltage or frequency. Relay also gives information when it wants to close the CB.

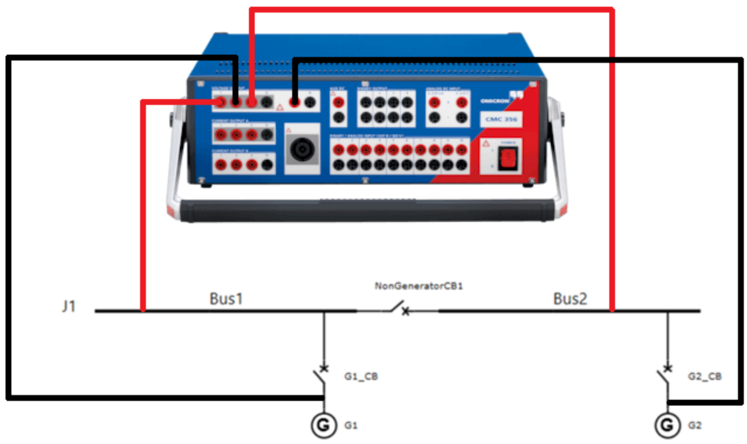


Figure 47. Omicron measurements.

Figure 48 shows how digital outputs are connected from the relay to the Omicron. Close position comes from the circuit breaker simulator in order to get the actual closing time of the circuit breaker. The close position is taken from the breaker being tested.

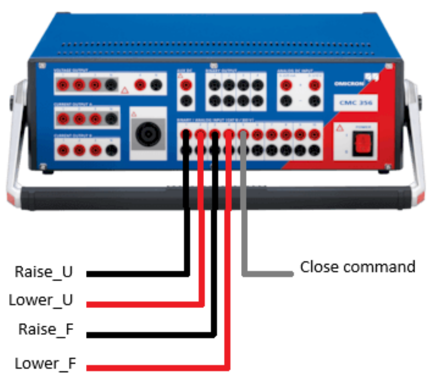


Figure 48. Omicron inputs.

7.4 Necessary Steps in PCM600, Before Using Autosynchronization Wizard

To start the configuration wizard, the project needs to have at least one relay with generator autosynchronizer package and one relay with network autosynchronizer package, or you will get an error message as seen in **Figure 49**.

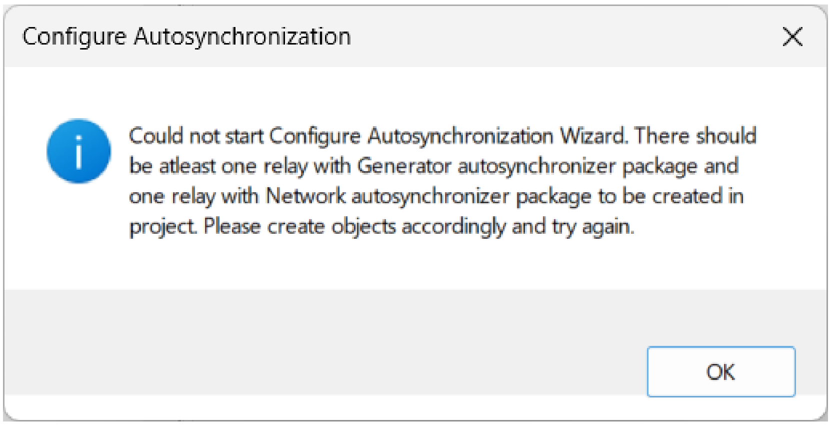


Figure 49. Error in the configuration, if the relays do not meet the requirements.

7.5 Autosynchronizer Wizard Tool

The usage of autosynchronizer wizard tool is not explained adequately enough in REX640 manuals. Here we give the steps on how to use the autosynchronization wizard and what to do after the wizard has completed. **Figure 50** shows the steps on using the wizard.

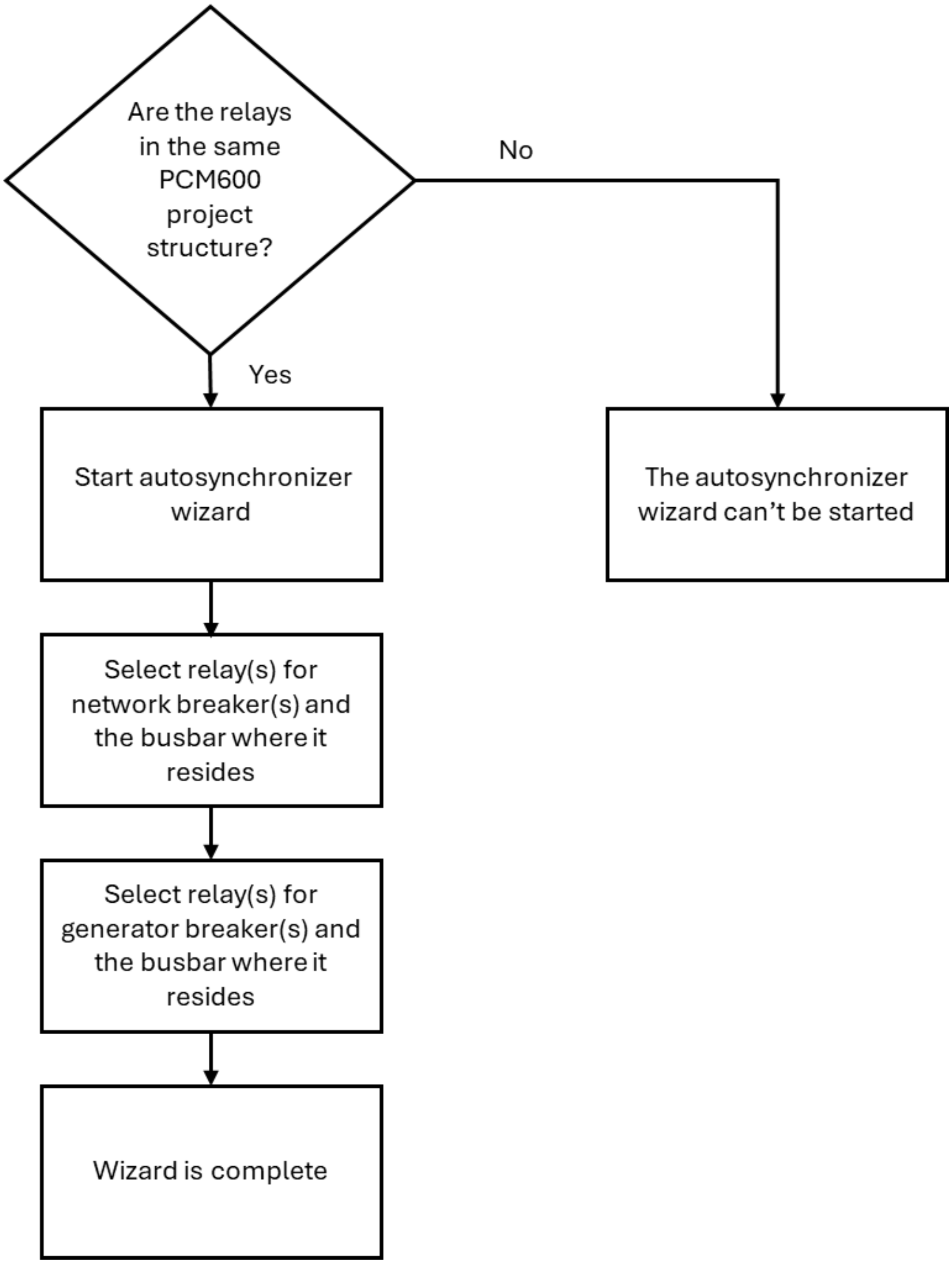


Figure 50. Work process flow chart of using wizard.

All the relays must be at the same voltage level to start the autosynchronization configuration wizard and must be REX640 as seen in **Figure 51**.

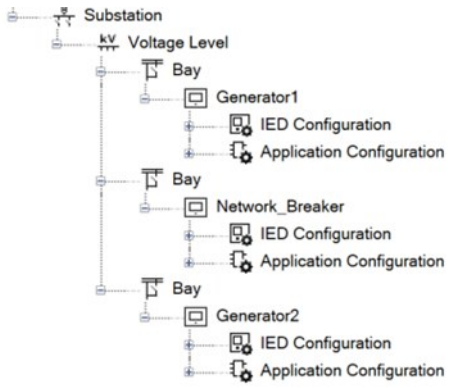


Figure 51. Relays in PCM600.

The autosynchronization configuration wizard can be started by right clicking substation and clicking "**Configure Autosynchronization**" as seen in **Figure 52**.

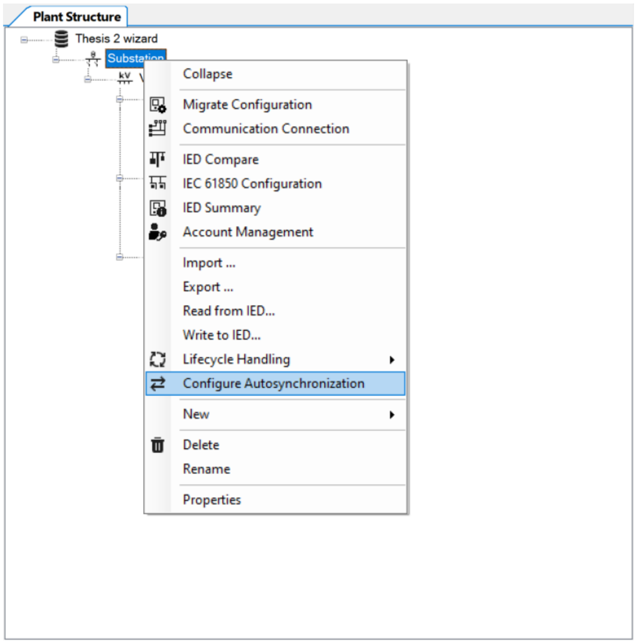


Figure 52. Starting the autosynchronizer wizard.

First, a relay is selected for non-source circuit breakers, the bus connection is also given to each of the relays as seen in **Figure 53**. The IP address and IED name should be the same as in the relay that you choose.

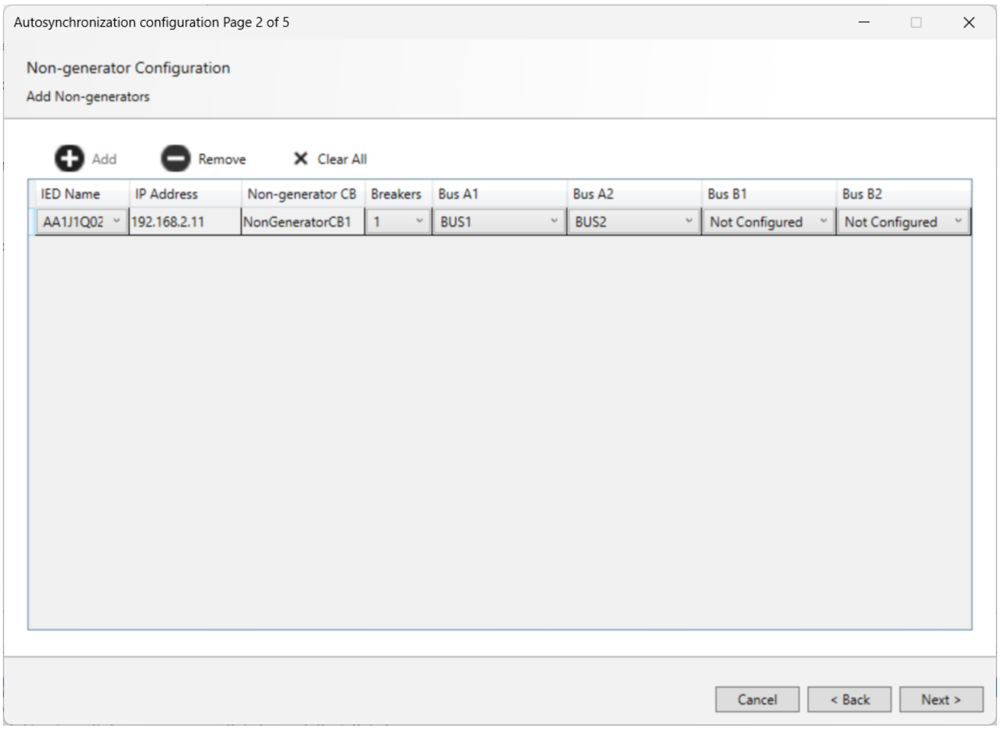


Figure 53. Setting non-source circuit breaker.

The bus's connection to each generator is also set on the next page and the source circuit breakers for the generator are selected as seen in **Figure 54**. Generators' names must be given to each generator chosen. IP addresses and IED names should be checked to make sure they match the relays.

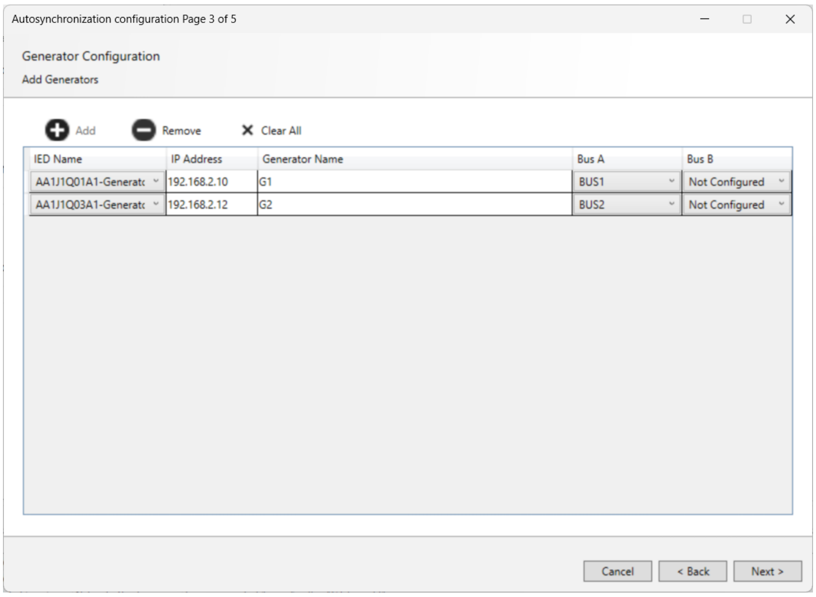


Figure 54. Setting generators bus placement.

When all the relays and connections have been set, you will see all the information and you can check if they are correct as seen in **Figure 55**.

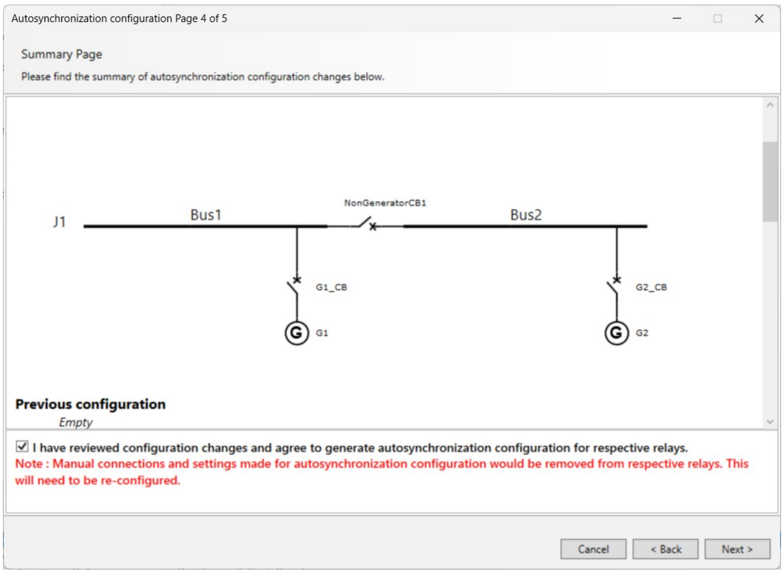


Figure 55. Summary of the wizard.

On the same page by scrolling down you will see information about all the relays, all the names, all the bus placements, and all the non-source and source circuit breakers as seen in **Figure 56**.

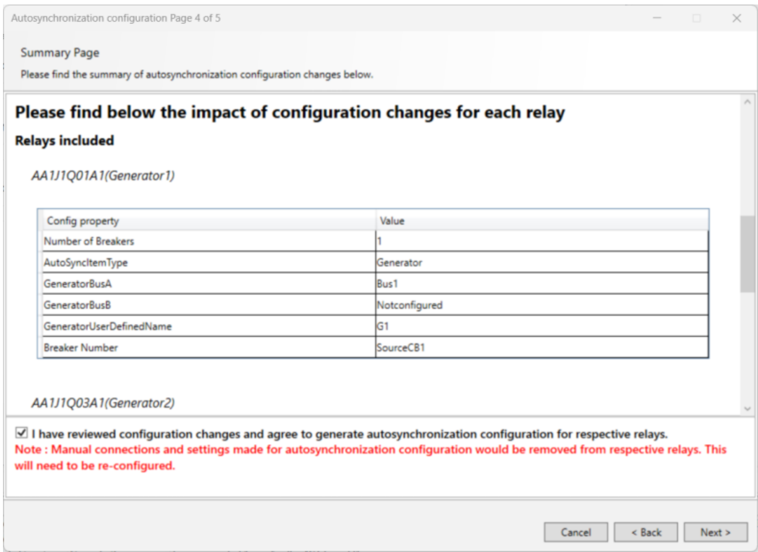


Figure 56. Confirming relays wizard settings.

Figure 57 shows the finish page, the wizard is complete and can be closed, after this you can’t change the wizard configuration.

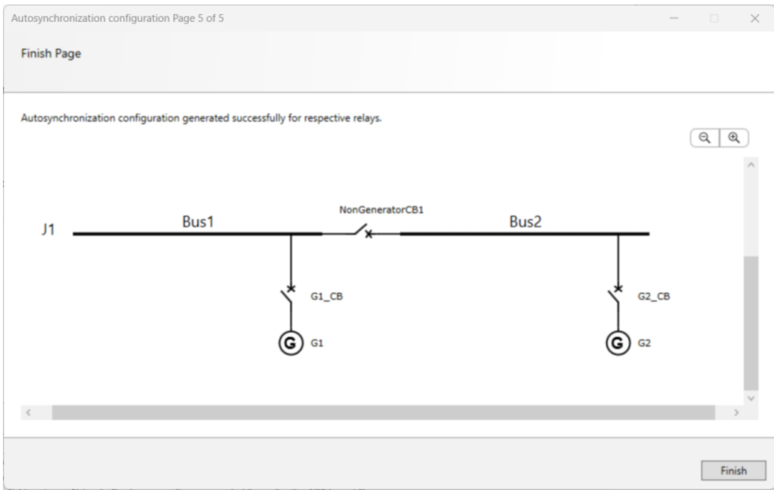


Figure 57. Confirming the wizard.

Autosynchronizer wizard automatically does GOOSE communication between the relays. The GOOSE communication can be checked in PCM600 between the relays. We will discuss how to verify that GOOSE communication works between the relays later.

7.6 Finalizing Configurations

Figure 58 shows a new MainApplication sheet called AutoSync, which the autosynchronizer wizard created. The configuration still lacks the inputs from the measurements and inputs and outputs from the circuit breaker. You can see all the finalized configurations in Appendix 2.

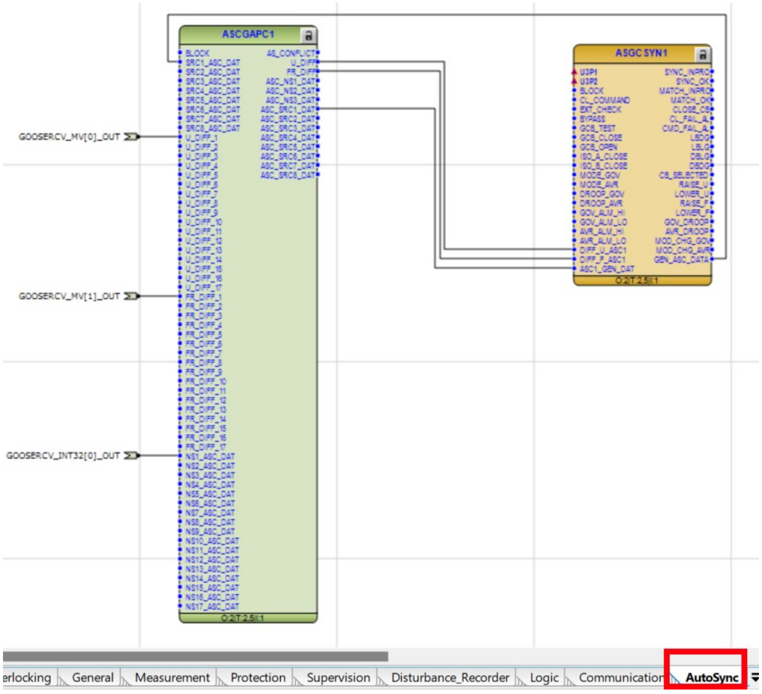


Figure 58. Wizard created a new MainApplication sheet.

7.6.1 Adding Voltage Measurements

The wizard does not add three-phase voltage preprocessing functions to the configuration, those should be added to the project as seen in **Figure 59**. To simplify, in the configuration to be tested, only one-phase voltage measurements from both sides of the breaker are used.

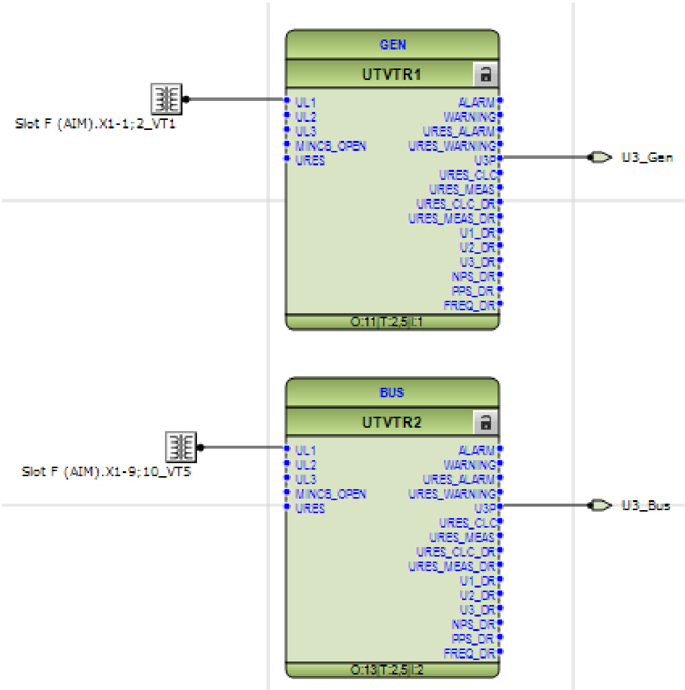


Figure 59. Added voltage measurements.

Figure 60 shows how the UTVTR outputs are connected to the ASGCSYN function block. UTVTR1's (`U3_Gen`) is connected as generator voltage and UTVTR2's (`U3_Bus`) is bus voltage.

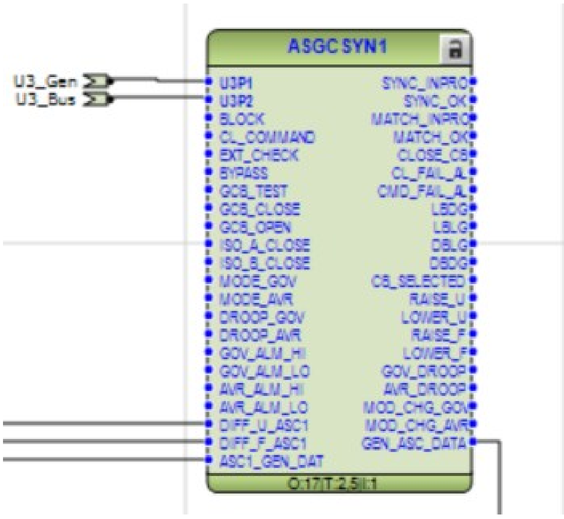


Figure 60. Adding voltage measurements to ASGCSYN.

Figure 61 shows examples, how other inputs are connected to ASGCSYN. CL_COMMAND gives signals to the function to start synchronizing, this signal is usually taken from a panel button.

EXT_CHECK must be set TRUE for ASGCSYN to start working when given permission. ISO_A_CLOSE is also set to TRUE for making sure that the disconnector is closed (disconnectors are not used in this example). Next `Droop_GOV` and `Droop_AVR` are set TRUE in the case Central PMS (power management system) parameter is set to NO. Circuit breaker positions are from CBXCBR's output.

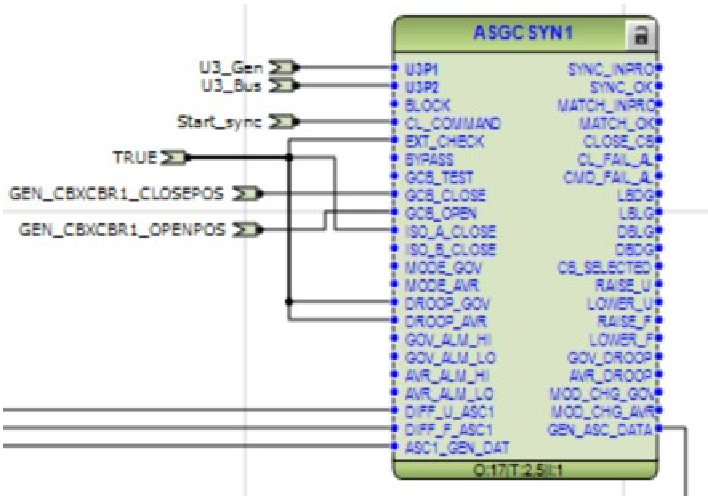


Figure 61. Adding inputs to ASGCSYN.

Figure 62 shows the outputs added to the ASGCSYN. SYNC_OK output is given when the generator and bus are in sync, SYNC_OK and CLOSE_CB outputs must be given to the circuit breaker block CBXCBR for the CB to close. RAISE_U, LOWER_U, RAISE_F and LOWER_F outputs are given to the output hardware channels, to give commands to the AVR and the governor.

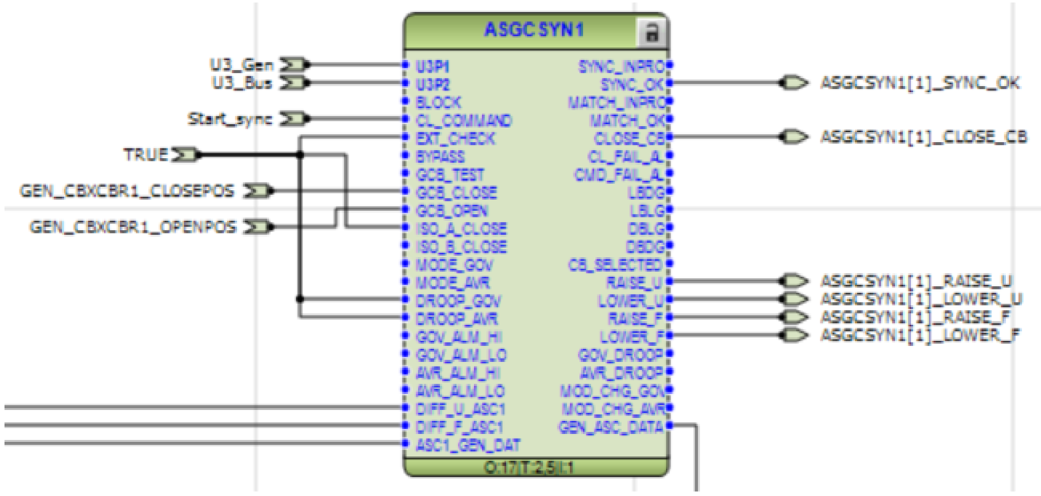


Figure 62. Adding outputs to ASGCSYN.

7.6.2 Adding a Source Circuit Breaker

Figure 63 shows an example on how to connect inputs and outputs of the circuit breaker block CBXCBR. The position of the circuit breaker must be given to the function for it to know when to close or to open.

ENA_OPEN and ENA_CLOSE must be set to true for enabling CB opening and closing. To enable the function to open or close the CB, BLK_OPEN and BLK_CLOSE must be set to false.

AU_CLOSE and SYNC_OK signals from the ASGCSYN must be connected to the CBXCBR function.

Outputs from the CBXCBR are: EXE_OP as open command to the circuit breaker, EXE_CL as close command to the circuit breaker, OPENPOS as CB open position information for ASGCSYN and CLOSEPOS as close position information to ASGCSYN.

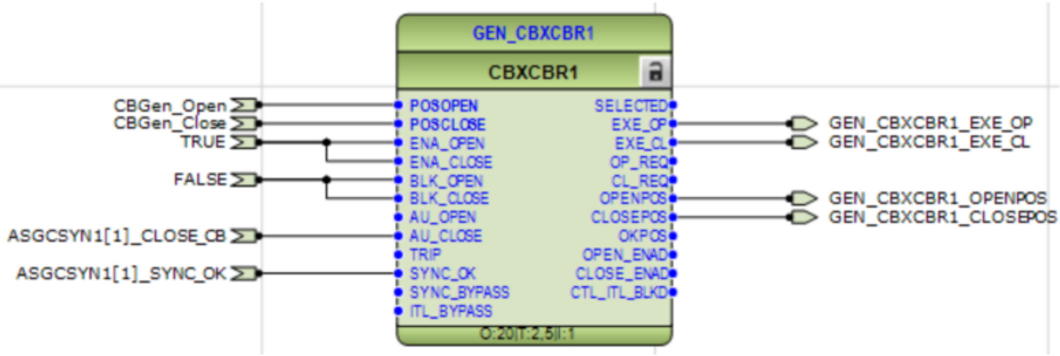


Figure 63. Circuit breaker block configurations.

7.6.3 Adding Non-source Circuit Breaker

ASNSCSYN is configured as the same way as ASGCSYN, but it does not have as many inputs and outputs. Voltage measurements, circuit breaker (CBXCBR) inputs are added the same way as in the ASGCSYN function block. **Figure 64** shows the fully configured ASNSCSYN.

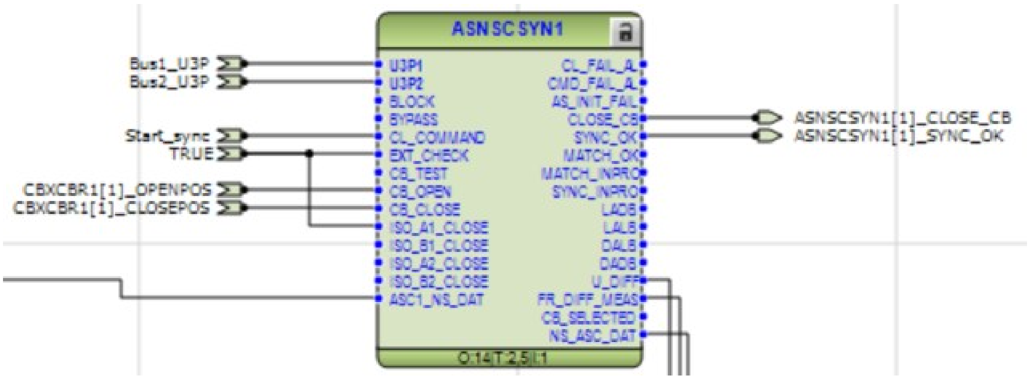


Figure 64 ASNSCSYN function block.

7.6.4 Source Selection

Each relay must have a source selection set if the network has ASGCSYN and ASNSCSYN. ASCGAPC must know which source to synchronize first before other sources can be synchronized. **Figure 65** shows that the selection is made with each relay’s ASCGAPC control parameters. The tuning source is selected in the case when a non-source circuit breaker (NSCB) is trying to be synchronized to another energized bus.

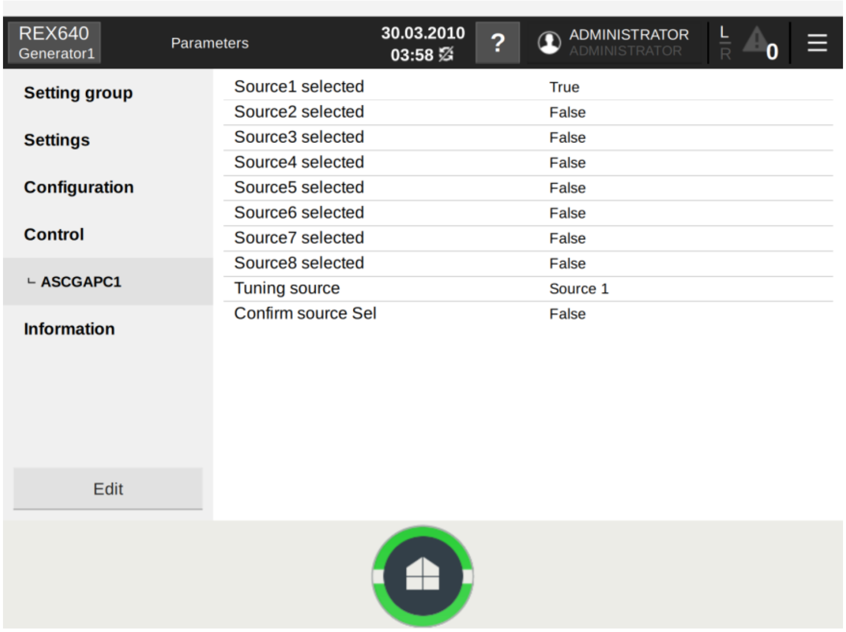


Figure 65. Source selected for generator 1.

7.6.5 Parameters

The parameters for testing ASGCSYN are given in **Figure 66** and **Figure 67**.

AUTOSYNCG			
Operation		on	
Synchrocheck mode		Asynchronous	
Dead voltage value		0,20	xUn
Live voltage value		0,50	xUn
Maximum voltage		1,20	xUn
Minimum voltage		0,80	xUn
Voltage match mode		Variable Pulse	
Frequency match mode		Variable Pulse	
Minimum Syn time		0	ms
Maximum Syn time		60000	ms
Energizing time		100	ms
Central PMS present		No	
Volt pulse off Intv		2000	ms
Volt pulse Min Dur	500	500	ms
Freq pulse off Intv		10000	ms
Freq pulse Min Dur	500	500	ms
Auto Syn mode		Automatic synchronising m	

Figure 66. ASGCSYN general parameters.

settingGroup 1		
Live dead mode	Off	
Freq Diff Ov Synch	0,002	xFn
Freq Diff sub Synch	0,002	xFn
Coarse Freq Diff Ov	0,002	xFn
Coarse Freq Diff sub	0,002	xFn
Voltage Diff Ov Ex	0,01	xUn
Voltage Diff Un Ex	0,01	xUn
Coarse Volt Diff Ov	0,01	xUn
Coarse Volt Diff Un	0,01	xUn
Angle Diff positive	5	deg
Angle Diff negative	5	deg
Volt rate of change	0,003	xUn/s
Freq rate of change	0,002	xFn/s
Phase shift	0	deg
Closing time of CB	60	ms
Multiple command	Off	
Synchronization Dir	Always over synchronous	
Voltage offset	0,000	xUn
Frequency offset	0,000	xFn

Figure 67. ASGCSYN setting group parameters.

See **Figure 68** and **Figure 69** for ASNSCSYN parameter settings.

Group / Parameter Name	IED Value	PC Value	Unit	Min	Max
ASNSCSYN1: 1					
AUTOSYNC(1)					
Operation		on			
Synchrocheck mode		Asynchronous			
Dead bus voltage		0,2	xUn	0,1	0,8
Live bus voltage		0,5	xUn	0,2	1,0
Max energizing V		1,05	xUn	0,50	1,30
Phase shift		0	deg	-180	180
Minimum Syn time		0	ms	0	60000
Maximum Syn time		60000	ms	100	6000000
Energizing time		100	ms	100	60000
Closing time of CB		60	ms	40	250
Auto Syn mode		Automatic synchronising mo			

Figure 68. ASNSCSYN general parameters.

settingGroup 1					
Live dead mode		Off			
Diff voltage		0,03	xUn	0,01	0,50
Diff frequency	0,040	0,040	xFn	0,001	0,060
Diff angle	5	5	deg	5	90
Multiple command		Off			
Voltage offset		0,000	xUn	-0,100	0,100
Frequency offset		0,000	xFn	-0,010	0,010

Figure 69. ASNSCSYN setting group parameters.

Just to simplify, the settings used in this thesis, are slightly different than those used in Appendix 1. The parameters are written to the relay with PCM600.

8 VERIFYING CONFIGURATIONS

In this chapter, we will go through, how to verify the configuration. First, we will go through how to check that the relays communicate with each other through GOOSE. Next, we will evaluate the configuration with Omicron to see that the configuration works as intended. The detailed verification is explained in Appendix 1.

8.1 GOOSE Communication

The communication between the relays is done by GOOSE. **Table 5** shows meaning of different GOOSE signal data.

Table 5. GOOSE signal data table.

LD0.ASCGAPC1.Dif.VClc.mag.f	Voltage difference calculation
LD0.ASCGAPC1.Dif.VClc.q	Quality of goose signal
LD0.ASCGAPC1.DifHzClc.mag.f	Frequency difference calculation
LD0.ASCGAPC1.DifHzClc.q	Quality of goose signal
LD0.ASCGAPC1.DatOutSrc1.stVal	Input data from source number 1
LD0.ASCGAPC1.DatOutSrc1.q	Quality of goose signal
LD0.ASCGAPC1.DatOutSrc2.stVal	Input data from source number 2
LD0.ASCGAPC1.DatOutSrc2.q	Quality of goose signal

Figure 70 shows how to check GOOSE signals. The relay shows what communication it receives and what it sends.

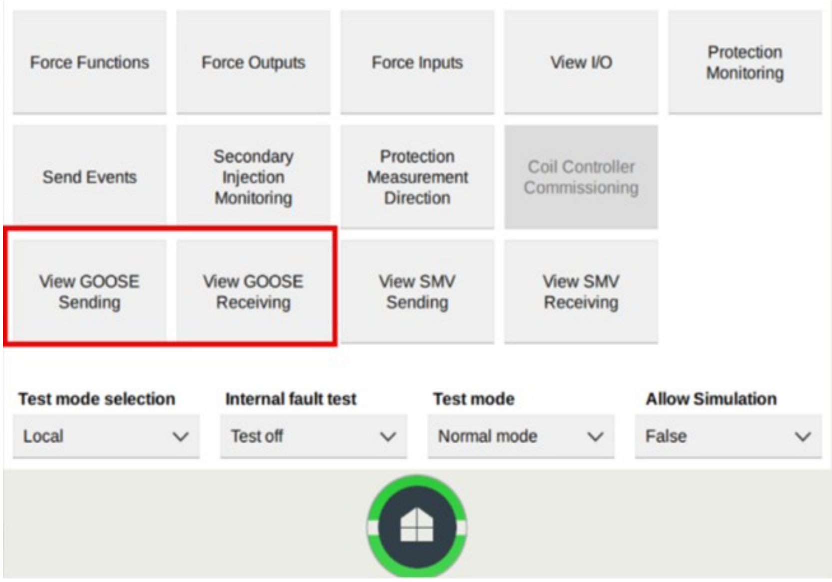


Figure 70. Checking GOOSE.

Figure 71 shows that the Generator 1 relay sends information to the network breaker relay. The number of the data changes depending on the inputs given to the ASGCSYN function block. The different kind of combination of the inputs can be found in Appendix 1.

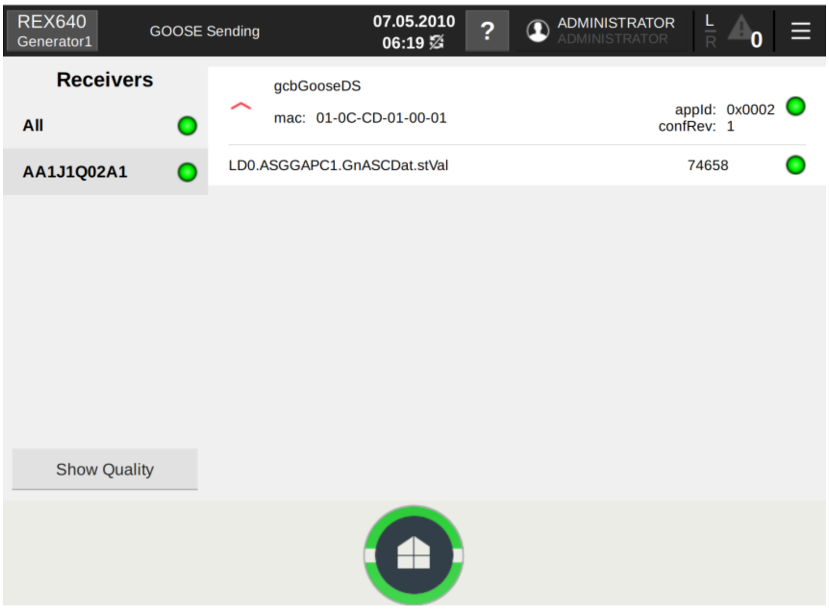


Figure 71. Checking GOOSE sending between relays.

Figure 72 shows that generator 1 receives GOOSE communication from network breaker relay.

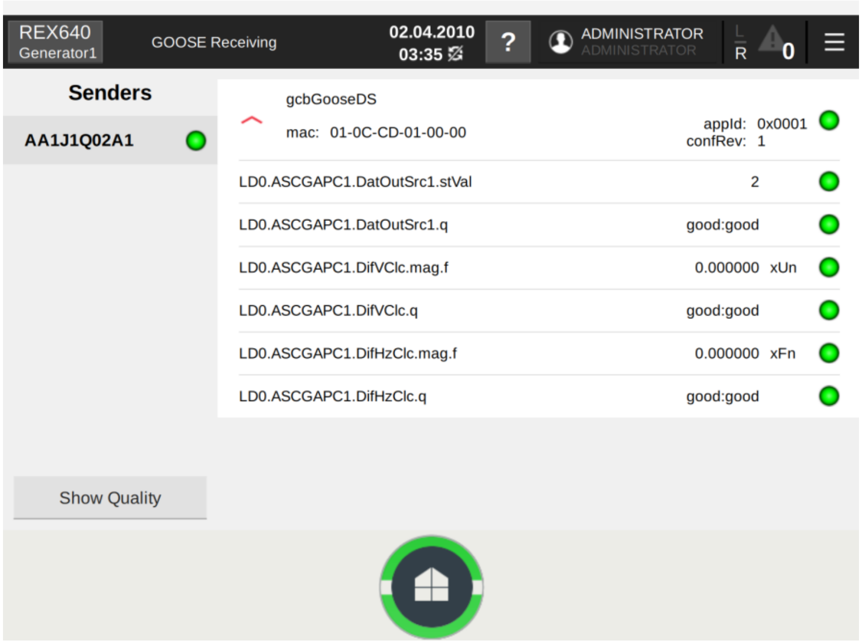


Figure 72. Relay receiving GOOSE.

8.2 Testing ASGCSYN

Figure 73 shows how the autosynchronizer adjusts the voltage and frequency seeking values which fulfils the closing conditions.

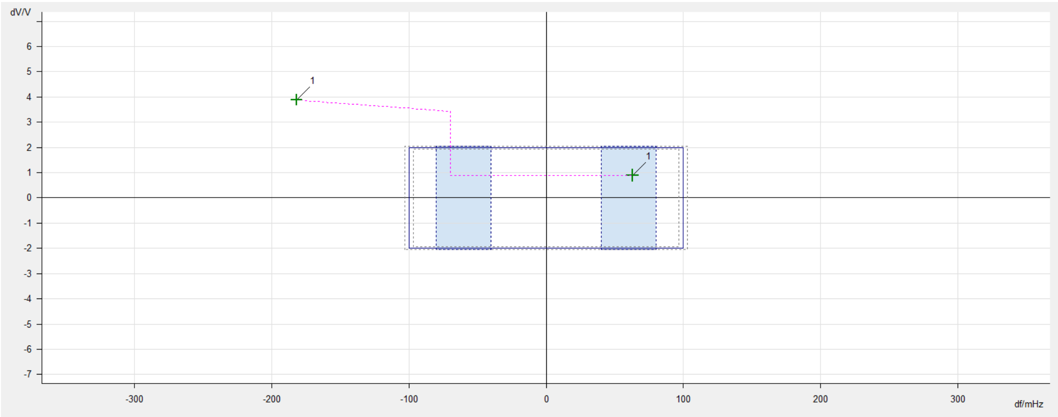


Figure 73. Relay synchronized Sync View.

Figure 74 shows the angle at the CB closing command and the actual CB closing. The relay gives command at the negative phase angle so that the CB will close at over-synchronous side (positive angle side).

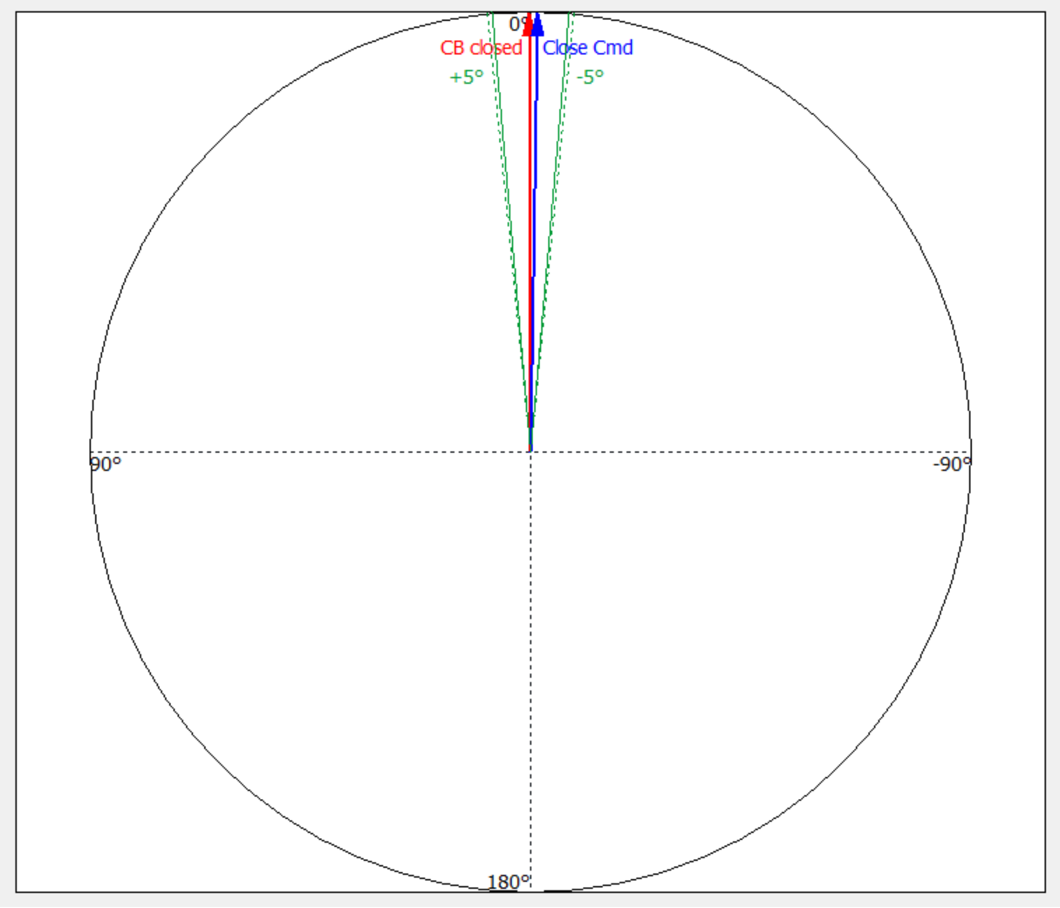


Figure 74. Synchroscope view of Omicron.

Figure 75 shows the voltage, frequency, and phase angle at the starting point, the end point, and the point when CB is closed.

Adjustment Test (Deltas)

Start point			EP On CB Close Command EP On CB Close				Synchro Time	Gen. Model	Result
ΔV	Δf	ΔPhi	ΔV	Δf	ΔPhi	tΔPhi=0			
3,876 V	-0,182 Hz	0,000 °	0,891 V 0,891 V	0,063 Hz 0,063 Hz	-0,838 ° 0,525 °	0,037 s 0,023 s	12,597 s	dV/dt= 0.8 V/s df/dt= 0.2 Hz/s	Passed

(EP=End point)

Adjustment Test (Abs. Value)

Start point			EP On CB Close Command EP On CB Close			Synchro Time	Gen. Model	Result
V	f	Phi	V	f	Phi			
103,876 V	49,818 Hz	0,000 °	100,891 V 100,891 V	50,063 Hz 50,063 Hz	-54,838 ° -53,475 °	12,597 s	dV/dt= 0.8 V/s df/dt= 0.2 Hz/s	Passed

(EP=End point)

Figure 75. Report view of the synchronization.

Figure 76 shows the synchronization results. The tests were made with the same starting point. The EP (end point) shows the difference between the values when the closing command was given by the relay, and when the CB actually closes. The CB simulator is set to 60 ms closing time.

Test	Start point			EP CB close command EP on CB close			Synchro Time (s)	Gen Model	Result
	V	f	Phi	V	f	Phi			
1	103,876	49,818	0	100,919	50,07	-137,595	15,333	dv/ dt = 0,8 v/ s	Passed
				100,919	50,07	-136,181		df/ dt = 0,2 Hz/ s	
2	103,876	49,818	0	100,919	50,58	-98,151	13,815	dv/ dt = 0,8 v/ s	Passed
				100,919	50,58	-96,896		df/ dt = 0,2 Hz/ s	
3	103,876	49,818	0	100,911	50,061	-117,9	13,814	dv/ dt = 0,8 v/ s	Passed
				100,911	50,061	-116,58		df/ dt = 0,2 Hz/ s	
4	103,876	49,818	0	100,907	50,063	2,618	11,86	dv/ dt = 0,8 v/ s	Passed
				100,907	50,063	3,98		df/ dt = 0,2 Hz/ s	
5	103,876	49,818	0	100,907	50,057	-94,408	13,935	dv/ dt = 0,8 v/ s	Passed
				100,907	50,057	-93,175		df/ dt = 0,2 Hz/ s	
6	103,876	49,818	0	100,903	50,055	121,585	29,047	dv/ dt = 0,8 v/ s	Passed
				100,903	50,055	122,775		df/ dt = 0,2 Hz/ s	
7	103,876	49,818	0	100,696	50,057	90,987	18,125	dv/ dt = 0,8 v/ s	Passed
				100,696	50,057	90,22		df/ dt = 0,2 Hz/ s	
8	103,876	49,818	0	100,887	50,058	-107,218	30,554	dv/ dt = 0,8 v/ s	Passed
				100,887	50,058	-105,963		df/ dt = 0,2 Hz/ s	
9	103,876	49,818	0	100,919	50,058	49,446	20,903	dv/ dt = 0,8 v/ s	Passed
				100,919	50,058	50,058		df/ dt = 0,2 Hz/ s	
10	103,876	49,818	0	100,891	50,063	-54,838	12,597	dv/ dt = 0,8 v/ s	Passed
				100,891	50,063	-53,475		df/ dt = 0,2 Hz/ s	

Figure 76. Results of 10 tests.

The signals needed in ASGCSYN, so that it works in the generator breaker synchronization, are shown in **Table 6**. The relay is se `Local/remote` = Local.

Table 6. ASGCSYN operating signals.

Signal	True	False
EXT_CHECK	X	
GCB_CLOSE		X
GCB_OPEN	X	
ISO_A1_CLOSE		X
ISO_A1_CLOSE		X
MODE_GOV		X
DROOP_GOV		X
DROOP_AVR		X
GOV_ALM_HI		X
GOV_ALM_LO	X	X
AVR_ALM_HI		X
AVR_ALM_LO	X	X

X defines the status of the signal.

Table 7 shows which signals prevent the synchronization.

Table 7. ASGCSYN non-operating signals.

Signal	True	False
EXT_CHECK		X
GCB_CLOSE	X	

GCB_OPEN		X
ISO_A1_CLOSE		X
ISO_A1_CLOSE		X
MODE_GOV		X
DROOP_GOV		X
DROOP_AVR		X
GOV_ALM_HI	X	
GOV_ALM_LO		X
AVR_ALM_HI	X	
AVR_ALM_LO		X

X defines the status of the signal.

8.3 Testing ASNSCSYN

When starting to synchronize an asynchronous situation where bus A and bus B are not in synchronization, the selected tuning source must have its circuit breaker closed and feed either bus. The relay must be set `remote mode` to be able to participate in the tuning. **Figure 77** shows the participating window when trying to synchronize the non-source circuit breaker when both buses are live.

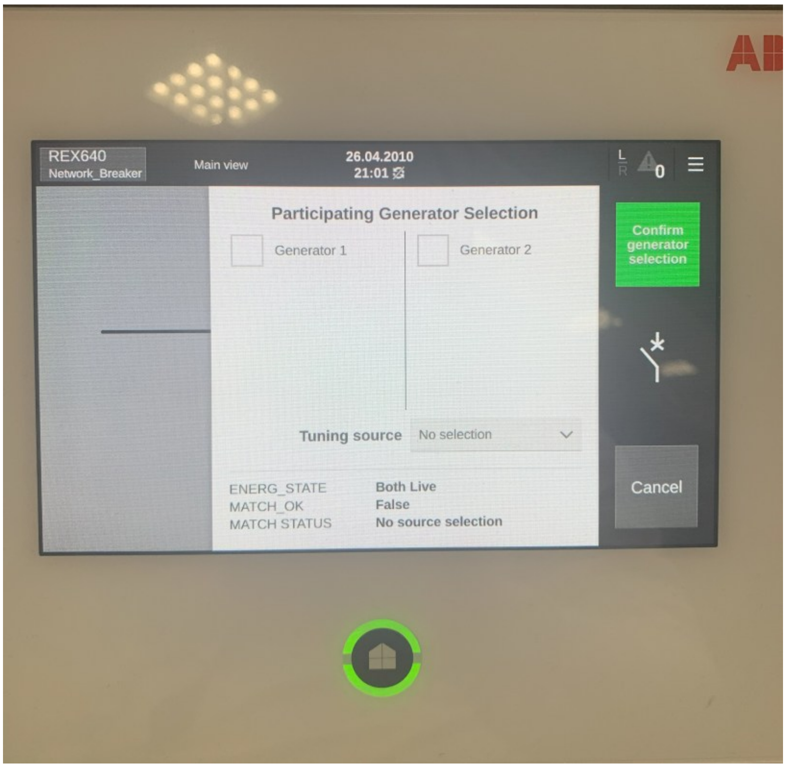


Figure 77. Selecting participating generator.

Figure 78 shows the available participating generators, now only generator 1 has its CB closed and is in remote mode. Generator 2 has remote mode **ON,** but the CB is not closed.

Figure 78. Participating generator.

Figure 79 shows selecting the tuning source after the participating generator has been chosen. It must be chosen also here to make sure which the generator does the tuning.

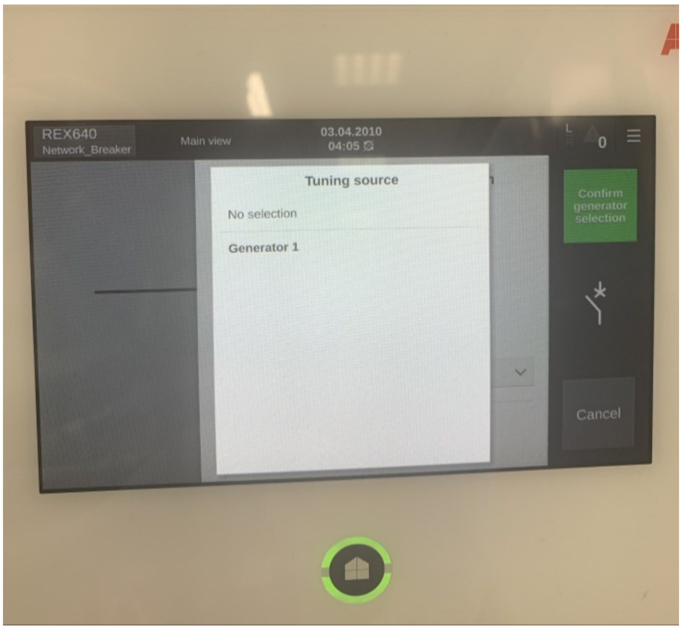


Figure 79. Selecting tuning source.

Figure 80 shows the synchronization window when the tuning source has been selected. It shows that matching is in process, if the tuning source has not been selected, then the match status would read: "tuning source not selected".

Figure 80. Matching in process.

The generator relay which is participating in tuning must be set to `local/remote` = remote.

The ASNSCSYN needs a tuning source to synchronize the busbars. In this case, the information of the generator that is selected is added to the **Table 8** and **Table 9**. These two tables show what signals the functions need to work, and what signals makes it that the function does not work.

Table 8. Signals where synchronization works.

Signal	**True**	**False**
EXT_CHECK	X	
CB_CLOSE		X

CB_OPEN	X	
GCB_CLOSE (The tuning source)	X	
ISO_A_Close (The tuning source)	X	

X defines the status of the signal.

Table 9. Signals where synchronization does not work.

Signal	**True**	**False**
EXT_CHECK		X
CB_CLOSE	X	
CB_OPEN		X
GCB_CLOSE (The tuning source)		X
ISO_A_Closed (The tuning source)		X

X defines the status of the signal.

9 CONCLUSIONS AND DEVELOPMENT PROPOSAL

The focus of the thesis was to create a working and tested configuration on autosynchronizer function. There is no guide on what to do after using autosynchronizer wizard, which has caused many customers to send support requests, as they do not know the mandatory signals for the function to work. Many do not even know that the autosynchronizer wizard is available.

As an example, while working on this thesis, one customer reported that they could not start synchronization from the relay. It was noticed that they did not have the right circuit breaker in their SLD (single line diagram), which resulted the synchronization unable to be started from the relay. The customer did not have the EXT_CHECK true in any way in their configuration when closing the circuit breaker locally.

This thesis was a long project, which succeeded in creating a technical note. The easiest part of the thesis was making the configuration, but the most difficult part was testing all the functionalities. This work required a lot of testing and orientation.

All objective for this thesis has been successfully completed. If this kind of technical note would have been available already when autosynchronizer functions were released, support would have saved weeks of their work, and some projects postponing would have avoided. ABB R&D has reviewed and provided positive feedback on the technical note.

Future improvement ideas and proposals:

- Further clarification is recommended regarding the GOOSE code combinations. Because comprehensive lists are not available.
- To make the autosynchronizer documentation simple as possible and fast to use, it would be beneficial to add hyperlinks pointing to the additional information.

- Remotely initiating close command from upper-level system would also be beneficial to be tested.
- For future improvements of autosynchronization documentation a follow-up project, where a real generator or real-time simulator used for testing would be important to have.

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APPENDICES

APPENDIX 1. Technical Note

2NGA002584 EN

Technical Note

Issued: March 2025
Rev: A / 26 March 2025

ABB Oy, Distribution Solutions

REX640 autosynchronizer configurations

Configuration and testing guide

Contents:

1 Scope

The present document describes how to configure and test the REX640 autosynchronization functions with Omicron secondary injection test device. This document is intended for persons who already have basic information and some experience on testing autosynchronization. This is an Omicron test where we don't use real generator. In this guideline, we will go through the process of testing relay autosynchronization functions using Omicron. Please note that this test is not intended for commissioning or synchronizing a real generator, as those processes involve entirely different procedures and considerations.

First, the guidelines provide basic instructions for configuring ASGCSYN, ASNSCSYN, and the coordinator function ASCGAPC using the Autosynchronizer Wizard. Next, necessary steps are provided for completing the autosynchronization configuration. Following this, the procedure for verifying mandatory signals and GOOSE communication is outlined. Finally, the document concludes with instructions on how to test the autosynchronizer configuration using Omicron.

KEYWORDS: autosynchronizer, wizard, REX640, PCM600, Omicron

2 Introduction

Before a generator can be connected to a network, it must be synchronized with the system in terms of voltage, frequency, and phase. Any significant deviation during synchronization can cause severe damage to both the generator and the network. Synchronization can be performed manually, semi-automatically, or automatically.

In automatic synchronization, a synchronizing device manages the generator’s frequency and voltage using the governor and Automatic Voltage Regulator (AVR). Once the synchronization criteria are met, the device sends a close command to the generator circuit breaker (CB) to connect the generator safely to the grid.

After synchronization, the generator's output must be continuously adjusted to match the changing power demand. This applies to both active power (real power) and reactive power, ensuring stable and efficient operation within the network.

3 Application case and connections

In this technical note, we will use an example of two generators and one network breaker, as shown in **Figure 1.**

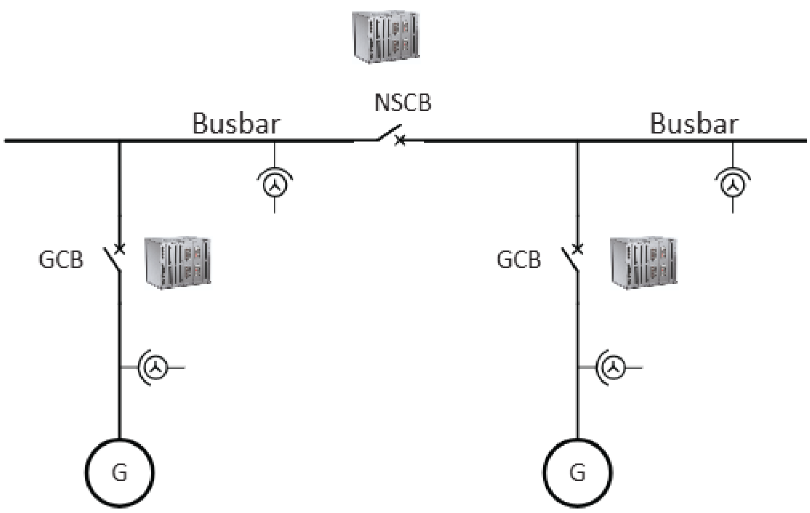

Figure 1. Selected system diagram.

4 Starting with wizard

Manually configuring the autosynchronization scheme in PCM600 can be complex and time-consuming, especially when the system includes both generator circuit breakers (GCBs) and non-generator circuit breakers (also known as non-source circuit breakers, NSCBs). The "Configure Autosynchronization" wizard in PCM600 helps to simplify this process. It allows users to set up the autosynchronization scheme using easy-to-understand terms, making it easier to interpret the network topology.

The relay can synchronize both GCBs and NSCBs, such as grid connection or bus coupler circuit breakers, by using specific function blocks to manage the synchronization process:

- **ASGCSYN**: Used for synchronizing GCBs.
- **ASNSCSYN**: Used for synchronizing NSCBs.
- **ASCGAPC**: A coordination function that manages control requests and enables communication between relays in the autosynchronization system.

The "Configure Autosynchronization" wizard generates the configuration with IEC61850-8-1 GOOSE engineering, function block parameters in the Parameter Setting, and necessary connections in the Application Configuration for ASGCSYN, ASNSCSYN, and ASCGAPC. It also provides a preview of the network topology in the form of a Single Line Diagram (SLD).

Wizard work process is shown in **Figure 2**.

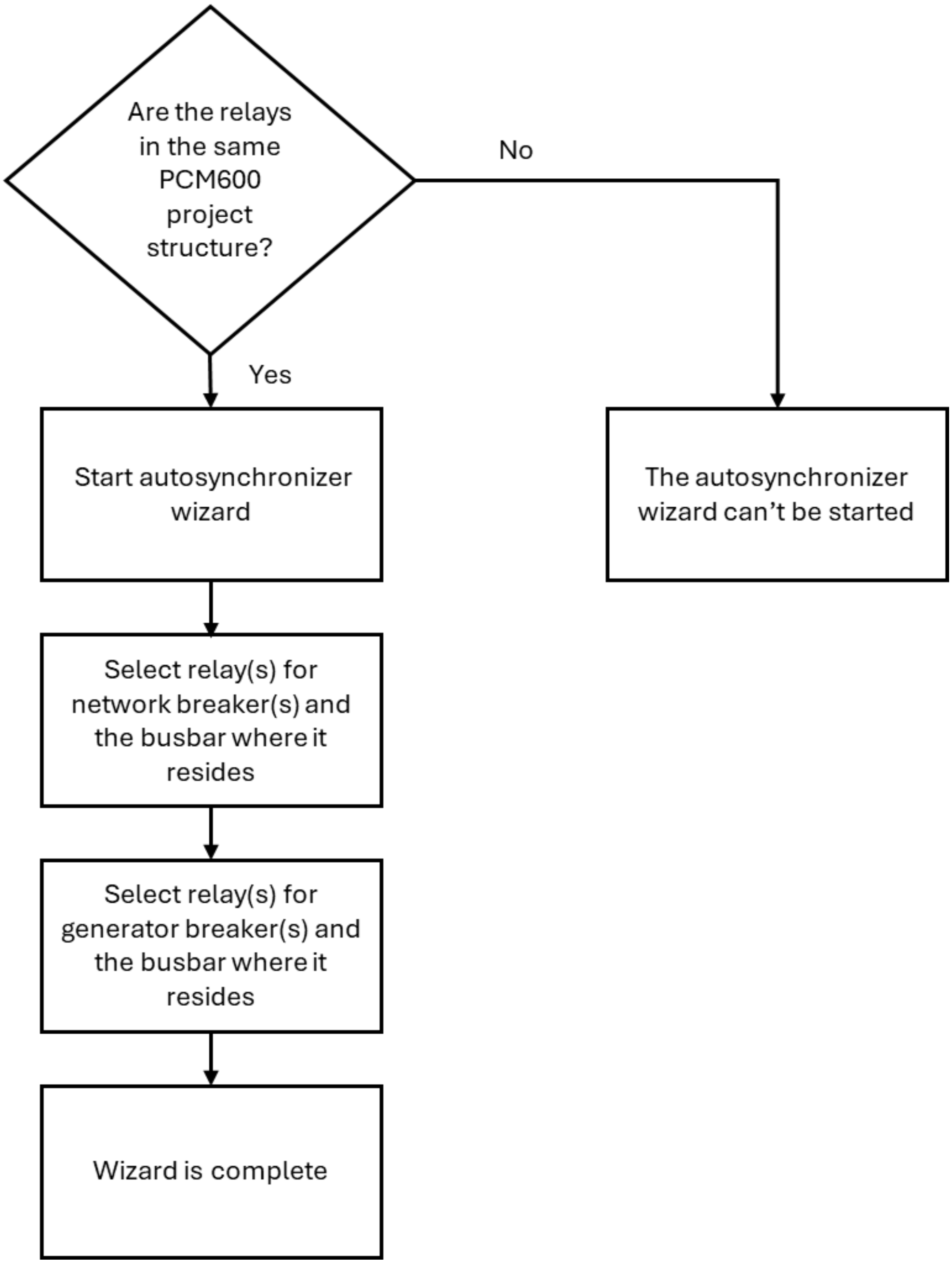

Figure 2. Wizard work process flowchart.

4.1 Example case

This technical note shows how to create a configuration for two parallel generator network with a network breaker between them as illustrated in **Figure 3**.

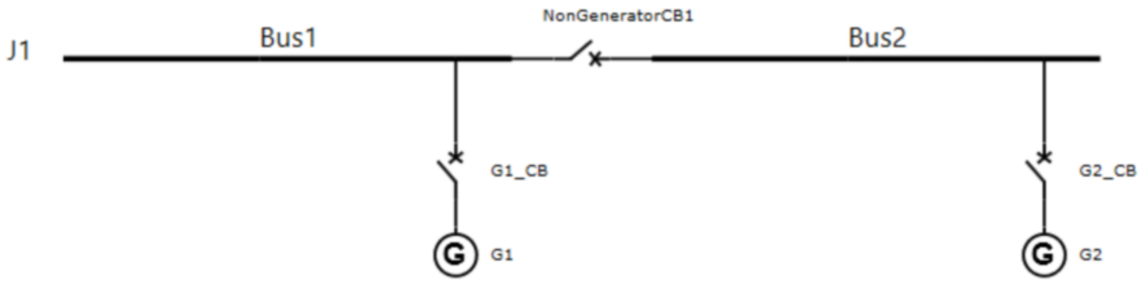

Figure 3. Network configuration used in this guide.

To start the Wizard, the substation must be at least in the same voltage level, and at least one relay must have the generator autosynchronizer package and one relay must have the network autosynchronizer package in the created project as seen in **Figure 4**. In this example we will be using three relays which control the breakers.

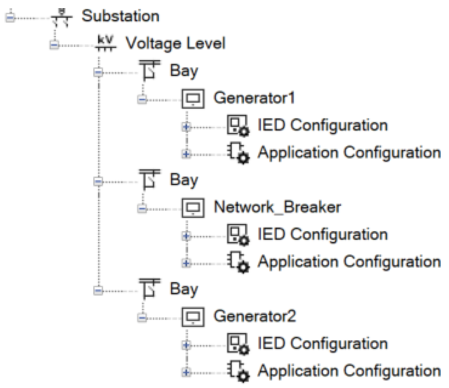

Figure 4. How relays are shown in PCM600.

The wizard can be started by right clicking substation and selecting **Configure Autosynchronization** as seen in **Figure 5**.

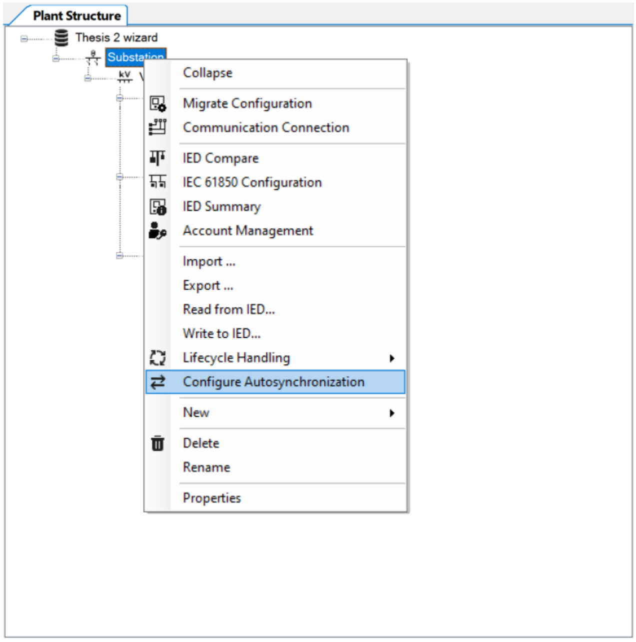

Figure 5. How to start autosynchronizer configuration wizard.

The first screen is a welcoming page as seen in **Figure 6**. On Welcome Page, click Next to configure first the topology for NSCBs and then for GCBs.

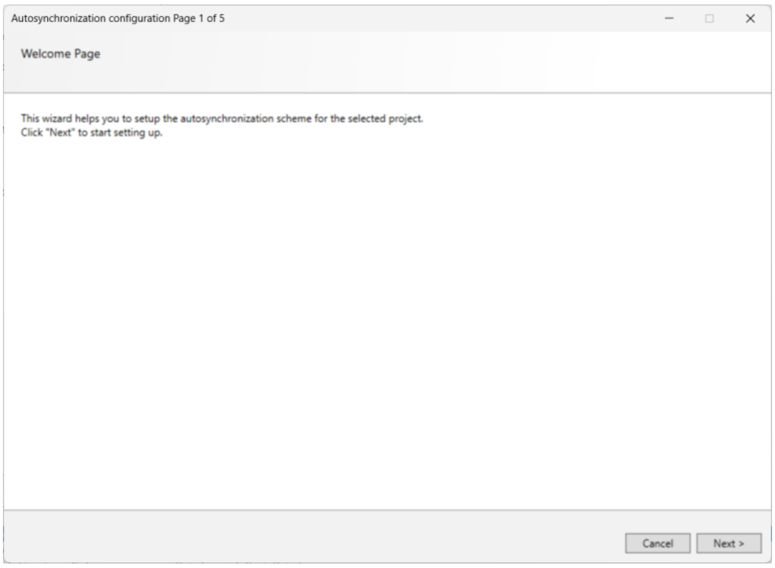

Figure 6. Configuration wizard pop-up.

Next, we will choose non-source (non-generator) and source (generator) breakers to be added into the configuration.

The non-generator CB is added and the relay that controls it. As seen in **Figure 3** we want the non-source CB to be between generator 1 and generator 2. Therefore, we add the busbars A1-A2 as seen in **Figure 7**.

On the Non-generator Configuration page, configure the topology by adding, removing or clearing NSCBs. The page displays the relays from the PCM600 project setup that support the Network autosynchronizer application package. It is possible to synchronize up to 17 NSCBs in the configuration.

- **IED Name**: Shows a list of relays with non-generator capabilities that can be selected and added to the configuration
- **IP Address**: Shows the IP address of the selected non-generator (read only)
- **Non-generator CB ID**: Shows an autogenerated non-generator circuit breaker ID to identify the breaker in the SLD preview controlled by the relay (read only)
- **Breakers**: Used to specify the number of breakers a relay can control
- **Bus A1**: Used to specify the Bus A1 value for a non-generator in a single bus system
- **Bus A2**: Used to specify the Bus A2 value for a non-generator in a single bus system
- **Bus B1**: Used to specify the Bus B1 value for a non-generator in a double bus system
- **Bus B2**: Used to specify the Bus B2 value for a non-generator in a double bus system

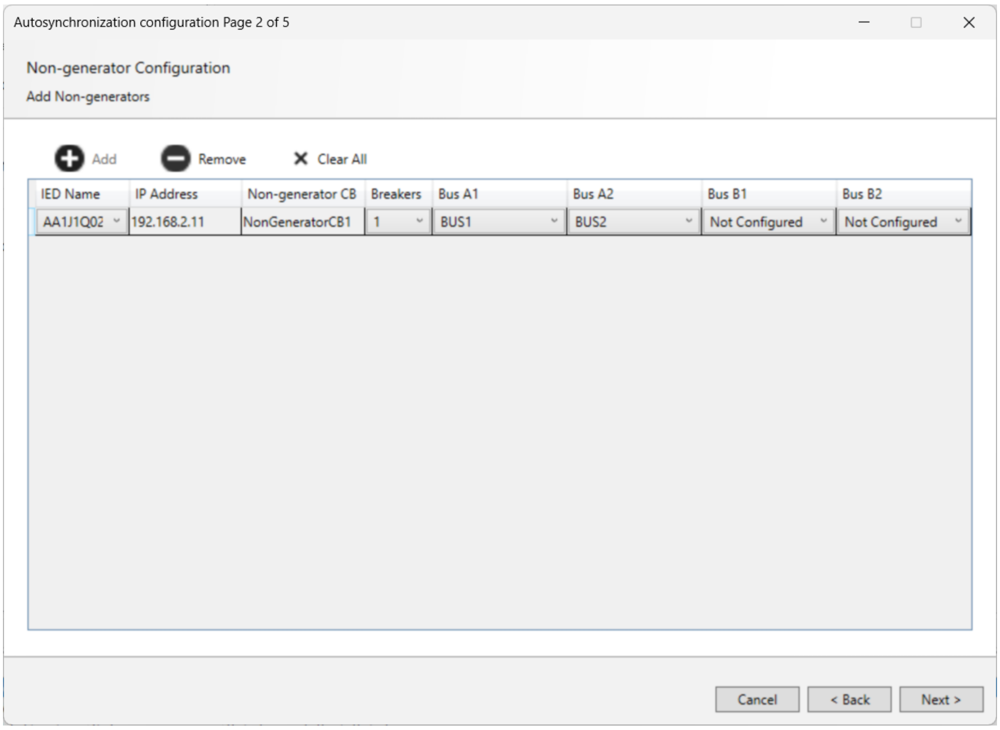

Figure 7. Selecting non-source circuit breaker.

Generator relays are added to the correct busbars as seen in **Figure 8**. On the Generator Configuration page, configure the topology by adding, removing or clearing GCBs.

The page displays the relays from the PCM600 project setup that support the Generator autosynchronizer application package. It is possible to synchronize up to eight GCBs to the configuration.

- **IED Name**: Shows a list of relays with generator capabilities that can be selected and added to the configuration
- **IP Address**: Shows the IP address of the selected generator (read only)
- **Generator Name**: Used to specify a user-defined name for the generator
- **Bus A**: Used to specify the Bus A value for a generator in a single bus system
- **Bus B**: Used to specify the Bus B value for a generator in a double bus system

NOTE: Bus A and Generator Name are mandatory to configure for generators. Use unique values in Bus A and Bus B for a given generator.

NOTE: The value in Generator Name is later shown in the SLD preview and the REX640 LHMI dialog where the synchronization for NSCBs is initiated. The generator name can be modified in this field only.

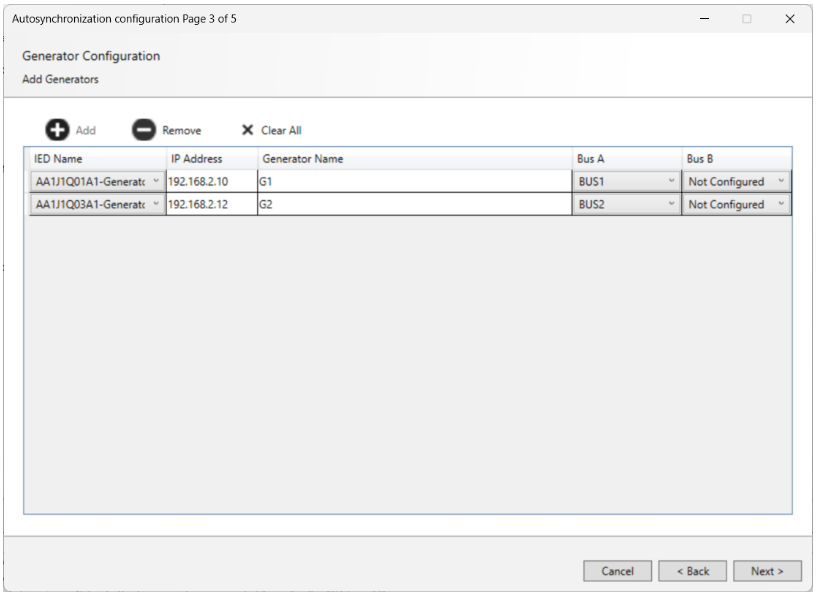

Figure 8. Selecting relays for generators.

In page 4 the configuration shows what the configuration looks like, and all the information of the relays as seen in **Figure 9** and **Figure 10**.

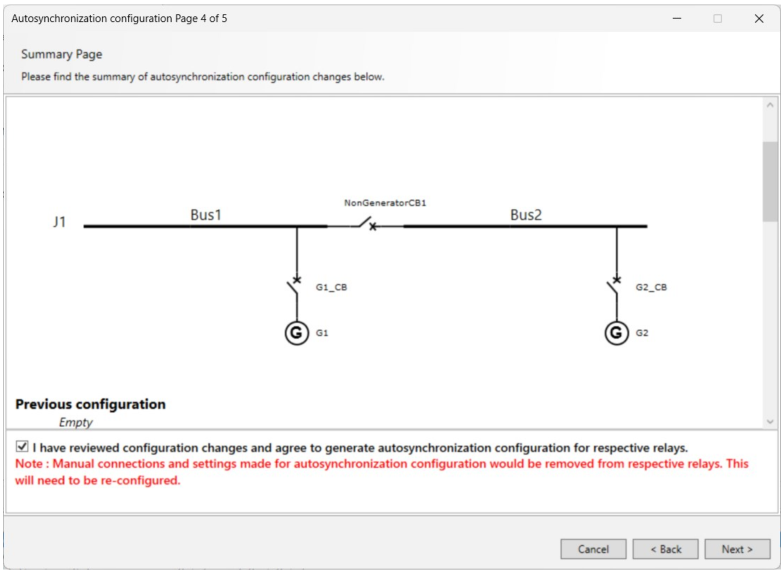

Figure 9. Information on what the configuration looks like.

NOTE: In case Autosynchronization Configuration has already been used to complete the configuration, the impact of configuration changes for each relay is shown on

Summary Page. Review the configuration changes by comparing the SLDs of the current and previous configurations before initiating the configuration generation.

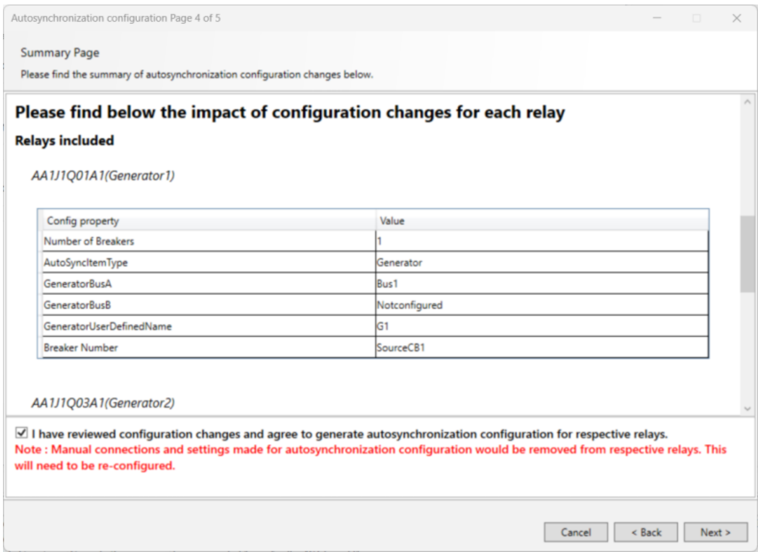

Figure 10. Information about generator 1

In page 5 of the wizard configuration the configuration is done, and you can continue by pressing finish as seen in **Figure 11**.

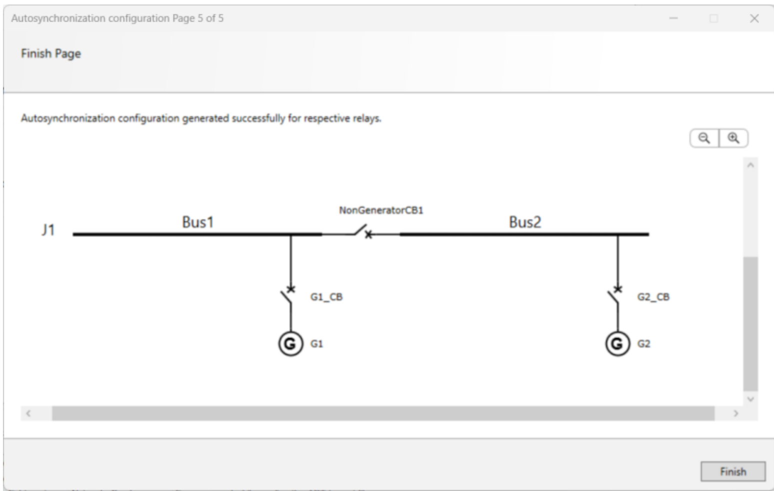

Figure 11. Autosynchronization view.

The GOOSE data sets generated by the tool containing all the entries required to be exchanged among the relays for the autosynchronization process. No further user actions are required regarding the GOOSE engineering for the autosynchronization process. However, GOOSE data exchange for any other logic or scheme may be handled manually.

5 After wizard is completed

In this section, we will review the aspects that the wizard has not configured, as well as the input and output variables that must be configured to complete the autosynchronization functions. The main objective is to have a fully operational system.

5.1 ASGCSYN (generator circuit breaker)

When the wizard is finished a new `MainApplication` has been added called `AutoSync` which has ASCGAPC and ASGCSYN. In **Figure 12** you can see that the voltage measurements (U3P1 and U3P2) are not yet connected to the ASGCSYN. Circuit Breaker control (CBXCBR) is also missing.

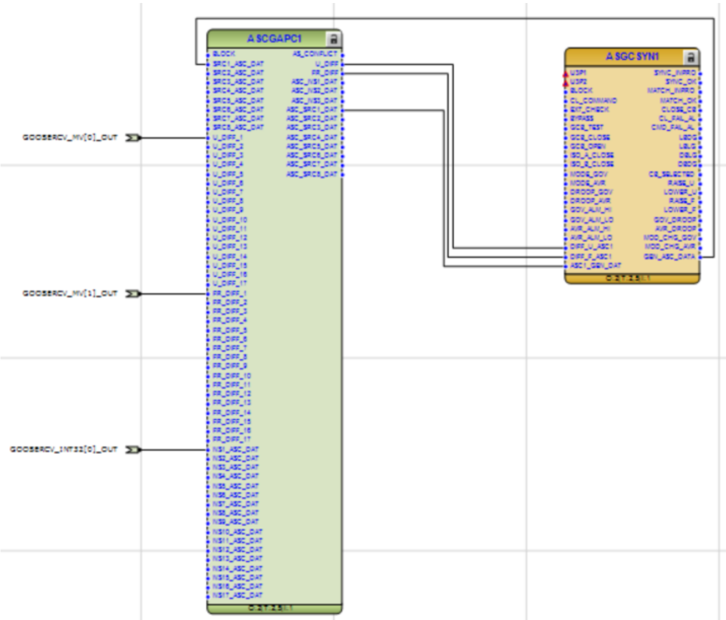

Figure 12. Generator 1 AutoSync MainApplication.

5.1.1 Adding ASGCSYN missing inputs and outputs

First the generator and busbar voltage preprocessing function UTVTR must be added. UTVTR1 is used for generator voltage and UTVTR2 for bus voltage. See **Figure 13**. These outputs are connected to **ASGCSYN**. **U3P1** (for generator) and **U3P2** (for busbar).

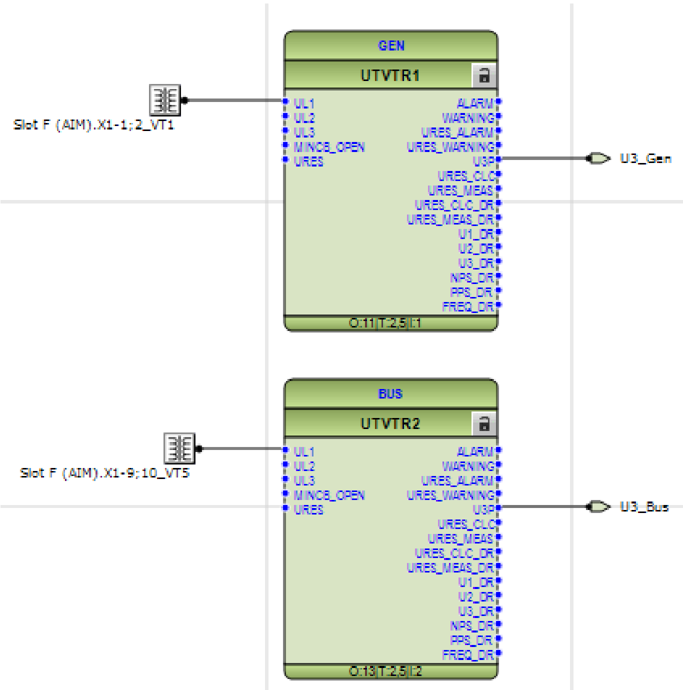

Figure 13. Configuring voltage measurements.

Next, ASGCSYN mandatory inputs and outputs are added. EXT_CHECK must be set TRUE so that the logic will be allowed to start synchronizing. ISO_A_CLOSE is set to TRUE to represent a disconnector which needs to be closed in synchronization. GCB_OPEN and GCB_CLOSE are needed from CBXCBR to know the CB position. DROOP_GOV and DROOP_AVR are set to TRUE for ASGCSYN, being able to participate in non-source breaker synchronizing.

`SYNC_OK` and `Close_CB` are given to circuit breaker control to close the circuit breaker when the system is in synchronization. `RAISE_U`, `LOWER_U`, `RAISE_F`, and `LOWER_F` are made as outputs that control AVR and governor.

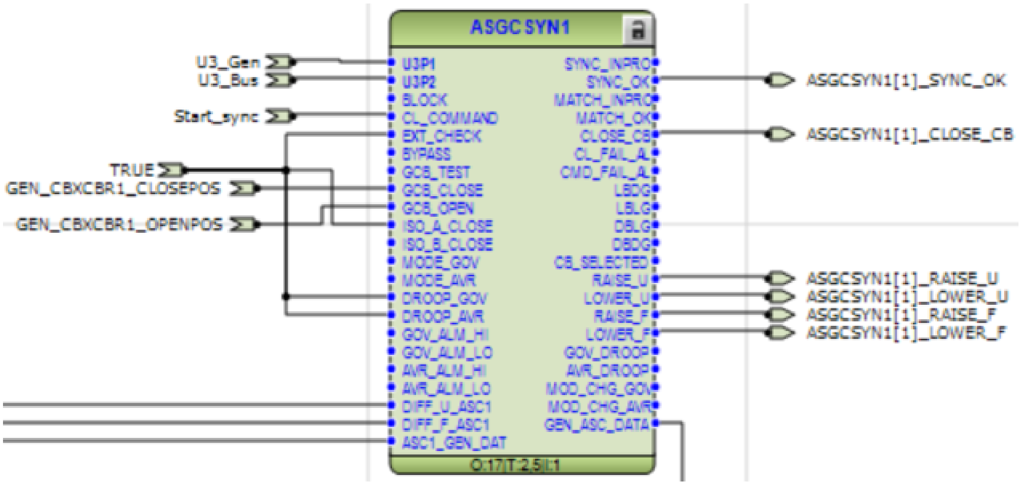

Figure 14. Added inputs and outputs to the ASGCSYN.

For CBXCBR to close the CB the `CLOSE_CB` and `SYNC_OK` must be connected to CBXCBR as seen in **Figure 15** and **Figure 16**.

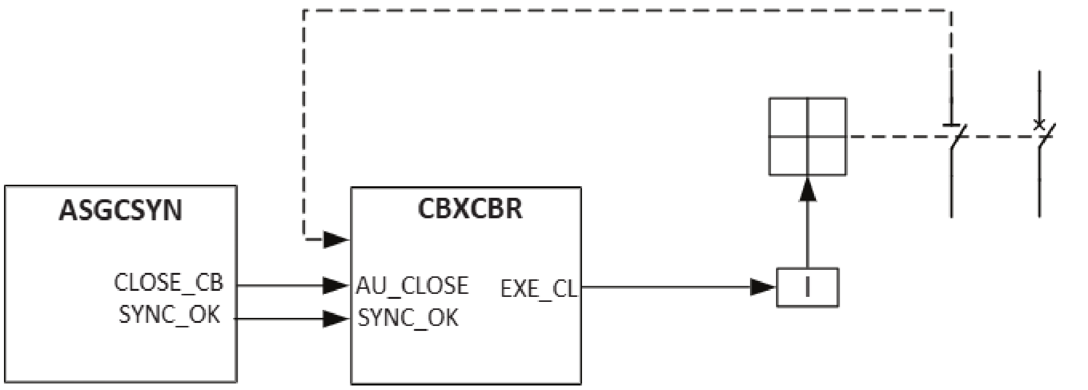

Figure 15. ASGCSYN and breaker connection.

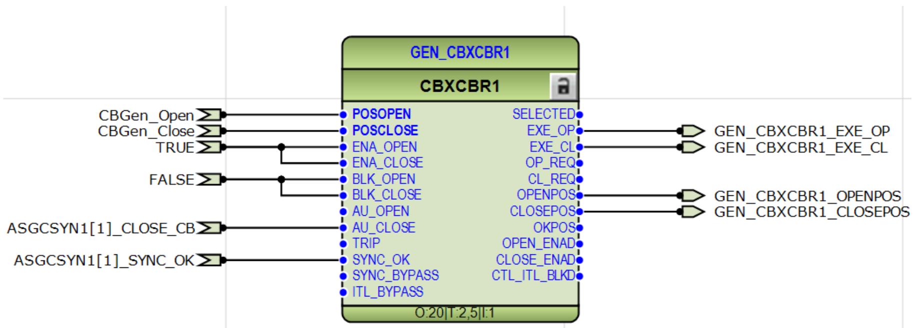

Figure 16. Generator relay CBXCBR after adding inputs and outputs.

5.1.2 Information about droop

ASGCSYN Central PMS (power management system) must be set to **YES** for the MODE_GOV and MODE_AVR to take inputs. If the PMS is set to **NO** governor and AVR mode is decided through DROOP_GOV and DROOP_AVR. For example, from above **Figure 14** both DROOP_GOV and DROOP_AVR are set to true which is totally correct if the actual physical signals are not available. For the matching of frequency and voltage, the governor or AVR mode must be 1 (Droop) or 2 (Fixed MW). Otherwise, the MOD_CHG_GOV or MOD_CHG_AVR output is used for the mode change request.

When the setting Central PMS present is set to YES and the Governor or AVR mode is not 1 (Droop) or 2 (Fixed MW), then the function sets MOD_CHG_GOV or MOD_CHG_AVR output to Droop or Fixed MW. Otherwise, the function sets MOD_CHG_GOV or MOD_CHG_AVR output to **No change**.

5.2 ASNSCSYN (non-source breaker)

As in generator relays the ASNSCSYN in the non-source breaker relay is not fully configured after the wizard has finished. See **Figure 17**.

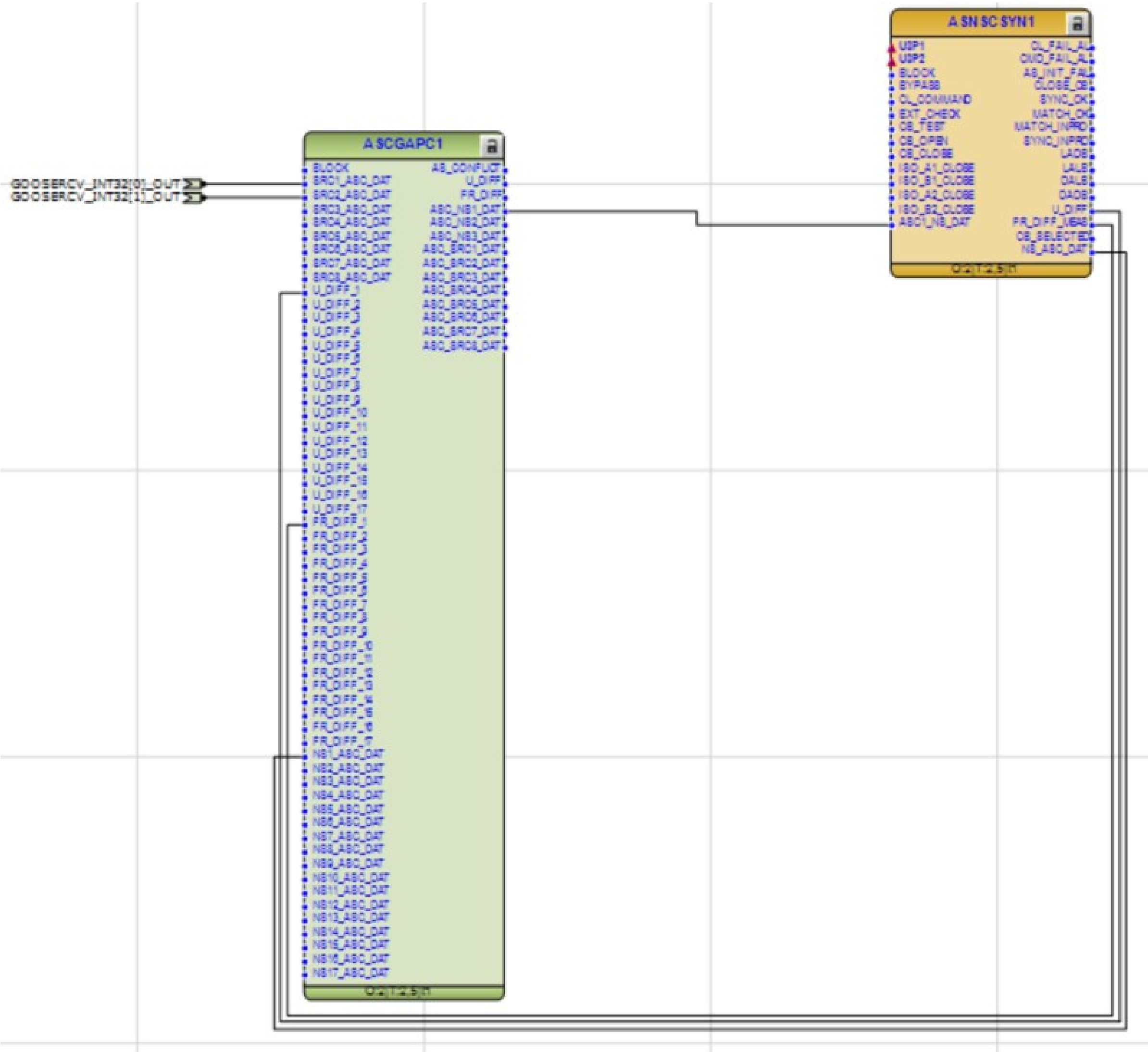

Figure 17. Non-source breaker missing inputs and outputs.

Figure 18 shows how busbar 1 and busbar 2 voltage measurements are made. The outputs from the measurements are connected to the ASNSCSYN U3P1 and U3P2.

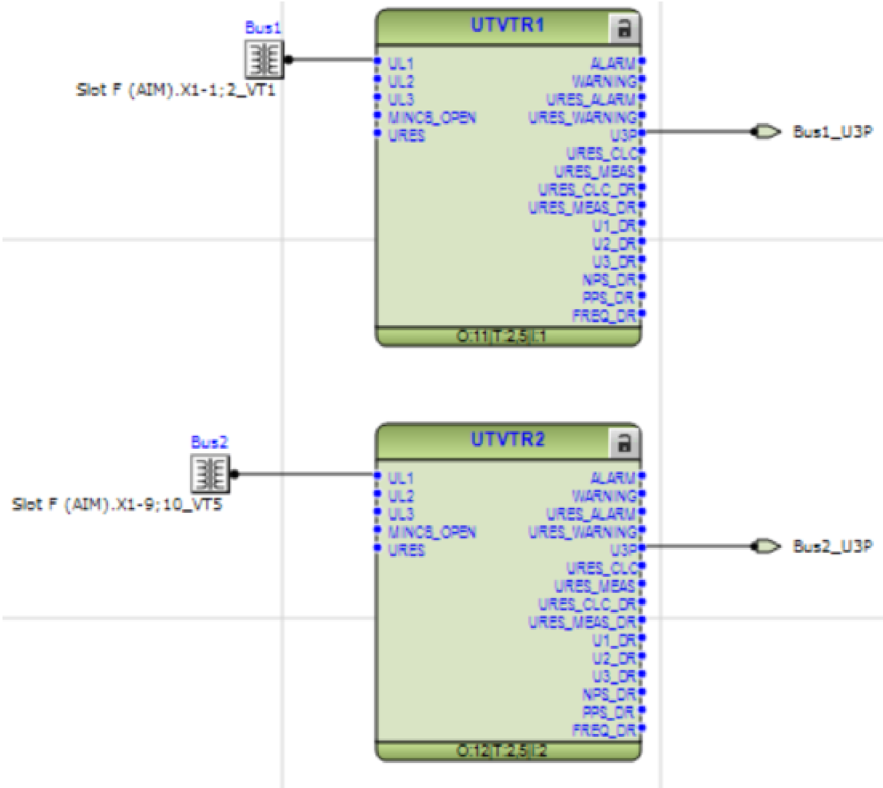

Figure 18. Voltage measurements for ASNSCSYN.

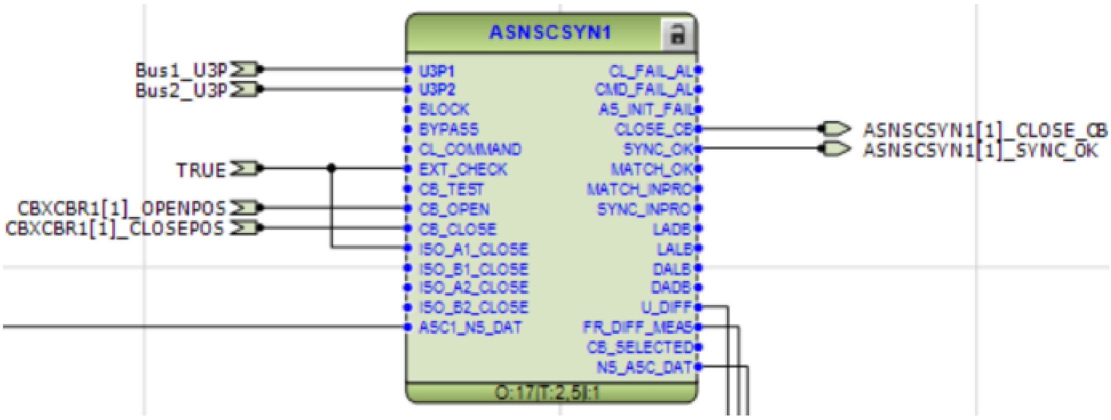

Figure 19. Adding inputs and outputs to ASNSCSYN.

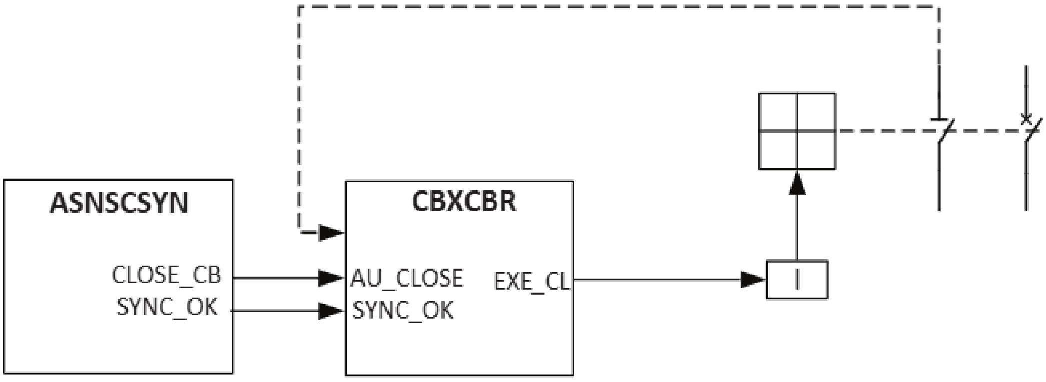

Figure 20. ASNSCSYN and breaker.

NOTE: ASNSCSYN `SYNC_OK` output must be connected to CBXCBR `SYNC_OK` input to allow breaker closing.

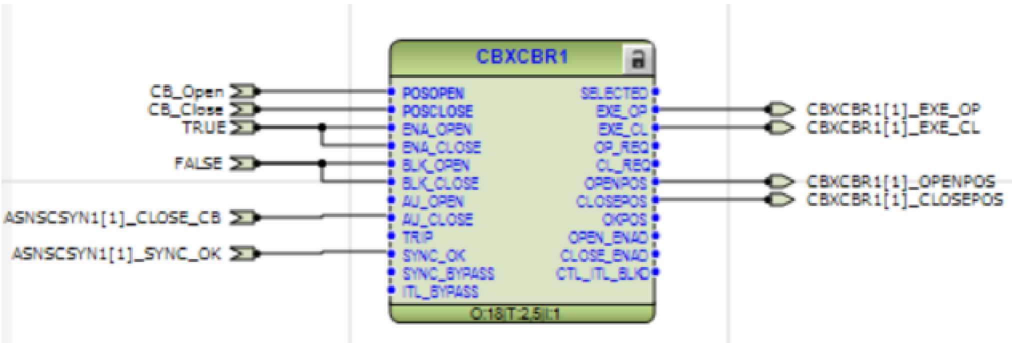

Figure 21. Adding inputs and outputs to CBXCBR in network breaker.

5.3 Configuring graphical display

You can add a graphical display to the relays HMI to control the circuit breaker and to start the autosynchronization from the HMI. **Figure 22** shows where the graphical display can be opened.

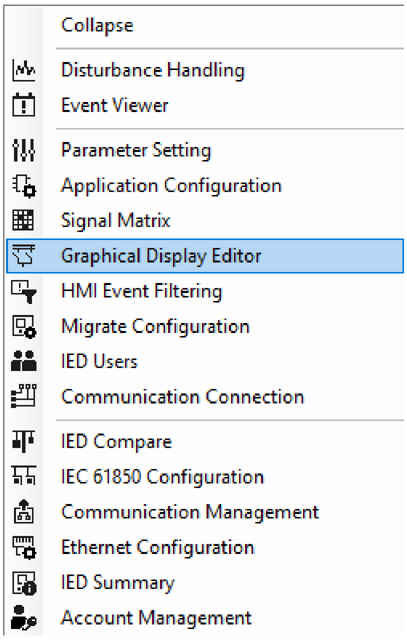

Figure 22. Graphical display editor tool.

To start configuring single line diagram (SLD) to HMI, the **SLD Editor** window must be opened in graphical display editor seen in **Figure 23**.

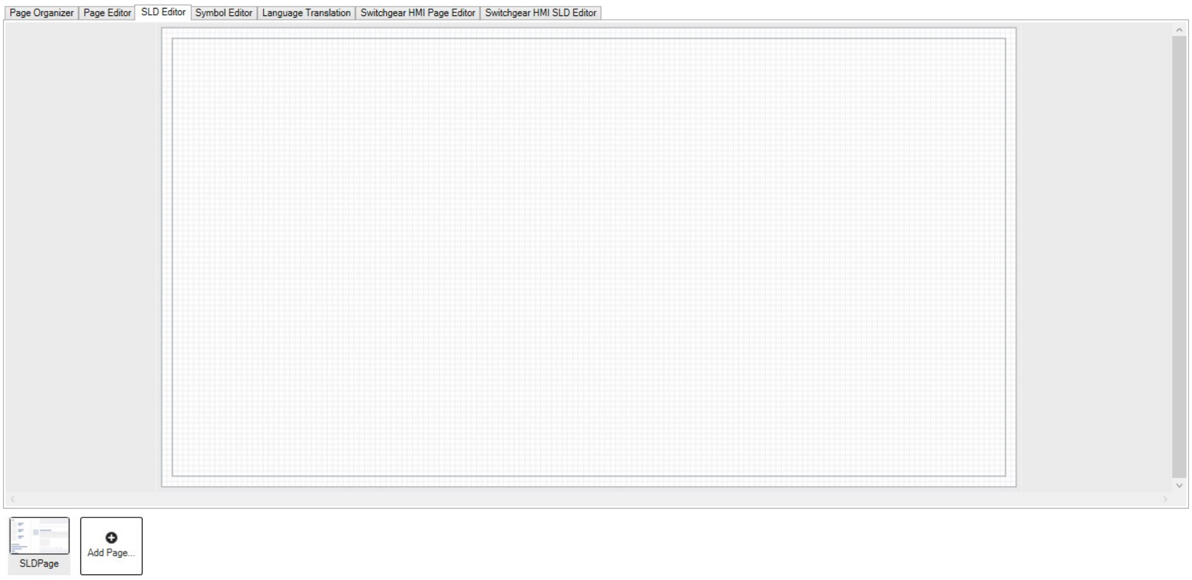

Figure 23. SLD editor window.

When adding circuit breaker to the SLD please note that in order to start the autosynchronization from the HMI the switching device must be `AS_source` as seen in **Figure 24**. As_non_source is meant for as it name implies to start non-source breaker autosynchronization.

NOTE: Synchronize oscilloscope functionality is built in to AS_source CB and AS_Non_Source CB and doesn't require further configuration.

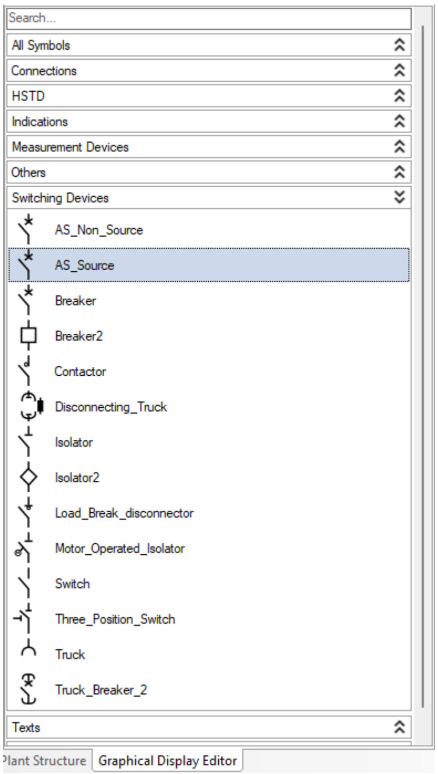

Figure 24. Symbol window.

AS_Source breaker's control must be set to the circuit breaker functions CBXCBR position as seen in **Figure 25**.

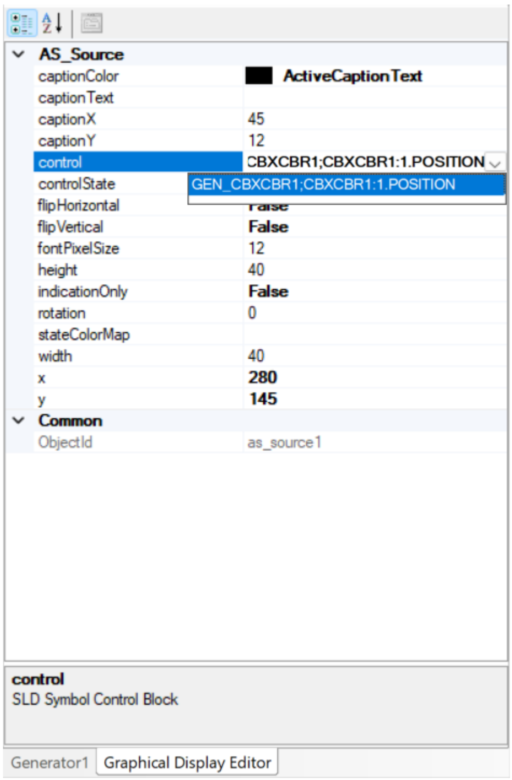

Figure 25. Setting AS_Source breakers control.

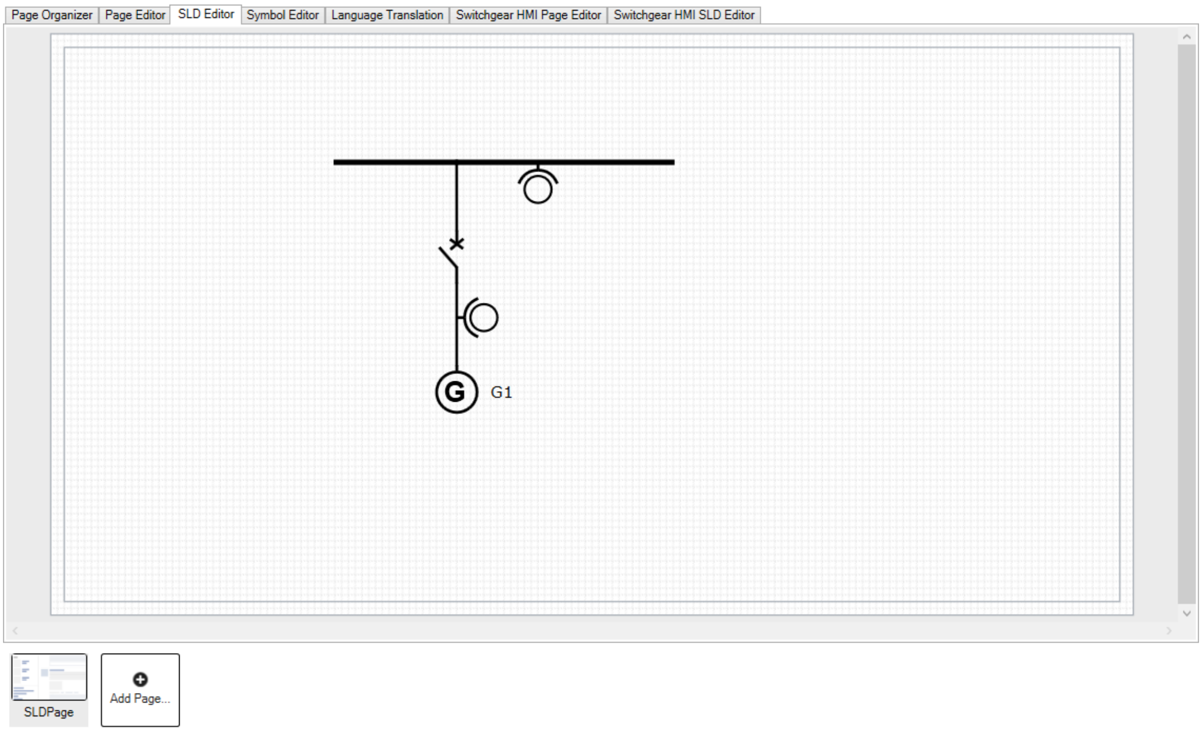

Figure 26. Ready graphical display.

To get the SLD to show in the HMI you have to add in to the Main Pages. To choose which window to put it, in this example Main view has been chosen as seen in **Figure 27**.

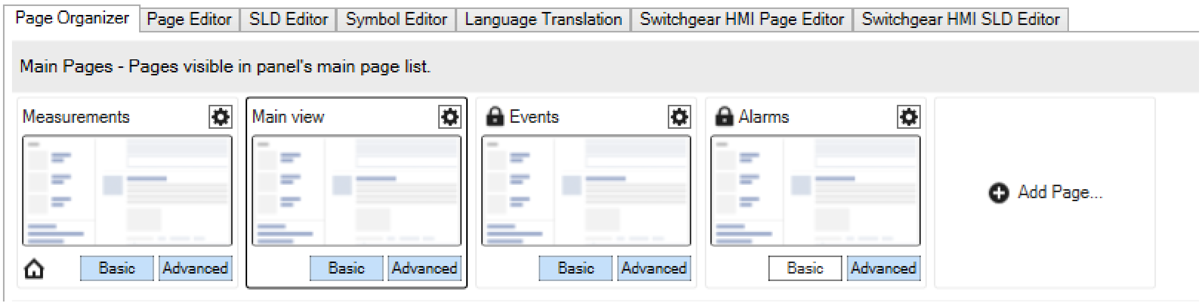

Figure 27. choosing a Main view window.

By choosing the left side of the Main view window you can choose which page is shown. This case we choose the page in which SLD view resides as seen in **Figure 28**.

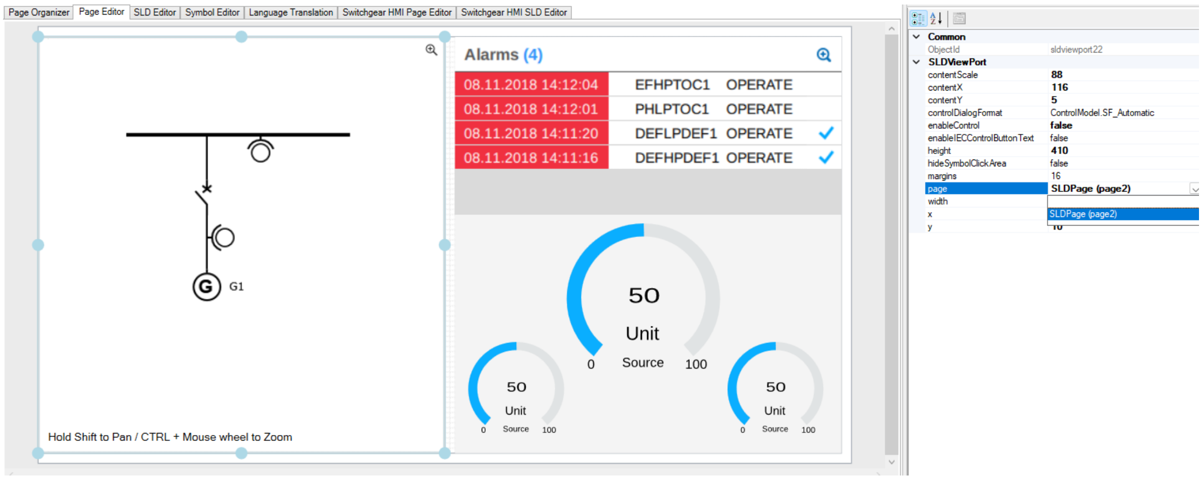

Figure 28. Adding the SLD page to the main window.

6 Verifying the configuration and GOOSE

When the configuration is ready it is advisable to check the relays communication between each other and to know what signals are necessary for the functions to operate.

Generator autosynchronizer can be started only when binary input status are as follows:

- EXT_CHECK = TRUE
- BLOCK = FALSE
- GCB_OPEN (The circuit breaker must be on the right position)

In **Table 1** we go all the necessary signals in detail.

Network autosynchronizer can be started only when binary input status and settings are as follows:

- EXT_CHECK = TRUE
- BLOCK = FALSE
- CB_OPEN = TRUE
- Local/Remote Mode = Local
- GCB_CLOSED (The Participant relay ASGCSYN) = TRUE
- ISO_A_CLOSE (The Participant relay ASGCSYN) = TRUE
- EXT_CHECK (The Participant relay ASGCSYN) = TRUE
- DROOP_GOV (The Participant relay ASGCSYN) = TRUE
- DROOP_AVR (The Participant relay ASGCSYN) = TRUE
- Local/Remote Mode = Remote (The participating relay)
- Relay autosync Mode = Automatic (The Participant relay)

In **Table 2** and **Table 3** we go all the necessary signals in detail.

6.1 ASGCSYN and ASNSCSYN signals status

What signals are needed in ASGCSYN that it works in generator breaker synchronization. **Table 1** and **Table 3** show the needed signals in different situations. **Setting Local/Remote must be Local.**

Table 1. Required input signals status for starting autosync ASGCSYN.

Signal	**True**	**False**
EXT_CHECK	**X**	
BLOCK		**X**
GCB_CLOSE		X
GCB_OPEN	**X**	

ISO_A1_CLOSE		X
ISO_A1_CLOSE		X
DROOP_GOV		X
DROOP_AVR		X
GOV_ALM_HI		X
GOV_ALM_LO	X	X
AVR_ALM_HI		X
AVR_ALM_LO	X	X

X defines the status of the signal. **Bolded signals are mandatory**.

The ASNSCSYN needs a tuning source to synchronize the busbars. In this case, the information of the generator that is selected is added to the **Table 2** and **Table 3**.

Table 2. Required input signals status for starting autosync ASNSCSYN.

Signal	**True**	**False**
EXT_CHECK	**X**	
BLOCK		**X**
CB_CLOSE		X
CB_OPEN	**X**	

X defines the status of the signal. **Bolded signals are mandatory**.

Relay that has the generator that is participating in tuning must be set to **`local/remote`** = **Remote**.

Table 3. Required input signals status from the participating ASGCSYN.

Signal	**True**	**False**
EXT_CHECK	**X**	
GCB_CLOSED	**X**	

ISO_A_CLOSE (in ASGCSYN, as the tuning source)	**X**	
DROOP_GOV (in ASGCSYN, as the tuning source)	**X**	
DROOP_AVR (in ASGCSYN, as the tuning source)	**X**	

X defines the status of the signal. **Bolded signals are mandatory**.

6.2 GOOSE communication codes

Goose Communication transmits packages, each of which is assigned a unique number. Every signal combination corresponds to a specific set of numbers, which are detailed in Appendix 2. There, you will find a comprehensive list of all possible combinations and their associated numerical values. This table is useful for troubleshooting, in case the autosynchronization is not working as expected.

6.3 Testing GOOSE communication

To verify the communication on the relays you must check each relays receiving and sending GOOSE signals. See **Figure 29**.

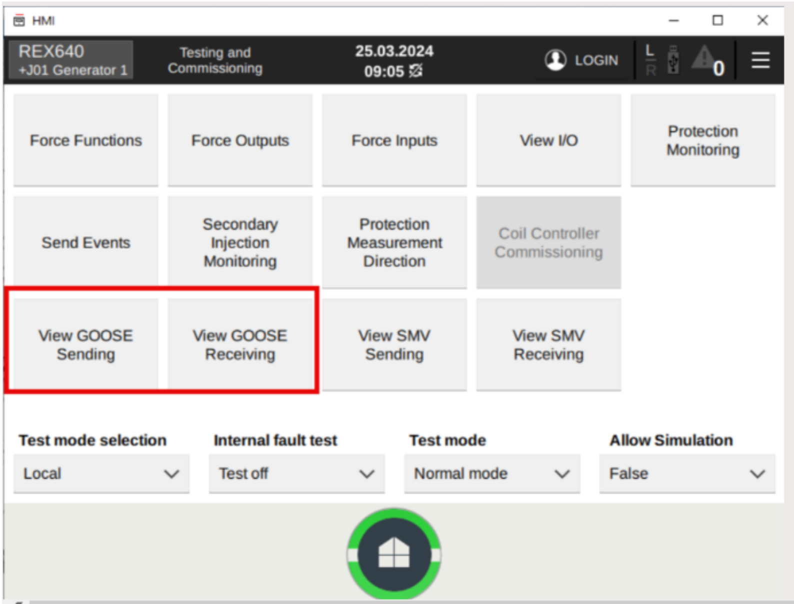

Figure 29. Where to find the goose communications.

Below are the GOOSE signals data for autosynchronization. **Table 4** shows the meaning of each data signal.

Table 4 GOOSE signal data.

LD0.ASCGAPC1.Dif.VClc.mag.f	Voltage difference calculation
LD0.ASCGAPC1.Dif.VClc.q	Quality of goose signal
LD0.ASCGAPC1.DifHzClc.mag.f	Frequency difference calculation
LD0.ASCGAPC1.DifHzClc.q	Quality of goose signal
LD0.ASCGAPC1.DatOutSrc1.stVal	Input data from source number 1
LD0.ASCGAPC1.DatOutSrc1.q	Quality of goose signal
LD0.ASCGAPC1.DatOutSrc2.stVal	Input data from source number 2
LD0.ASCGAPC1.DatOutSrc2.q	Quality of goose signal

Figure 30 shows how Generator 1 relay (participating relay) sends signals to Network breaker relay. The signal numbers change depending on the status of the ASGCSYN. The different

combinations are shown in Appendix 2. It is important to check that the value shown in **Figure 30** in the red box is correct. See Appendix 2.

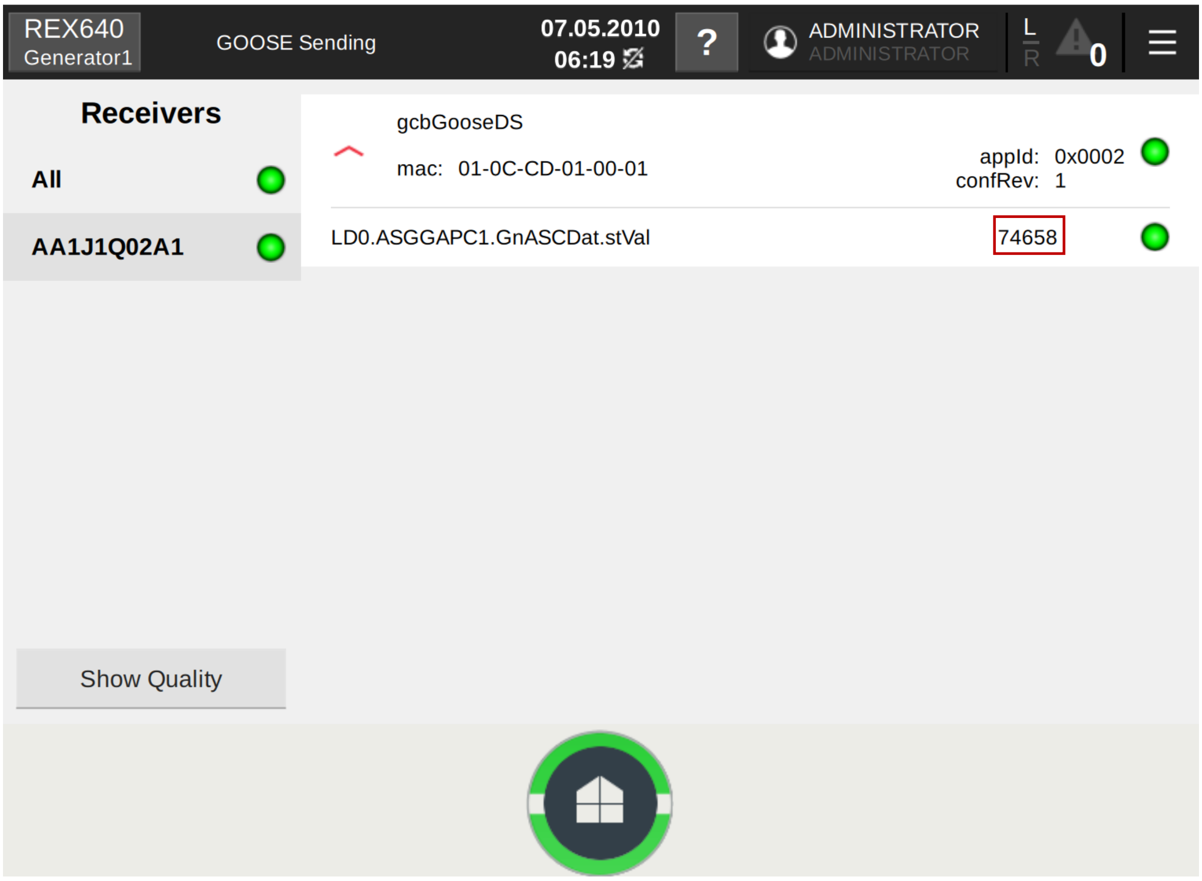

Figure 30. Goose sending.

Figure 31. shows what communication generator 1 relay receives from network breaker relay.

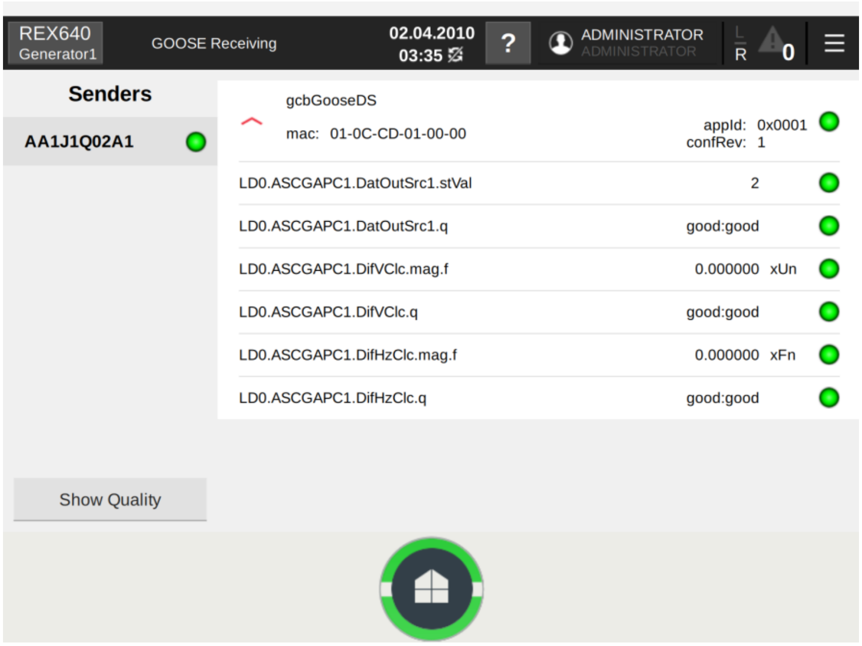

Figure 31. Goose receiving

7 Testing with Omicron using Synchronizer module

First, we will go through the parameters given to ASGCSYN and ASNSCSYN. Then, we will start testing ASGCSYN and ASNSCSYN.

7.1 Relay parameters

The testing parameters used in the example are in ASGCSYN as follows:

- **Volt pulse Min Dur** = 500 ms (The lengths of generated pulses, Variable interval)
- **Freq pulse off Intv** = 10000 ms (The lengths of generated pulses, Variable pulse)
- **Freq pulse Min Dur** = 500 ms (The lengths of generated pulses, Variable interval)

AUTOSYNCG				
Operation	on			
Synchrocheck mode	Asynchronous			
Dead voltage value	0,20	xUn	0,10	0,80
Live voltage value	0,50	xUn	0,20	1,00
Maximum voltage	1,20	xUn	0,50	1,30
Minimum voltage	0,80	xUn	0,50	0,95
Voltage match mode	Variable Pulse			
Frequency match mode	Variable Pulse			
Minimum Syn time	0	ms	0	60000
Maximum Syn time	60000	ms	100	6000000
Energizing time	100	ms	100	60000
Central PMS present	No			
Volt pulse off Intv	2000	ms	1000	20000
Volt pulse Min Dur	**500**	ms	50	2000
Freq pulse off Intv	**10000**	ms	1000	120000
Freq pulse Min Dur	**500**	ms	50	2000
Auto Syn mode	Automatic synchronising m			

Figure 32. Given test parameters.

Next is to give deviations and differences of voltage, frequency and phase. Synchronization direction is also given.

- +/-3 % **voltage deviation** (How much the voltage can deviate between the two synchronizing points)
- +/-4 % **frequency deviation** (How much the frequency can deviate between the two synchronizing points)
- +/-5-degree **phase difference** (How much the voltage can deviate between the two synchronizing points)
- Change **Synchronization Dir** to **always over synchronous**. This way we make sure that generator feeds active power when CB is closed.

settingGroup 1				
Live dead mode	Off			
Freq Diff Ov Synch	0,040	xFn	0,000	0,060
Freq Diff sub Synch	0,040	xFn	0,000	0,060
Coarse Freq Diff Ov	0,040	xFn	0,000	0,060
Coarse Freq Diff sub	0,040	xFn	0,000	0,060
Voltage Diff Ov Ex	0,03	xUn	0,00	0,40
Voltage Diff Un Ex	0,03	xUn	0,00	0,40
Coarse Volt Diff Ov	0,03	xUn	0,00	0,40
Coarse Volt Diff Un	0,03	xUn	0,00	0,40
Angle Diff positive	5	deg	5	90
Angle Diff negative	5	deg	5	90
Volt rate of change	0,003	xUn/s	0,001	0,050
Freq rate of change	0,002	xFn/s	0,001	0,050
Phase shift	0	deg	-180	180
Closing time of CB	60	ms	40	250
Multiple command	Off			
Synchronization Dir	Always over synchronous			
Voltage offset	0,000	xUn	-0,100	0,100
Frequency offset	0,000	xFn	-0,010	0,010

Figure 33. Given test parameters.

NOTE: To close the circuit breaker (CB), the frequency difference must be at least 1/3 of the frequency difference setting. For example, in a 50 Hz system with a frequency difference setting of 0.04, you need a frequency difference of 1/3 of 0.04, which equals 0.0133 xFn. Therefore, the minimum frequency difference required to close the CB is 50 x 0.0133 = 0.67 Hz. In other words, the starting range for frequency matching is from 48 Hz to 49.33 Hz.

Figure 34 shows how source and tuning source are selected. Generator 2 is selected as source 2 selected and tuning source 2.

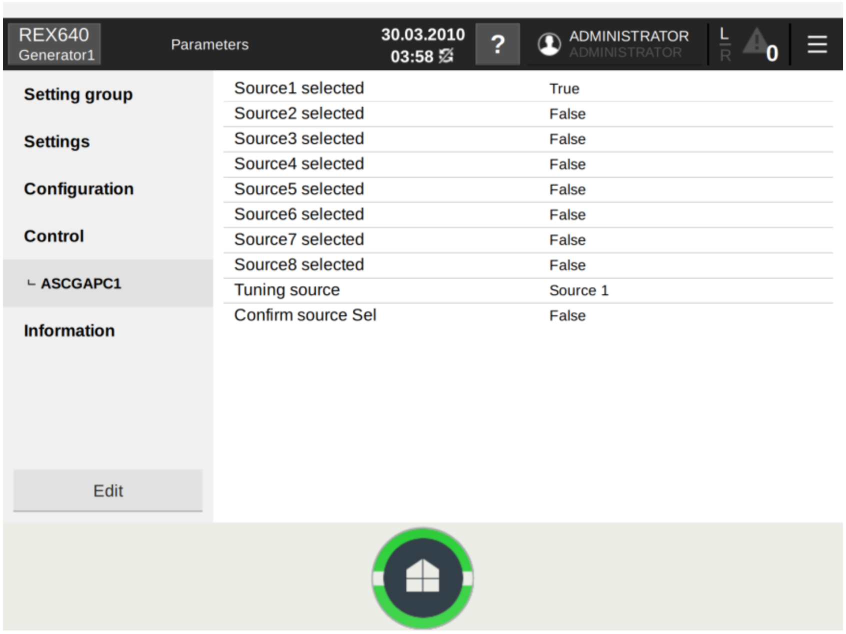

Figure 34. Source and tuning source selection.

Group / Parameter Name	IED Value	PC Value	Unit	Min	Max
ASNSCSYN1: 1					
AUTOSYNC(1)					
Operation		on			
Synchrocheck mode		Asynchronous			
Dead bus voltage		0,2	xUn	0,1	0,8
Live bus voltage		0,5	xUn	0,2	1,0
Max energizing V		1,05	xUn	0,50	1,30
Phase shift		0	deg	-180	180
Minimum Syn time		0	ms	0	60000
Maximum Syn time		60000	ms	100	6000000
Energizing time		100	ms	100	60000
Closing time of CB		60	ms	40	250
Auto Syn mode		Automatic synchronising m			

7.2 Testing ASGCSYN

In this example case the relays are made to use only one phase voltage for simplicity reasons seen in **Figure 35**.

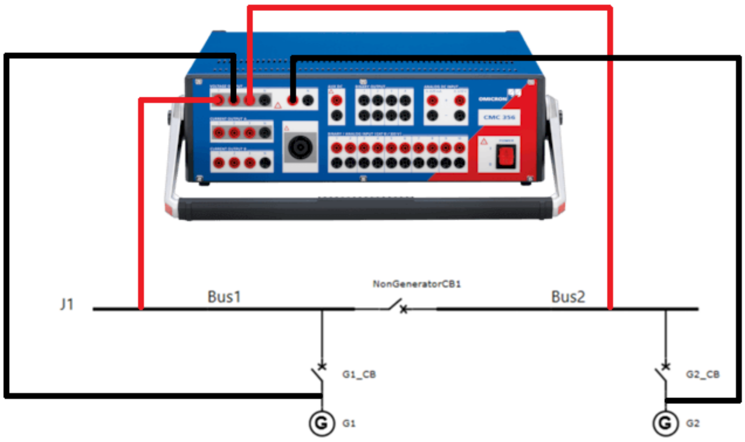

Figure 35. Illustration of Omicron voltage outputs.

Following figure shows Omicron binary input connection.

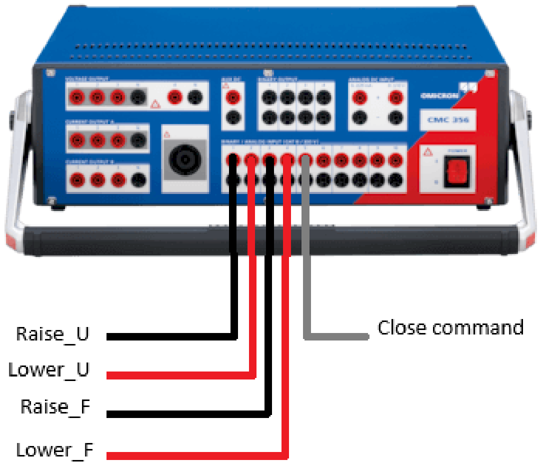

Figure 36. Illustration of Omicron inputs.

Following table shows the used Omicron signal list in this test setup.

Table 5. Omicron signal list.

Voltage output	**Binary inputs**
1, 2, 3, 4, N	1,2,3,4,5
1 = Voltage of bus 1 2 = Voltage of generator 1 3 = Voltage of bus 2 4 = Voltage of generator 2	1 = Raise_U 2 = Lower_U 3 = Raise_F 4 = Lower_F 5 = CB_Closed position

In addition to Omicron the circuit breakers must be simulated somehow. Appendix 1 gives a guideline on how to build simple circuit breaker simulator if such is not available.

Figure 37 illustrates how the circuit breaker simulator position signals are connected to REX640 (seen in the left-hand side) and how REX640 gives raise and lower commands to Omicron (seen in the right-hand side).

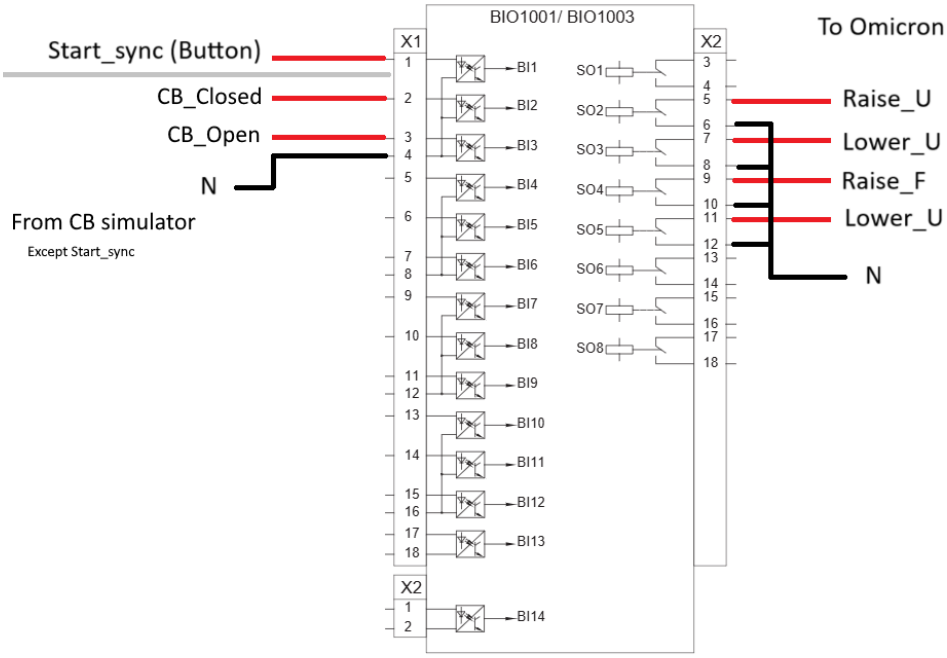

Figure 37. Inputs from circuit breaker simulator and outputs to Omicron.

Omicron voltage outputs are connected to REX640 as shown in **Figure 38**.

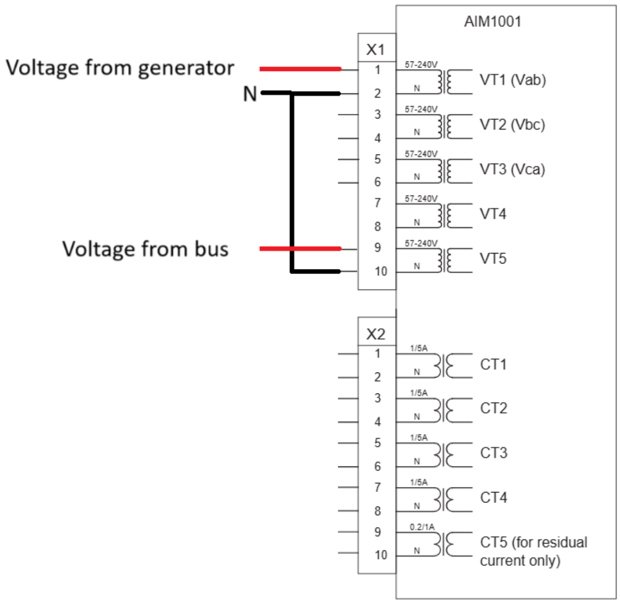

Figure 38. Omicron voltage output connection to relay.

REX640 gets is auxiliary power from external power supply, REX640 SO1 and SO2 (signal output) are used as closing and opening command to the circuit breaker.

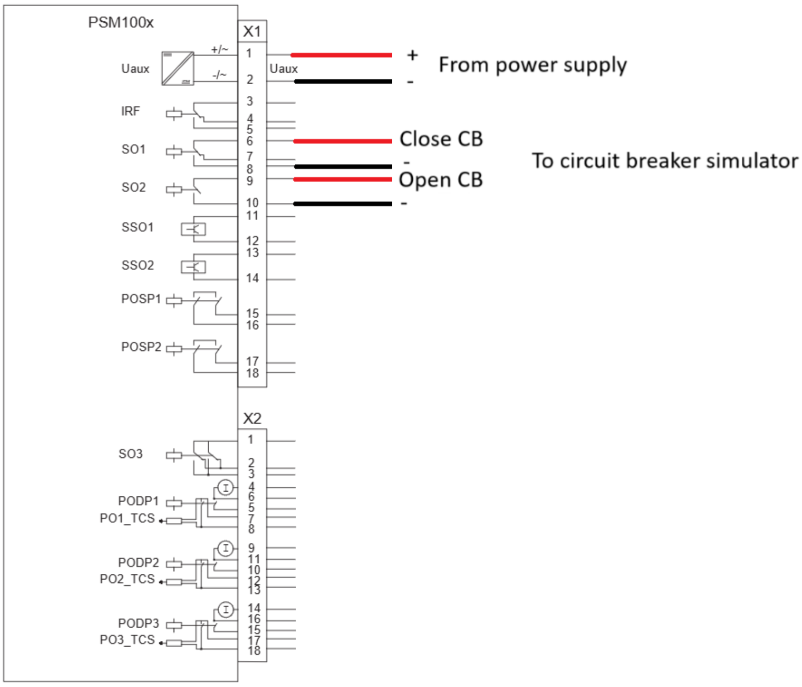

Figure 39**.** PSM auxiliary voltage and outputs.

We will use synchronizer module for testing the relay autosynchronizer configuration, see **Figure 40**.

Figure 40. Omicron module to be used in this technical note.

Appendix 3 shows how QuickCMC module can be used.

Figure 41 shows the view when opening the synchronizer module. In the view you can see system 1 and system 2. System 1 is used to give the busbar its voltage and frequency. System 2 is used to give the generator its voltage and frequency, and the difference to the wanted values where the synchronization is started.

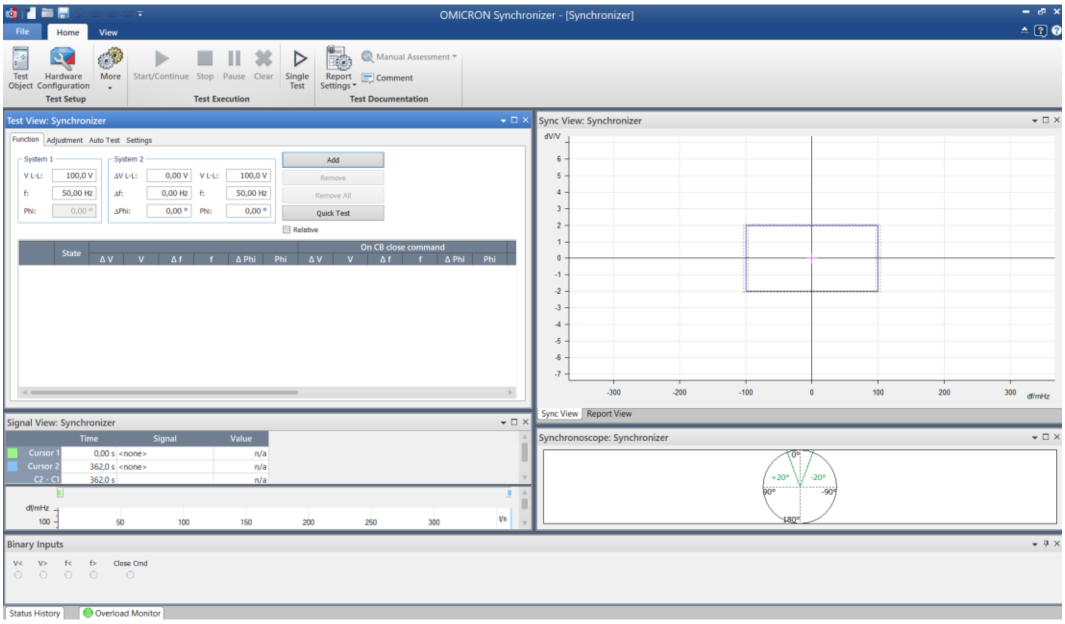

Figure 41. Omicron Synchronizer module view.

Figure 42 shows the analog inputs to Omicron. Only the four voltages are set to being used.

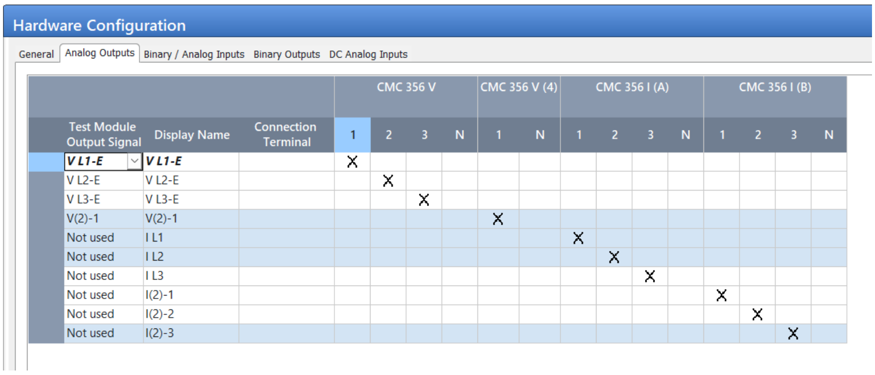

Figure 42. Omicron analog outputs.

Figure 43 shows the Binary/analog inputs to the Omicron, where the relay gives raise and lower commands to frequency and voltage.

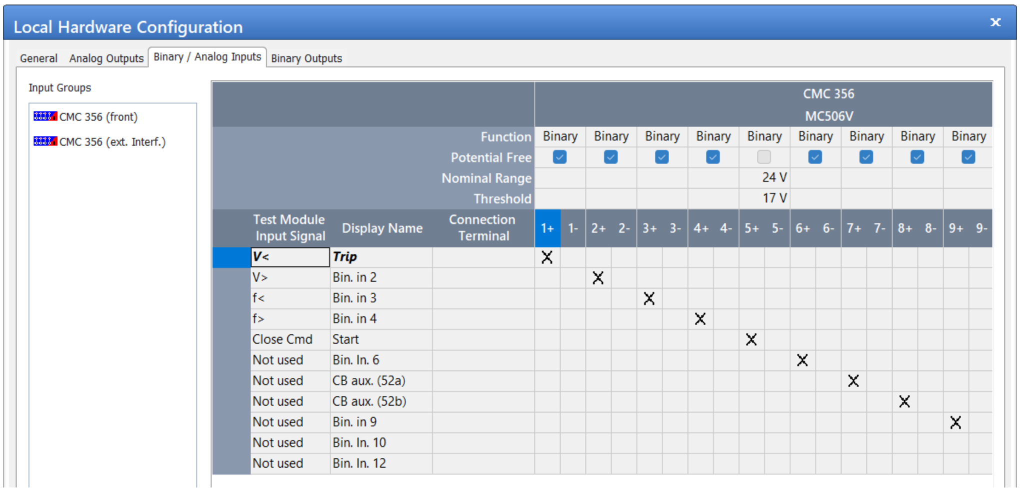

Figure 43. Omicron binary inputs.

Figure 44 shows adjustment window, in system 2 which the voltage, frequency and phase angle can be given to the generator in the beginning situation before synchronization. With the Add button a test parameter is created, and the test can be done following those parameters. You can add different situations of synchronization, but the problem is that it does those tests back-to-back.

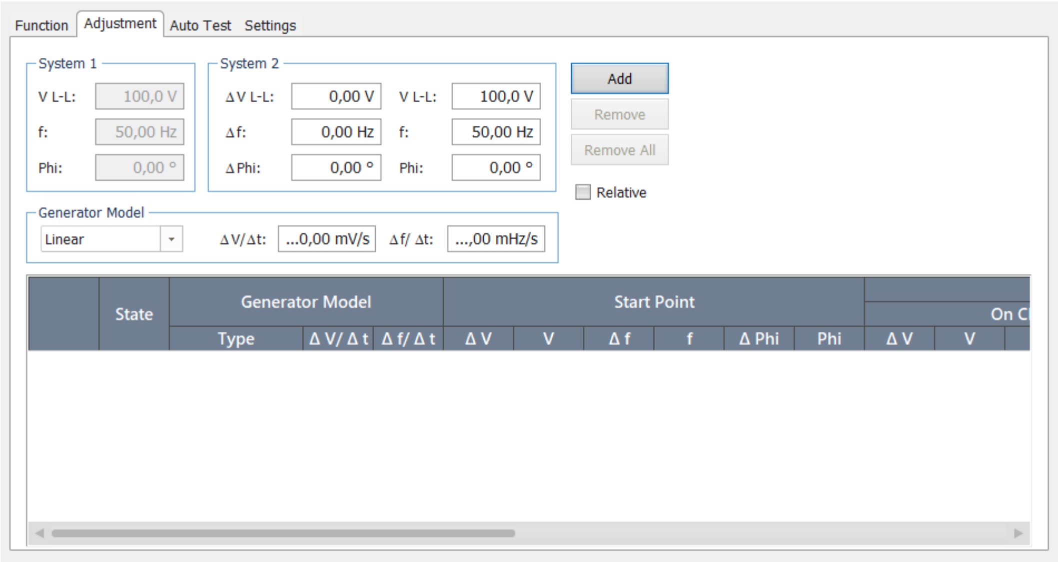

Figure 44. Synchronizer adjustment window.

1. V L-L = Phase to phase voltage

2. ΔV L-L = Phase to phase voltage difference, Δf = Frequency difference, ΔPhi = Phase angle difference

Figure 45 shows a sync view whereby clicking the field you can change the starting values of the generator and see the wanted synchronization areas in blue. Left-hand side area is under synchronous and right-hand side area is over synchronous.

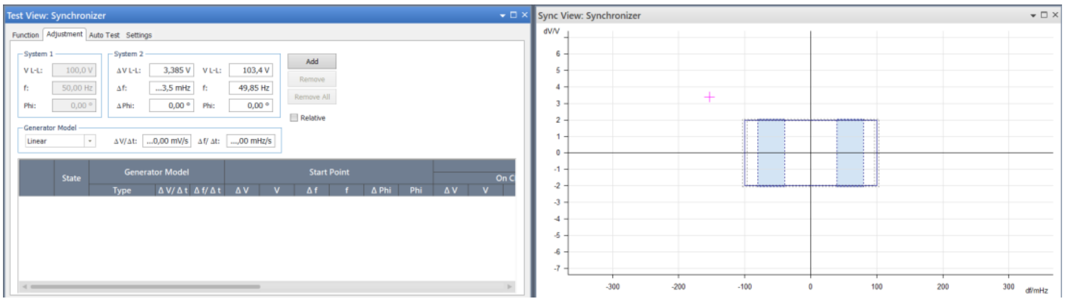

Figure 45. Sync view.

Figure 46 shows how autosynchronizer starts to seek the given over synchronous area on the right-hand side of the view.

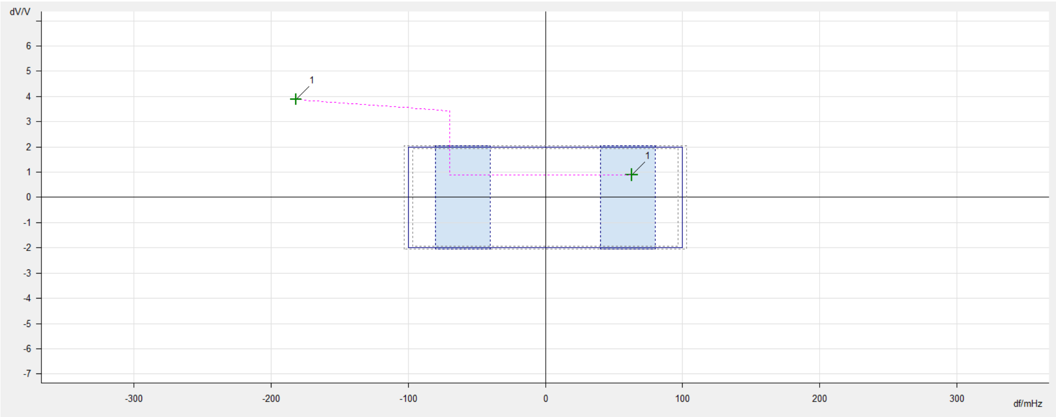

Figure 46. Relay synchronized Sync View.

Figure 47 Shows the closing time of the circuit breaker and the actual closing time of the circuit breaker. The generator makes it that the synchronization happens from negative phase angle side and such that it will be over synchronous when the CB closed due to CB closing time.

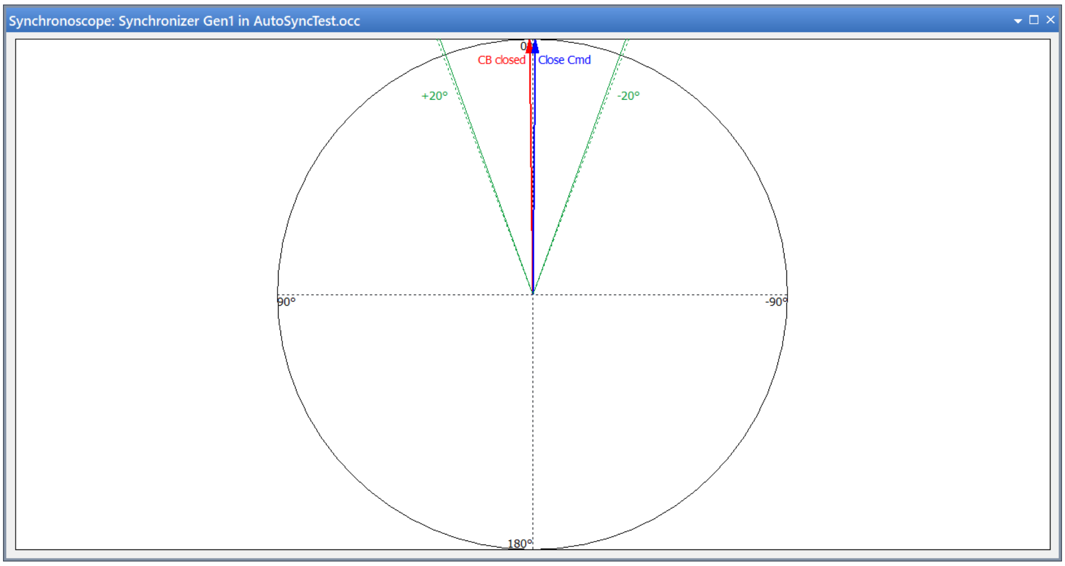

Figure 47. Synchroscope view of Omicron.

Figure 48 shows the starting point, the end point, and the point when CB is closed voltage, frequency, and phase angle. Synchronizing time is also shown which varies on in which point the synchronization is started.

Adjustment Test (Deltas)

Start point			EP On CB Close Command EP On CB Close				Synchro Time	Gen. Model	Result
ΔV	Δf	ΔPhi	ΔV	Δf	ΔPhi	tΔPhi=0			
3,876 V	-0,182 Hz	0,000 °	0,891 V 0,891 V	0,063 Hz 0,063 Hz	-0,838 ° 0,525 °	0,037 s 0,023 s	12,597 s	dV/dt= 0.8 V/s df/dt= 0.2 Hz/s	Passed

(EP=End point)

Adjustment Test (Abs. Value)

Start point			EP On CB Close Command EP On CB Close			Synchro Time	Gen. Model	Result
V	f	Phi	V	f	Phi			
103,876 V	49,818 Hz	0,000 °	100,891 V 100,891 V	50,063 Hz 50,063 Hz	-54,838 ° -53,475 °	12,597 s	dV/dt= 0.8 V/s df/dt= 0.2 Hz/s	Passed

(EP=End point)

Figure 48. Report view of the synchronization.

7.3 Testing ASNSCSYN

When starting to synchronize an asynchronous situation where bus A and bus B are not in synchronization, the selected tuning source must have its circuit breaker closed and feed either bus. The relay must be set `remote mode` to be able to participate in the tuning. **Figure 49** shows the participating window when trying to synchronize non-source circuit breaker when both buses are live.

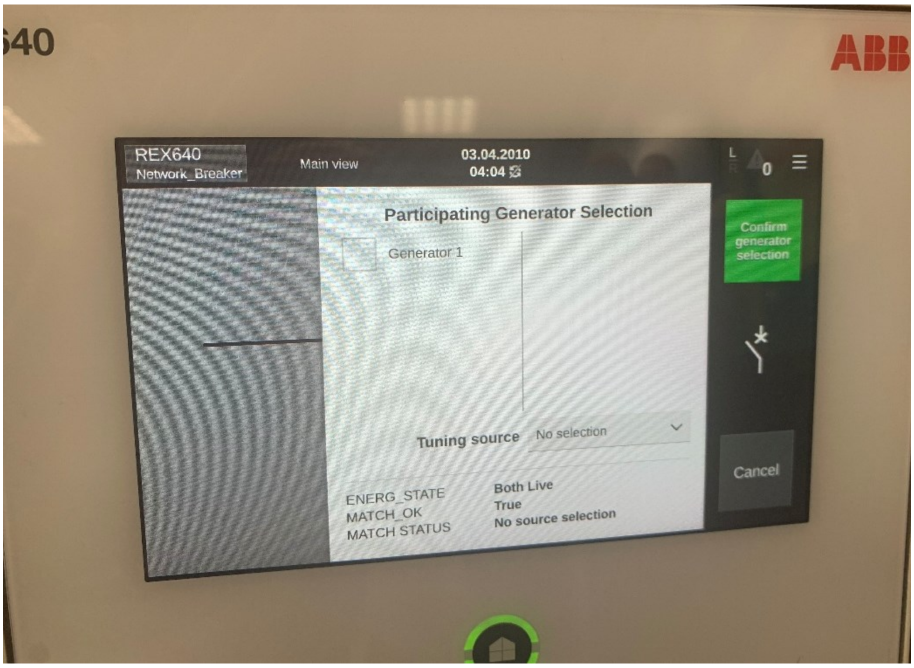

Figure 49. Selecting participating generator.

NOTE: ISO_A_Close has to be TRUE in the generators ASGCSYN function, to be able to participate. Droop_GOV and Droop_AVR need be set true if the Central power management system (PMS) setting is set to **NO**.

Figure 50 shows the available participating generators, now only generator 1 has it's CB closed and remote mode. Generator 2 has remote mode **ON,** but the CB is not closed.

Figure 50. Participating generator.

Figure 51 shows selecting tuning source after the participating generator has been chosen. It must be chosen also here to make sure which generator does the tuning.

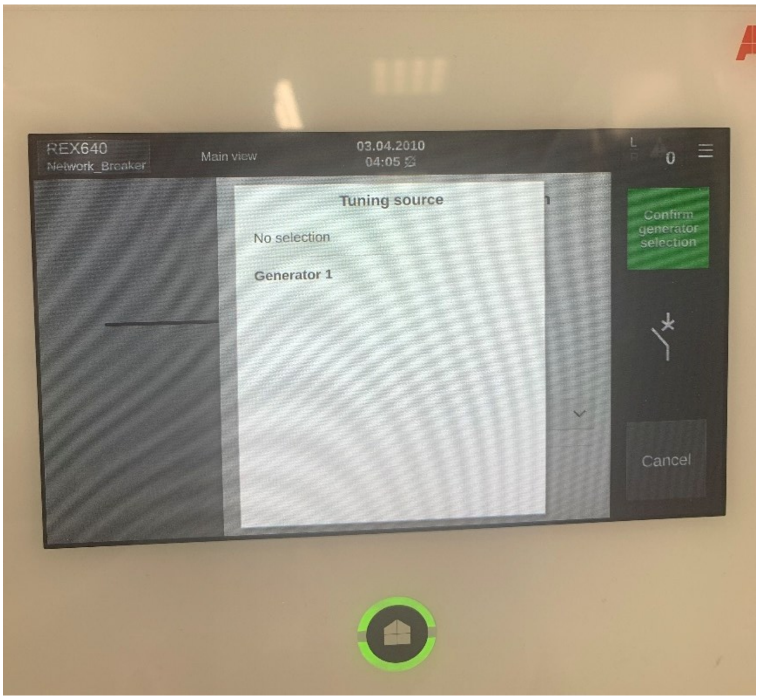

Figure 51. Selecting tuning source.

Figure 52 Shows when both generators are selectable as sources for tuning.

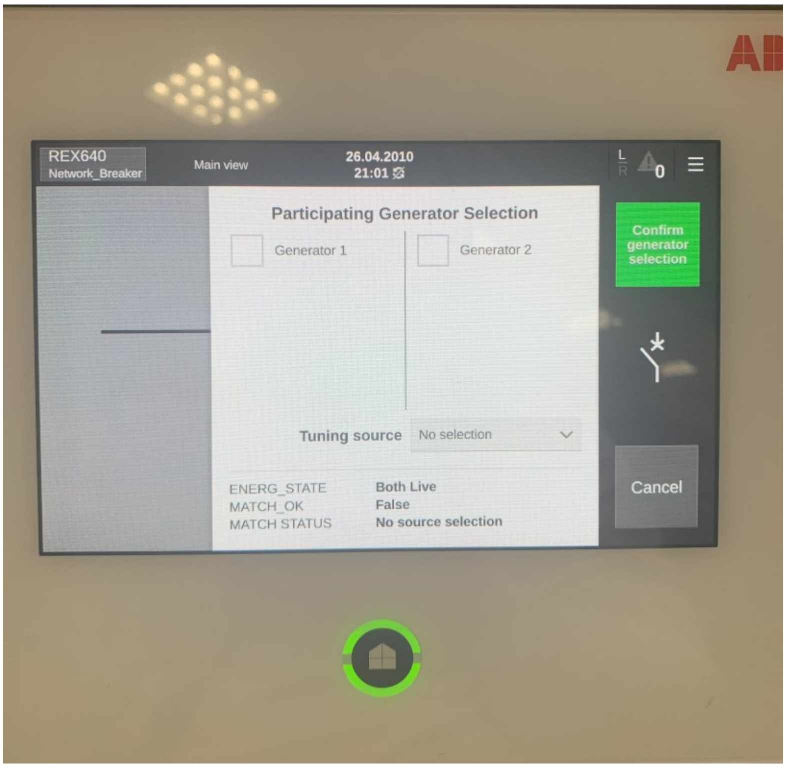

Figure 52. Both generators in selection.

Figure 53 shows the synchronization window when the tuning source has been selected. It shows that matching is in process, if the tuning source hasn't been selected then match status would read: "tuning source not selected".

Figure 53. Matching in process.

Appendix 1 Circuit breaker simulator

Figure 54 shows how to make a simple CB simulator using 3 auxiliary relays.

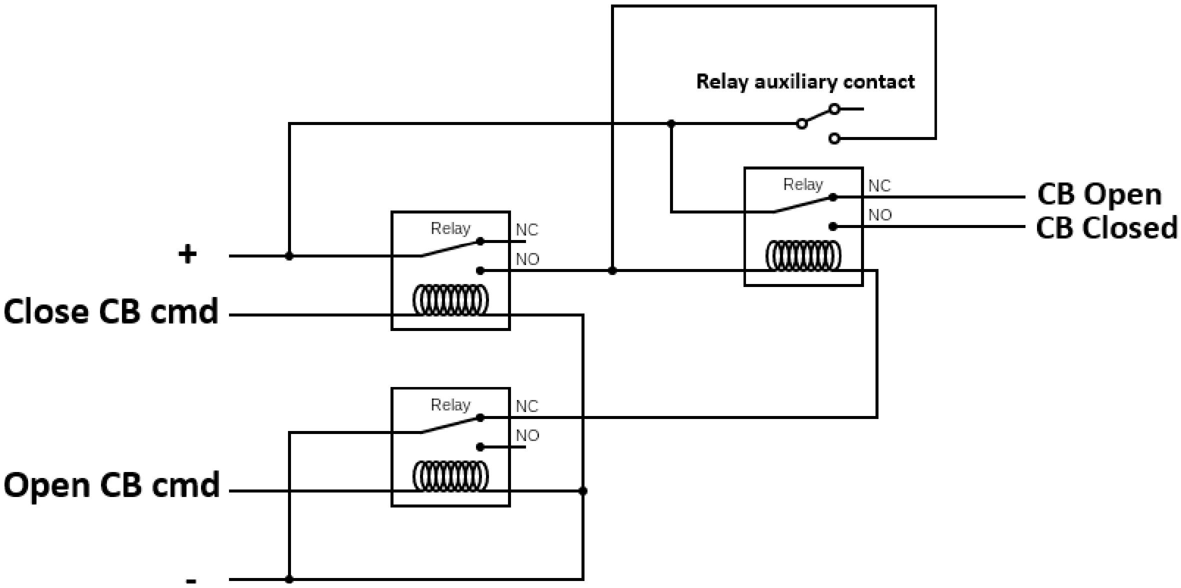

Figure 54 CB simulator with auxiliary relays.

Figure 55 shows how CB simulation can be done in relay configuration. The TONGAPC is used for setting CB closing and opening times.

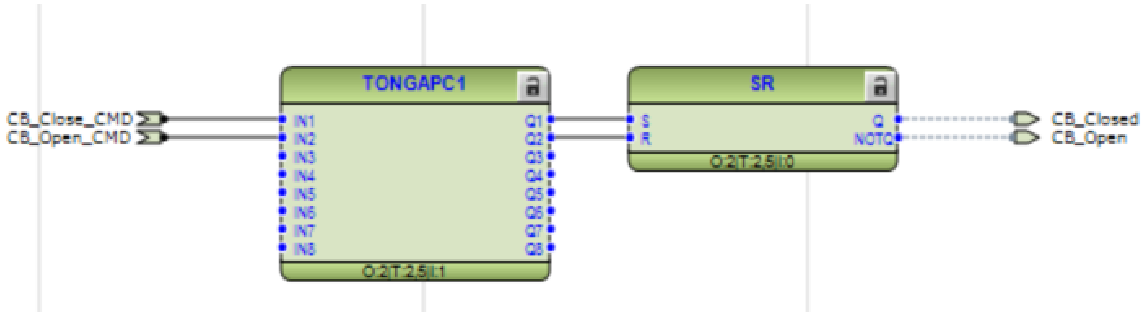

Figure 55 CB in relay configuration.

Appendix 2 List of GOOSE codes

EXT_CHECK	ISO_A_CLOSE	ISO_B_CLOSE	Droop_AVR	Droop_GOV	GOV_ALM_LO	GOV_ALM_HI	AVR_ALM_LO	AVR_ALM_HI	Local	Remote	CB_Open	CB_Closed	Value
									X		X		416
X									X		X		416
(X)	X								X		X		418
(X)		X							X		X		420
(X)			X						X		X		74144
(X)				X					X		X		928
(X)					(X)	(X)	(X)	(X)	X		X		131488
(X)	X	X							X		X		422
(X)	X	X			(X)	(X)	(X)	(X)	X		X		131494
(X)	X		X						X		X		74146
(X)	X		X		(X)	(X)	(X)	(X)	X		X		20518
(X)	X			X					X		X		930
(X)	X			X	(X)	(X)	(X)	(X)	X		X		132002
(X)	X				(X)	(X)	(X)	(X)	X		X		131490
(X)	X	X	X	X					X		X		74662
(X)	X	X	X	X	(X)	(X)	(X)	(X)	X		X		205734

(X)	X	X	X						X		X		74150
(X)	X	X	X		(X)	(X)	(X)	(X)	X		X		205222
(X)	X	X		X					X		X		934
(X)	X	X		X	(X)	(X)	(X)	(X)	X		X		132006
(X)	X		X	X					X		X		74658
(X)	X		X	X	(X)	(X)	(X)	(X)	X		X		205730
(X)		X	X						X		X		74148
(X)		X	X		(X)	(X)	(X)	(X)	X		X		205220
(X)		X		X					X		X		932
(X)		X		X	(X)	(X)	(X)	(X)	X		X		132004
(X)		X	X	X					X		X		74660
(X)		X	X	X	(X)	(X)	(X)	(X)	X		X		205732
(X)		X			(X)	(X)	(X)	(X)	X		X		131492
(X)			X	X					X		X		74656
(X)			X		(X)	(X)	(X)	(X)	X		X		205216
(X)				X	(X)	(X)	(X)	(X)	X		X		132000

									X			X	417
X									X			X	417
(X)	X								X			X	419
(X)		X							X			X	421
(X)			X						X			X	7414 5
(X)				X					X			X	929
(X)					(X)	(X)	(X)	(X)	X			X	131 489
(X)	X	X							X			X	423
(X)	X	X			(X)	(X)	(X)	(X)	X			X	131 495
(X)	X		X						X			X	7414 7
(X)	X		X		(X)	(X)	(X)	(X)	X			X	2051 9
(X)	X			X					X			X	931
(X)	X			X	(X)	(X)	(X)	(X)	X			X	132 003
(X)	X				(X)	(X)	(X)	(X)	X			X	131 491
(X)	X	X	X	X					X			X	7466 3
(X)	X	X	X	X	(X)	(X)	(X)	(X)	X			X	205 735

(X)	X	X	X						X			X	74151
(X)	X	X	X		(X)	(X)	(X)	(X)	X			X	205223

(X)	X	X		X					X			X	935
(X)	X	X		X	(X)	(X)	(X)	(X)	X			X	132007
(X)	X		X	X					X			X	74659
(X)	X		X	X	(X)	(X)	(X)	(X)	X			X	205731
(X)		X	X						X			X	74149
(X)		X	X		(X)	(X)	(X)	(X)	X			X	205221
(X)		X		X					X			X	933
(X)		X		X	(X)	(X)	(X)	(X)	X			X	132005
(X)		X	X	X					X			X	74661
(X)		X	X	X	(X)	(X)	(X)	(X)	X			X	205733
(X)		X			(X)	(X)	(X)	(X)	X			X	131493
(X)			X	X					X			X	74657
(X)			X		(X)	(X)	(X)	(X)	X			X	205217
(X)				X	(X)	(X)	(X)	(X)	X			X	132001
										X	X		448
X										X	X		448
(X)	X									X	X		450
(X)		X								X	X		452
(X)			X							X	X		74176
(X)				X						X	X		960
(X)					(X)	(X)	(X)	(X)		X	X		131520

(X)	X	X								X	X		454
(X)	X	X			(X)	(X)	(X)	(X)		X	X		131526
(X)	X		X							X	X		74178
(X)	X		X		(X)	(X)	(X)	(X)		X	X		20550
(X)	X			X						X	X		962
(X)	X			X	(X)	(X)	(X)	(X)		X	X		132034
(X)	X				(X)	(X)	(X)	(X)		X	X		131522
(X)	X	X	X	X						X	X		74694
(X)	X	X	X	X	(X)	(X)	(X)	(X)		X	X		205766
(X)	X	X	X							X	X		74182
(X)	X	X	X		(X)	(X)	(X)	(X)		X	X		205254
(X)	X	X		X						X	X		966
(X)	X	X		X	(X)	(X)	(X)	(X)		X	X		132038
(X)	X		X	X						X	X		74690
(X)	X		X	X	(X)	(X)	(X)	(X)		X	X		205762
(X)		X	X							X	X		74180
(X)		X	X		(X)	(X)	(X)	(X)		X	X		205252
(X)		X		X						X	X		964
(X)		X		X	(X)	(X)	(X)	(X)		X	X		132036
(X)		X	X	X						X	X		74692
(X)		X	X	X	(X)	(X)	(X)	(X)		X	X		205764
(X)		X			(X)	(X)	(X)	(X)		X	X		131524

(X)			X	X						X	X		74688
(X)			X		(X)	(X)	(X)	(X)		X	X		205248
(X)				X	(X)	(X)	(X)	(X)		X	X		132032

										X		X	449
X										X		X	449
(X)	X									X		X	451
(X)		X								X		X	453
(X)			X							X		X	74177
(X)				X						X		X	961
(X)					(X)	(X)	(X)	(X)		X		X	131521
(X)	X	X								X		X	455
(X)	X	X			(X)	(X)	(X)	(X)		X		X	131527
(X)	X		X							X		X	74179
(X)	X		X		(X)	(X)	(X)	(X)		X		X	20551
(X)	X			X						X		X	963
(X)	X			X	(X)	(X)	(X)	(X)		X		X	132035
(X)	X				(X)	(X)	(X)	(X)		X		X	131523
(X)	X	X	X	X						X		X	74695
(X)	X	X	X	X	(X)	(X)	(X)	(X)		X		X	205767
(X)	X	X	X							X		X	74183

(X)	X	X	X		(X)	(X)	(X)	(X)		X		X	205255
(X)	X	X		X						X		X	967
(X)	X	X		X	(X)	(X)	(X)	(X)		X		X	132039
(X)	X		X	X						X		X	74691
(X)	X		X	X	(X)	(X)	(X)	(X)		X		X	205763
(X)		X	X							X		X	74181
(X)		X	X		(X)	(X)	(X)	(X)		X		X	205253
(X)		X		X						X		X	965
(X)		X		X	(X)	(X)	(X)	(X)		X		X	132037
(X)		X	X	X						X		X	74693
(X)		X	X	X	(X)	(X)	(X)	(X)		X		X	205765
(X)		X			(X)	(X)	(X)	(X)		X		X	131525
(X)			X	X						X		X	74689
(X)			X		(X)	(X)	(X)	(X)		X		X	205249
(X)				X	(X)	(X)	(X)	(X)		X		X	132033

Appendix 3 QuickCMC module

Figure 56 shows where QuickCMC can be found.

Figure 56. Omicron QuickCMC

Figure 57 shows how the analog voltage outputs can be set up.

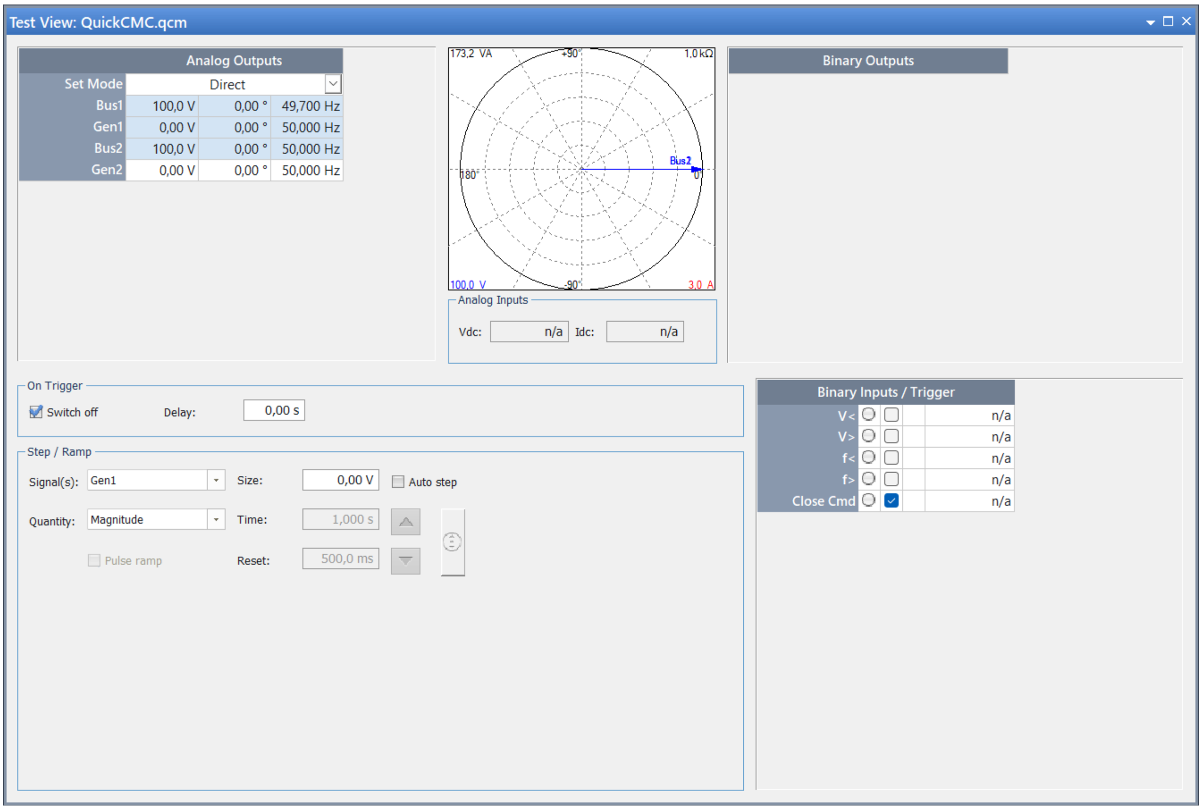

Figure 57. QuickCMC voltage analog outputs.

Figure 58 shows how the binary inputs can be set up for QuickCMC

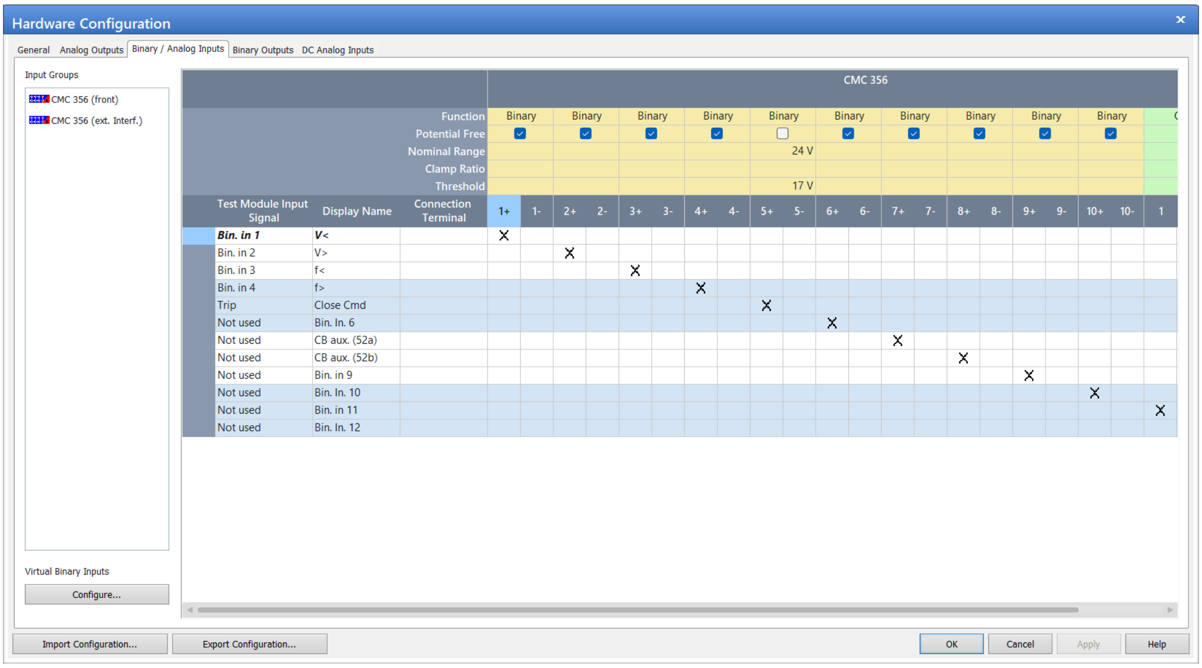

Figure 58. QuickCMC binary inputs.

Document revision history

Document revision/date	History
A / 26 March 2025	First revision

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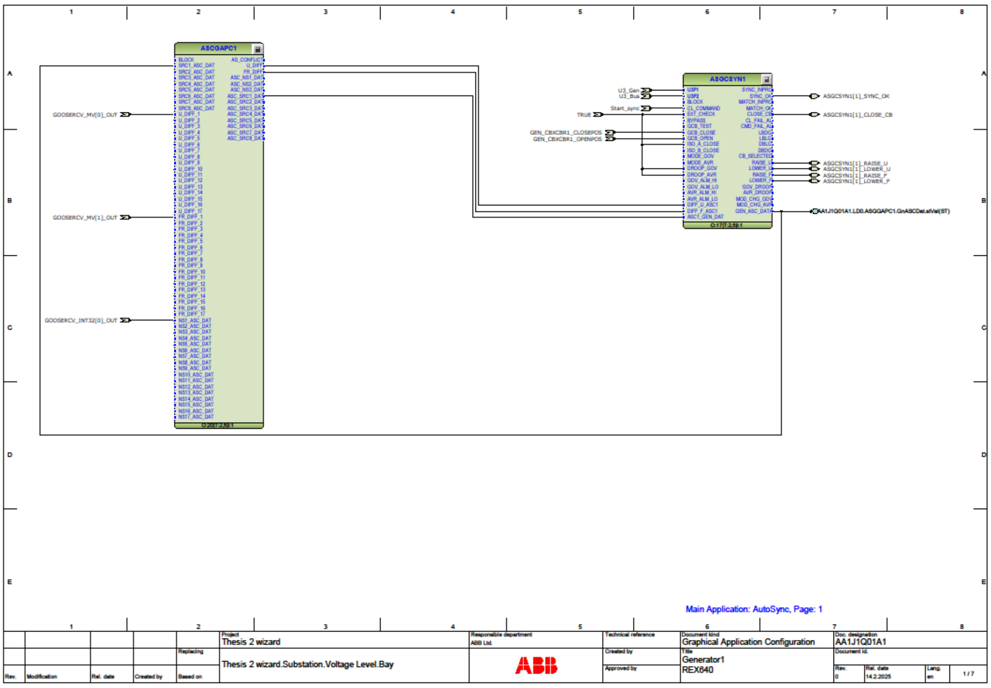
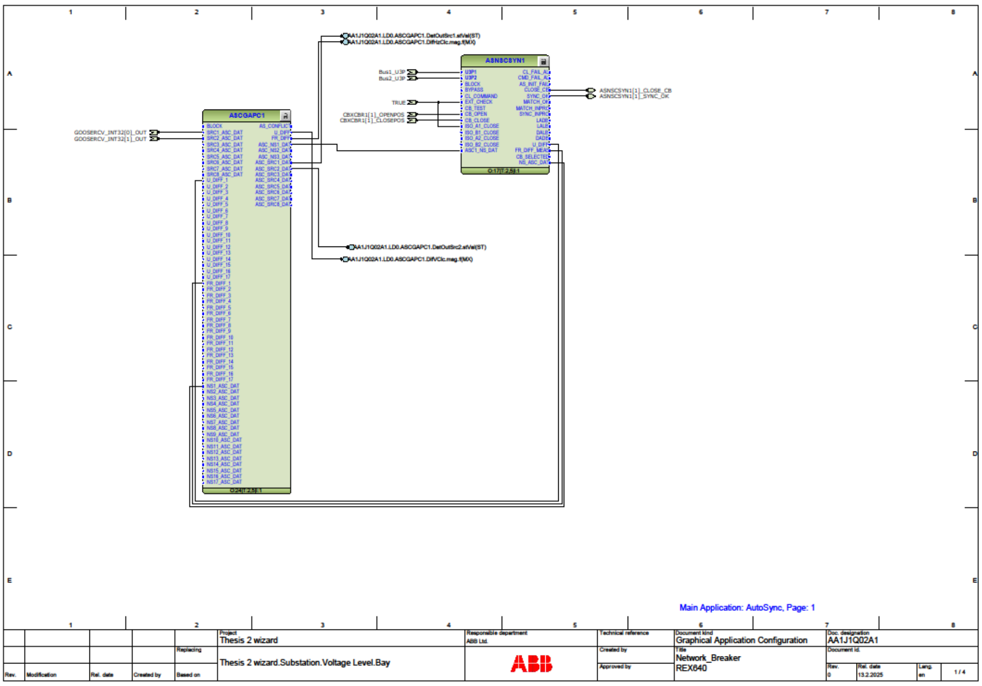
APPENDIX 2. REX640 Configurations Used In The Thesis

The configuration of generator and non-source breaker autosynchronizer functions are shown in the next figures.





APPENDIX 3. Synchronizing Modes

In the Manual mode synchronization is started by pressing the generators breaker on the relays HMI (human-machine interface) display. Auto Syn mode must be set for automatic and in this case Live dead mode is set to Off. **Figure 59** illustrates how autosynchronization can be initiated.

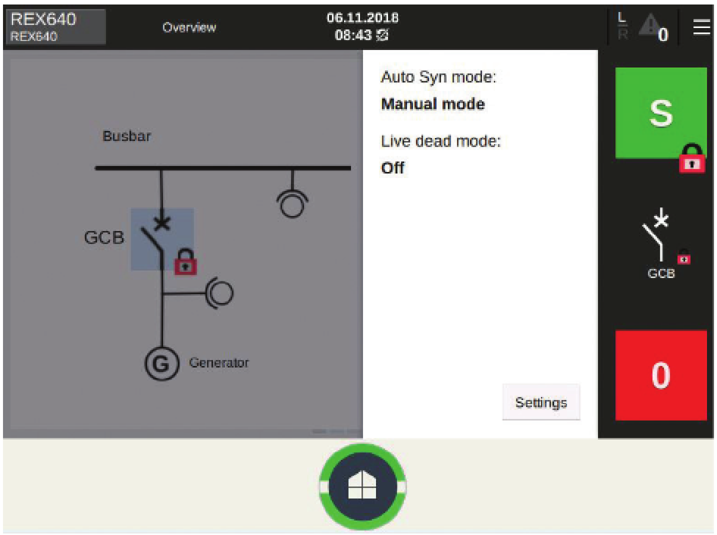


Figure 59. Starting synchronization with manual mode (ABB, 2023).

When the green S button is pressed, the synchronization dialogue opens and asks for the confirmation of synchronization as seen in **Figure 60**.

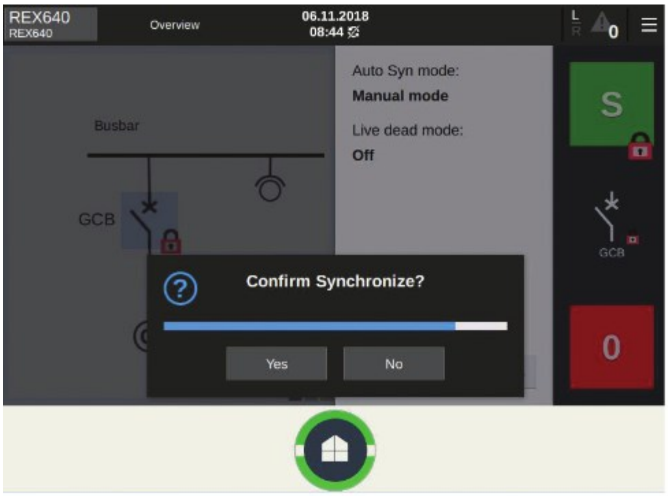


Figure 60. Confirmation on Synchronization with manual mode (ABB, 2023).

Figure 61 illustrates the synchroscope view upon opening, highlighting the raise and lower buttons for adjusting voltage and frequency. It is also possible to cancel the synchronization while in this window.

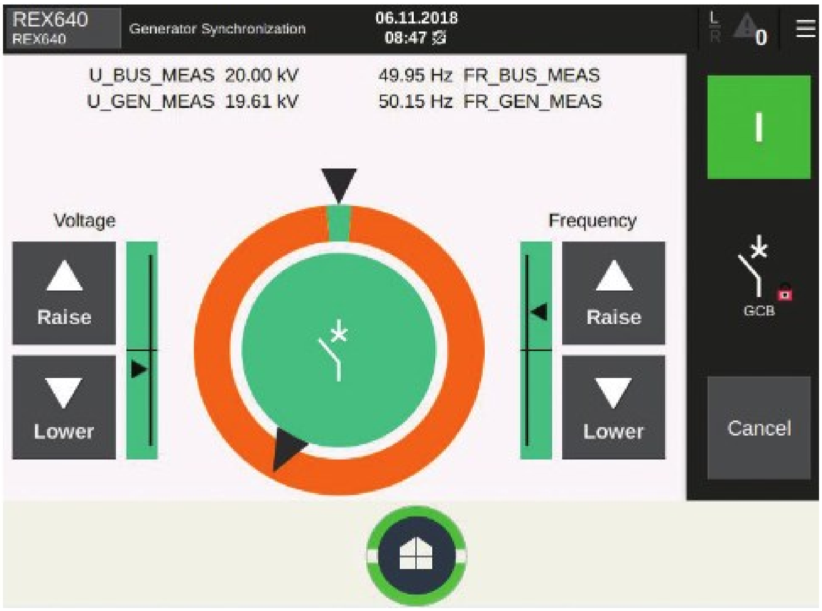


Figure 61. Synchroscope view manual mode (ABB, 2023).

When the voltage and the frequency are matched, pressing I button closes the circuit breaker as seen in **Figure 62**. When the synchronization is finished the synchronization window closes.

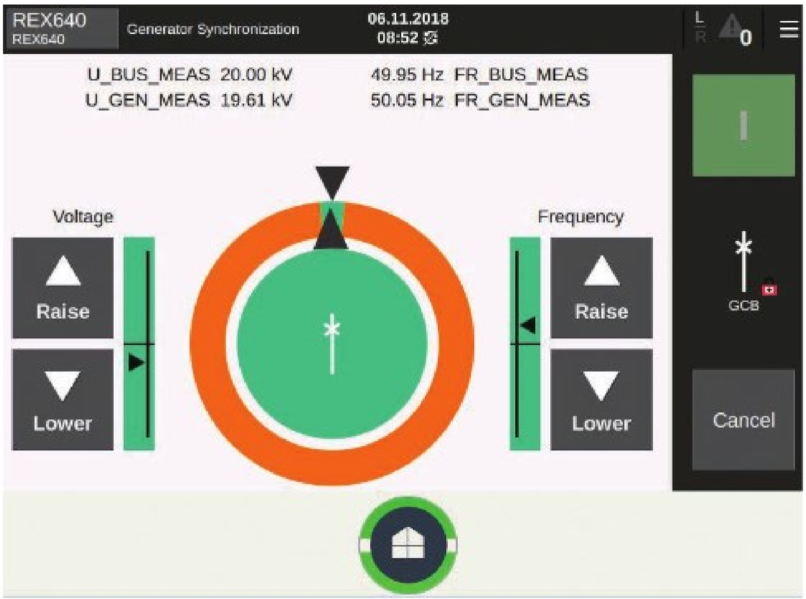


Figure 62. Closing the CB with manual mode (ABB, 2023).

Voltage and frequency are matched automatically, but the operator needs to give the circuit breaker close command manually when synchronization criteria are fulfilled. Semi-automatic mode is not used in this thesis, but it is good to know the different abilities of REX640 synchronization.

In automatic synchronizing mode voltage and frequency are matched automatically, and CB close command is also given automatically. The synchronization can start when Auto sync mode is set Automatic synchronizing mode and Live dead mode is set Off as seen in **Figure 63**.

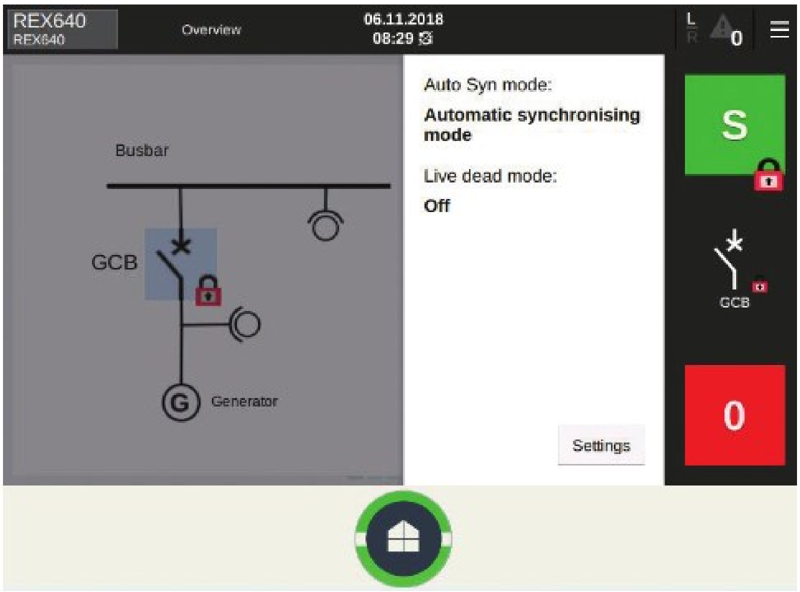


Figure 63. Automatic synchronization view (ABB, 2023).

Synchronization can be started when pressing S, after that a synchronization dialog will pop up and confirm synchronization as seen in **Figure 64**.

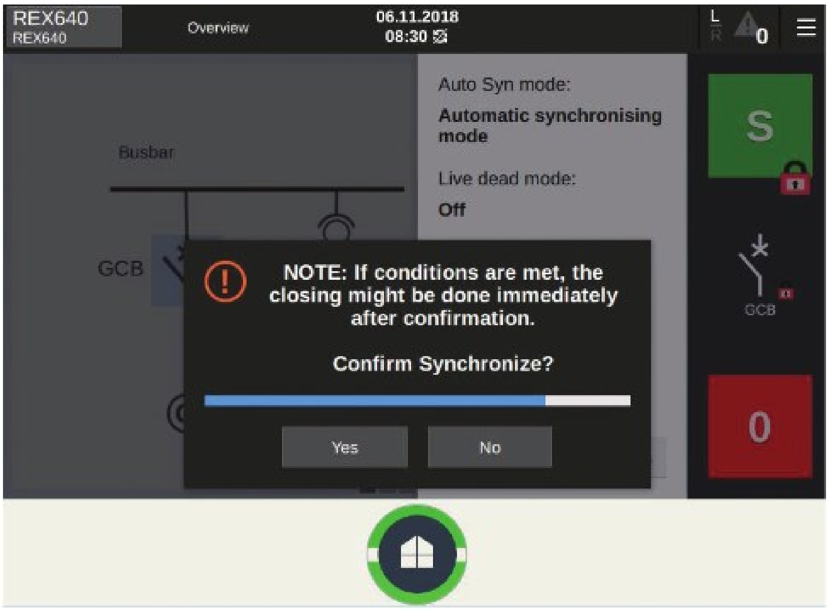


Figure 64. Confirmation of automatic Synchronization (ABB, 2023).

When autosynchronization starts the relay will give Raise and Lower commands until voltage and frequency are in synchronization as seen in **Figure 65**.

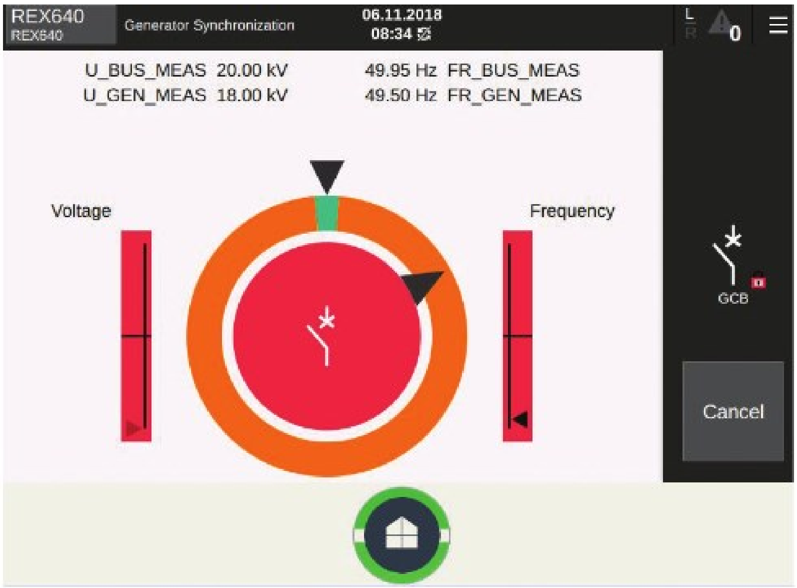


Figure 65. Autosynchronization start (ABB, 2023).

When the autosynchronization process is completed ASGCSYNC gives command to the CB to close. **Figure 66** shows the windows state when the CB has been closed.

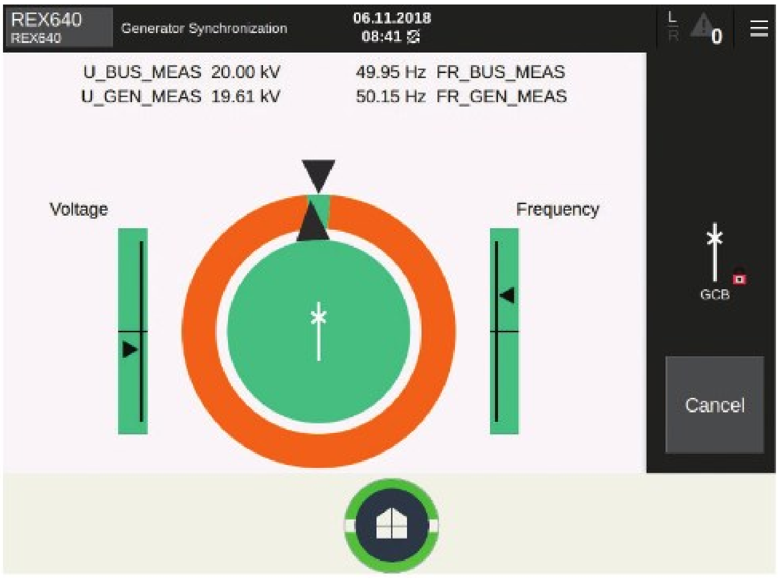


Figure 66. Autosynchronization complete (ABB, 2023).

APPENDIX 4. REX640 Application Manual Examples

REX640 application manual has one generator autosynchronization configuration example and one example for non-generator breaker. Both examples were done manually without using the PCM600 wizard.

The PCM600 wizard cannot be used unless there are at minimum of two relays which one has ASGCSYN, and one has ASNSCSYN function. I.e. Autosynchronization wizard is used to make configuration on multiple relays.

Generator Breaker Example, Generator Relay.

One generator autosynchronization single-line diagram looks like one seen in **Figure 67**.

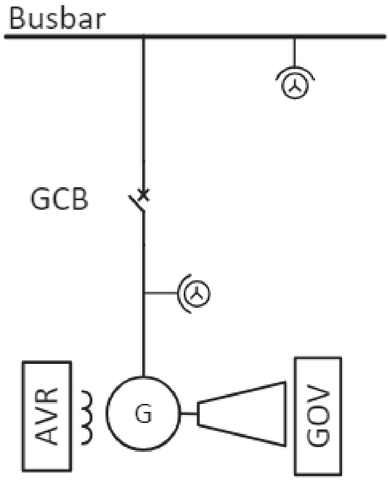


Figure 67. Single generator network (ABB, 2023)

Figure 68 shows how relays inputs and outputs are connected. From BI1 to B4 are binary inputs (indications of CB positions), from AI1 to AI4 (analog inputs) are VT measurements and BO1 to BO6 (Binary outputs) are the control commands for AVR, governor and CB.

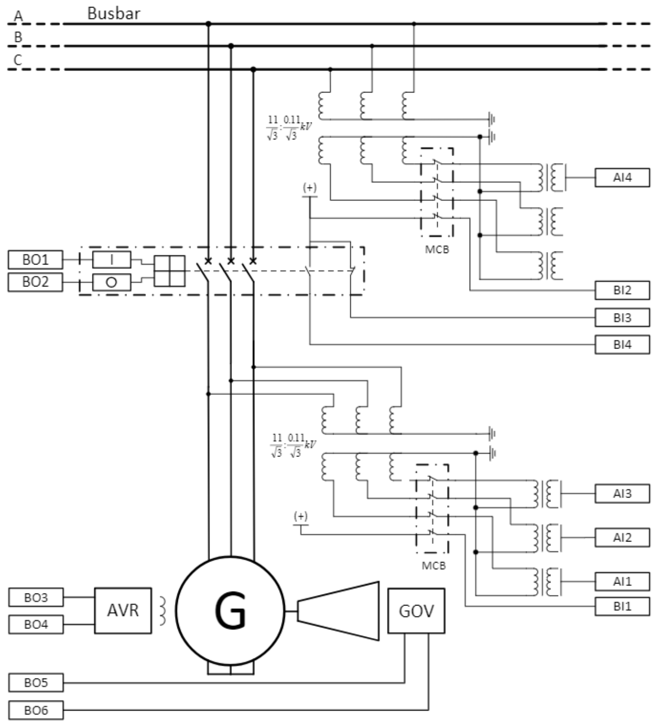


Figure 68. Relay interfaces and connections (ABB, 2023).

Voltage measurements are done in relay configuration with preprocessing function UTVTR. In the application manual example three voltage measurement channels are connected to UTVTR1 and only one voltage measurement for UTVTR2 together with status of MCBs (miniature CB) as seen in **Figure 69**. Also inputs for CB position inputs are shown here.

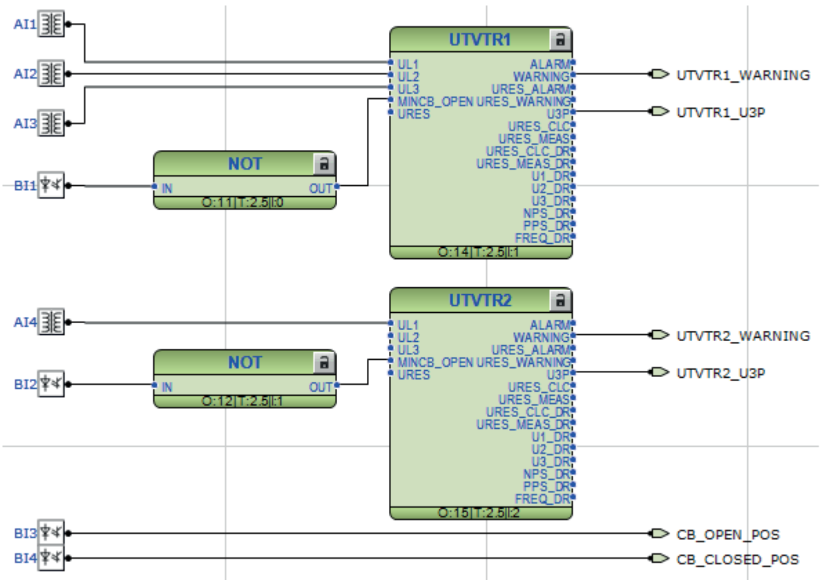


Figure 69. UTVTR1 and UTVTR2 function blocks (ABB, 2023).

The circuit breaker function CBXCBR needs position information from the circuit breakers (in this thesis these come from circuit breaker simulator). CLOSE_CB and SYNC_OK signals from ASGCSYN are required for CBXCBR to close the CB. ENA_OPEN and ENA_CLOSE must be true to enable CB to be opened or closed as seen in **Figure 70**.

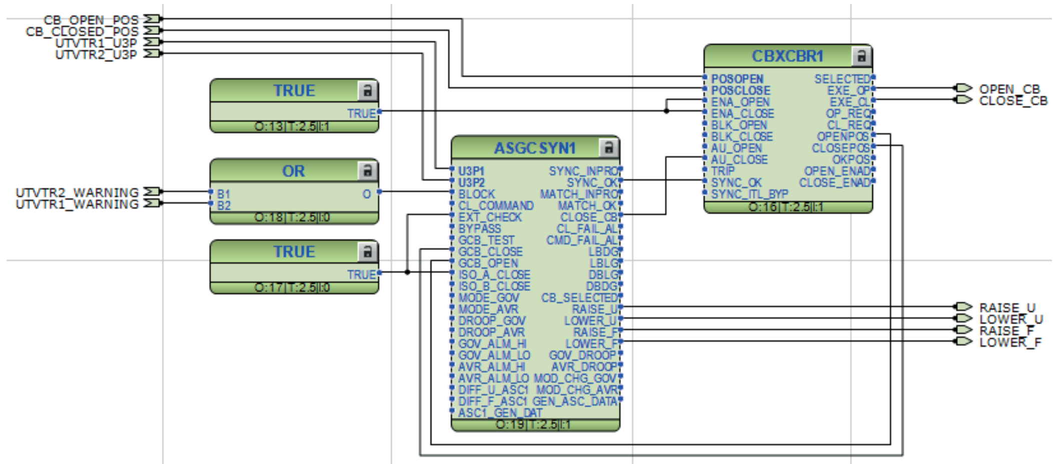


Figure 70. Configuration of autosynchronizer and CB control (ABB, 2023).

Relay binary outputs must be added to the configuration, to give commands to close CB and raise and lower voltage or frequency as seen in **Figure 71**.

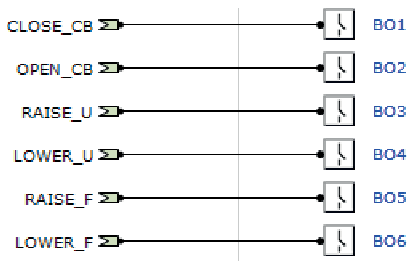


Figure 71. Relay output connections.

Non-generator Breaker Example, Generator Relay.

Figure 72 shows the relays connections. This differs from the previous example (chapter 7.1.1) in that way the relay has additional inputs from the AVR and governor.

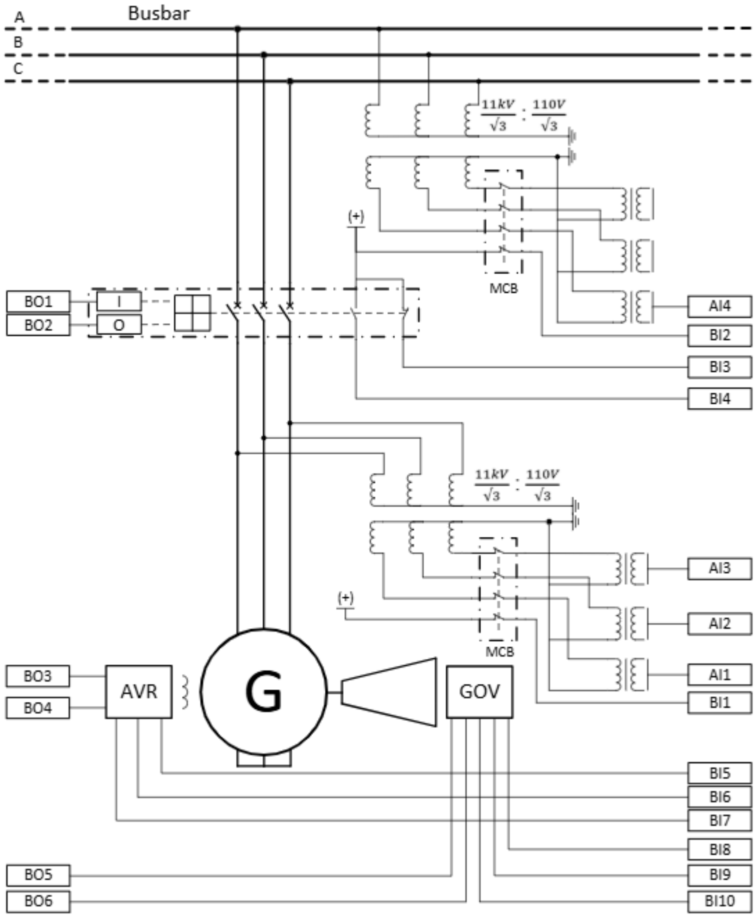


Figure 72. Relay interfaces and connections (ABB, 2023).

Figure 73 shows relays inputs and voltage preprocessing functions.

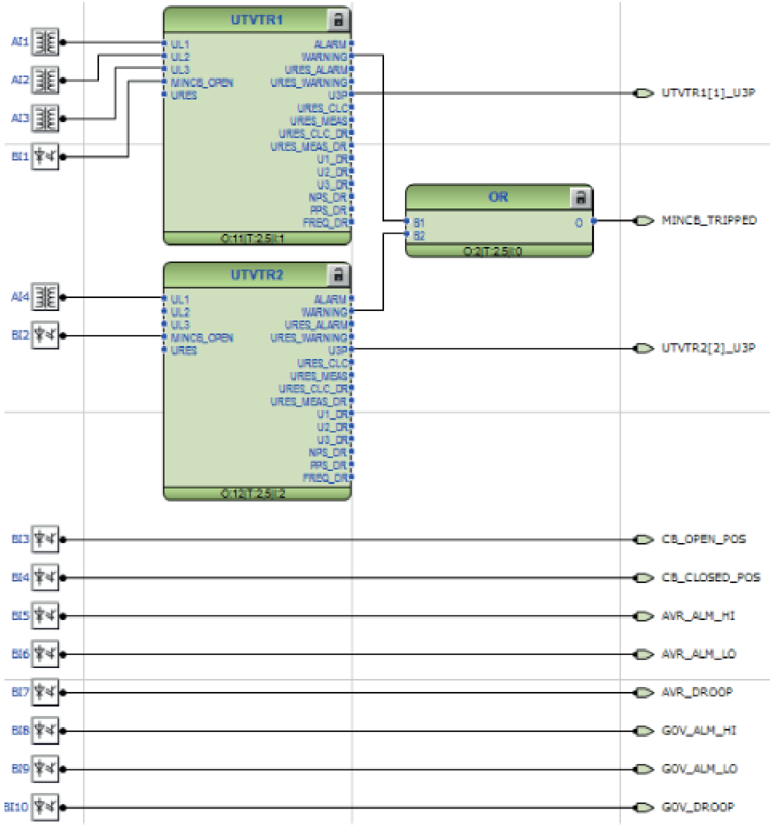


Figure 73. Voltage preprocessing functions and relays inputs (ABB, 2023).

Figure 74 shows outputs of the relay.

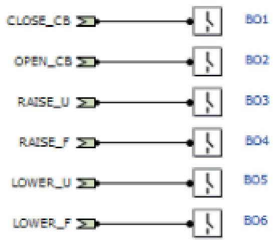


Figure 74. Configuration inputs (ABB, 2023).

Figure 75 shows how ASGCSYN and CBXCBR are connected, in addition to their inputs and outputs.

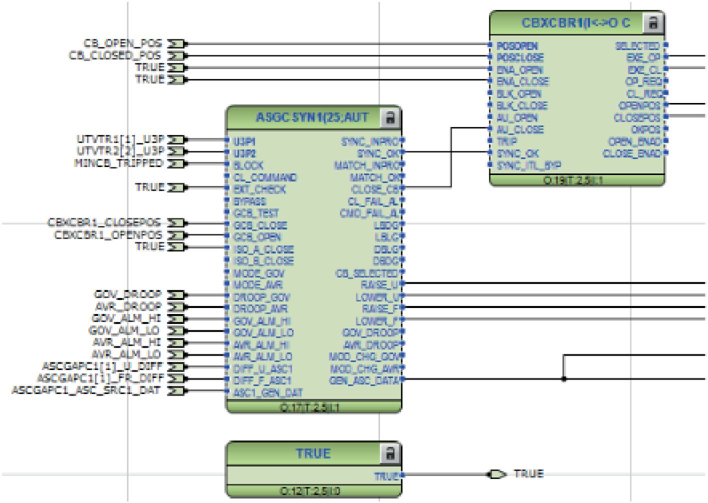


Figure 75. ASGCSYN control section (ABB, 2023).

Figure 76 shows ASCGAPC GOOSE communication inputs.

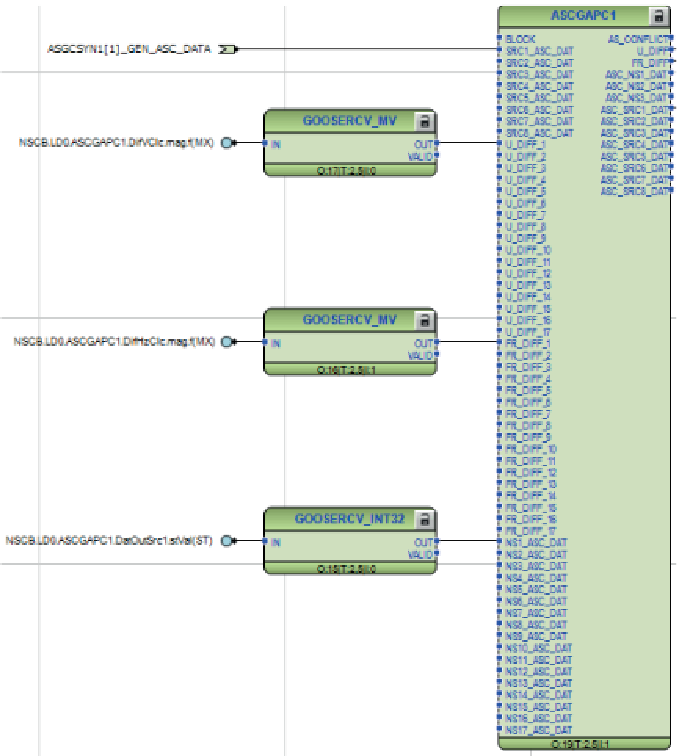


Figure 76. Configuration coordinator (ABB, 2023).

Non-generator Breaker Example, Non-source breaker.

When the non-source circuit breaker needs to be synchronized this part shows the needed information. **Figure 77** shows the relays inputs and outputs.

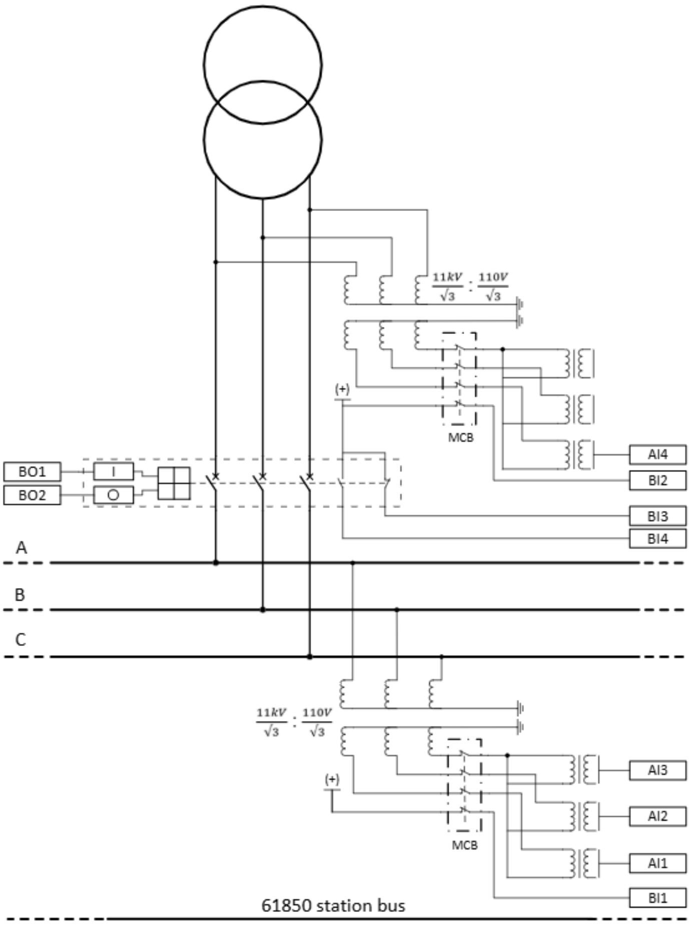


Figure 77. ASNSCSYN relay interfaces and VT connections (ABB, 2023).

Figure 78 shows voltage preprocessing and CB position inputs.

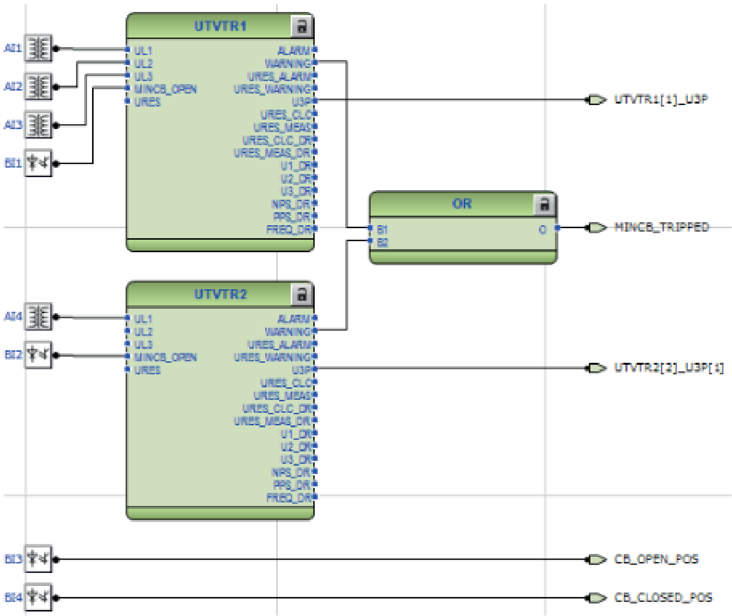


Figure 78. Voltage preprocessing functions and CB position inputs (ABB, 2023).

Figure 79 shows the ASNSCSYN and CBXCBR inputs and outputs.

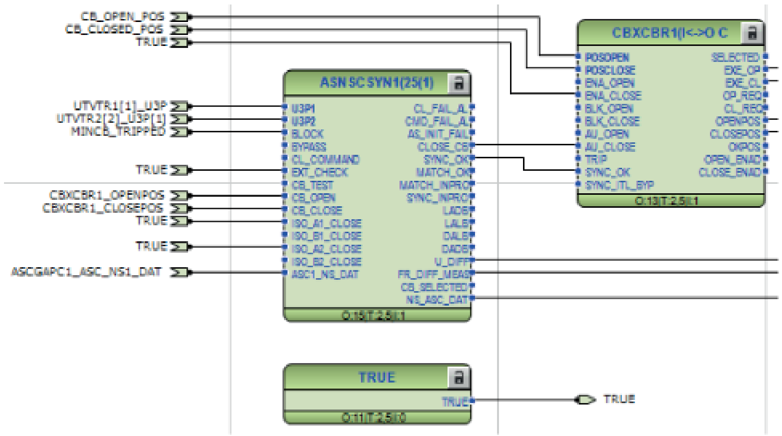


Figure 79. ASNSCSYN control section (ABB, 2023).

Figure 80 shows ASCGAPC autosynchronizer coordination inputs and outputs.

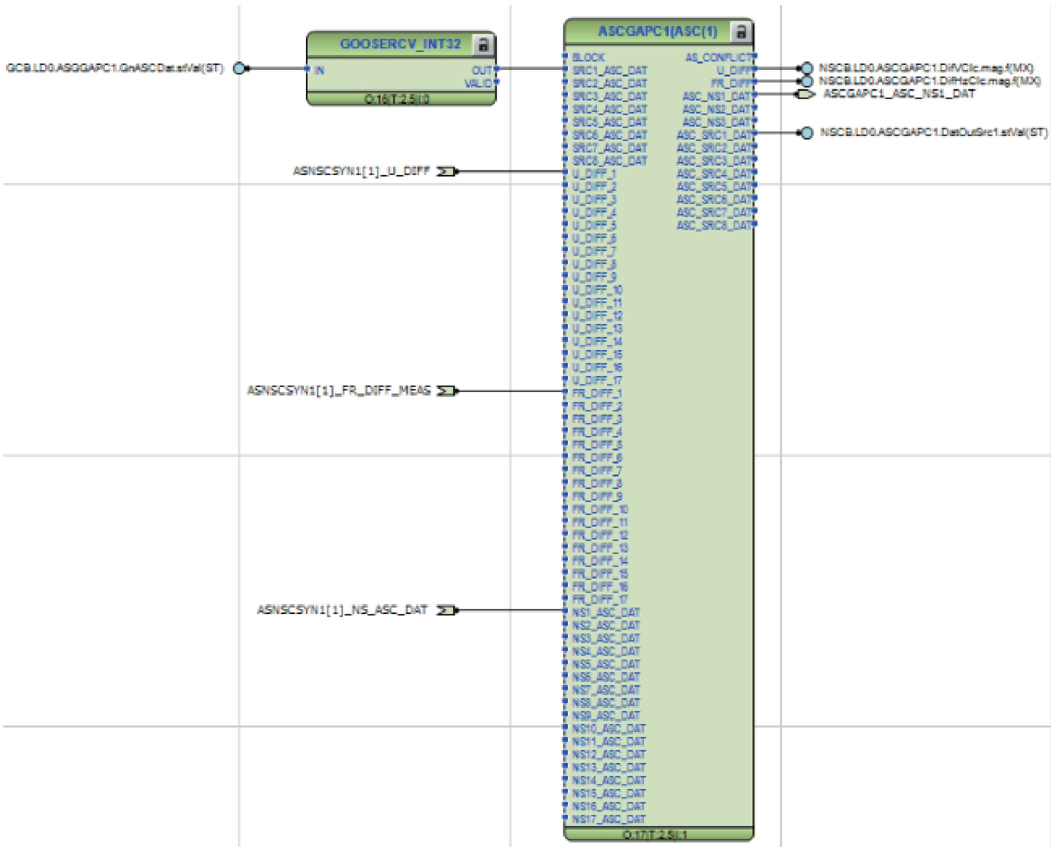


Figure 80. ASNSCSYN co-ordinator section (ABB, 2023).

Figure 81 shows the relays outputs.

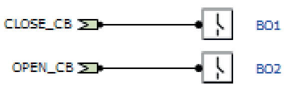


Figure 81. ASNSCSYN relay output connections (ABB, 2023).