

TABLE OF CONTENTS

7	<i>PRACTICAL EXERCISES MANUAL</i>	3
7.1	DESCRIPTION	3
7.1.1	Introduction	3
7.1.2	Description of the unit	6
7.1.3	Description of the process	50
7.1.4	Practical possibilities	63
7.1.5	Specifications	65
7.1.6	Dimensions and weight	74
7.1.7	Required services.....	74
7.2	THEORY	75
7.2.1	Smart Grids.....	75
7.2.2	Synchronous machines	76
7.2.3	Power Transmission and Distribution Lines.....	83
7.2.4	Reactive energy compensation	93
7.3	OPERATION	95
7.3.1	N-PPCM1. Control and Protection of Turbine-Generator Group Module 1	95
7.3.2	N-PSUB3 : Power Generation Substation Module 3	102
7.3.1	N-EALD: Network Analyzer Unit with Computer Data Acquisition.....	105
7.3.2	N-REG16: Voltage Regulation Module 1	108
7.3.3	N-BUS08. Distribution bus bar module	111
7.3.4	N-BUS09. Coupling Bus Bar Module	114
7.3.5	N-ERP-MF01. Digital Fault Simulator Module	117
7.3.6	N-CAR35T3D. Three-Phase Digital Bank of Commutable Resistors	121
7.3.7	N-CAR36T3D. Three-Phase Digital Bank of Commutable Inductances Module	123
7.3.8	N-CAR19T3D. Three-Phase Digital Bank of Commutable Capacitors Module	125
7.3.9	SCADA system	127
7.3.10	Starting up the application	139
7.3.11	Shutting down the application	139
7.4	MAIN INSTRUCTIONS, WARNINGS AND PRECAUTIONS	140
7.4.1	Previous considerations and precautions	140
7.4.2	Drivers installation and Communication ports configuration.....	142
7.4.3	IP address configuration	149
7.5	LABORATORY PRACTICAL EXERCISES	153
7.5.1	Practical exercise 1: Stand-alone manual control of voltage and frequency of the generator	153
7.5.2	Practical exercise 2: Stand-alone automatic control of voltage and frequency of the generator	157
7.5.3	Practical exercise 3: Synchronization operations with the synchronous generator and the grid.....	160
7.5.4	Practical exercise 4: Stand-alone operation with transmission line and loads.....	165
7.5.5	Practical exercise 5: Automatic synchronization with the grid along with transmission line and distributed loads.....	169
7.5.6	Practical exercise 6: Digital faults simulation in stand-alone mode.	174
7.5.7	Practical exercise 7: Stand-alone manual control of voltage and frequency of the generator with SCADA system.....	177
7.5.8	Practical exercise 8: Stand-alone automatic control of voltage and frequency of the generator with SCADA system.....	183
7.5.9	Practical exercise 9: Automatic synchronization operations with the synchronous generator and the grid with SCADA system.	189
7.5.10	Practical exercise 10: Stand-alone operation with transmission line and loads with SCADA system.	195
7.5.11	Practical exercise 11: Automatic synchronization with the grid along with transmission line and distributed loads with SCADA system.	202

7.5.12 Practical exercise 12: Digital faults simulation in stand-alone mode with SCADA system. 210

7.6 APPENDICES 218

7.6.1 Appendix 1: Stand-alone configuration 218

7.6.2 Appendix 2: Synchronization of the generator with the grid 219

7.6.3 Appendix 3: Stand-alone configuration along with transmission line and loads 220

7.6.4 Appendix 4: Synchronization with the grid along with transmission line and distributed loads. 221

7 PRACTICAL EXERCISES MANUAL

7.1 DESCRIPTION

7.1.1 Introduction

The Smart Grid Power System Application, with Automatic Control Generation, Transmission Lines and Loads with SCADA, “AEL-TI-”, is an application designed to study the operation of smart grids and the different agents involved in power generation, transmission, distribution and consumption.

The AEL-TI- provides teachers, students and researchers the most important knowledge about how a real smart grid works, which are the most important control variables and how the speed and voltage controller in the motor-generator works. With this application the user can study the generator controls and the synchronization with the grid for any power plant in general. Besides, the user will see from the control panel all alarms and signals that protect and show the generator state.

The AEL-TI- includes a SCADA Control System with which the user will manage and monitor a great amount of signals both manually and automatically. For example, start and stop turbine signals, turbine speed control signal, generator current excitation control signal, opening and closing maneuvers of circuit breakers and disconnectors, etc.

Through the SCADA Control System the user can control and study the motor-generator group in isolated operation or in synchronism with the grid. For isolated operation the application includes a series of commutable three-phase resistive, inductive and capacitive loads. In this way, the user can vary the active

power, capacitive reactive power and inductive reactive power. For synchronization operation with the grid, the application detects its presence; hence, the speed and voltage controller adjusts voltage phase angles and turbine frequency in order to get synchronization conditions with the national grid. Other important characteristic is that the user can take the full control over the speed and excitation signals to control the motor-generator group manually.

On the other hand, through the SCADA System it is possible to acquire all electrical parameters, such as generator output voltages, line currents, power factors, active powers, reactive powers, apparent powers, excitation voltage, excitation current, generator speed and frequency, PID speed signal, phasor diagrams, etc. Besides, the SCADA includes an oscilloscope that allows visualizing voltage and current true RMS values in order to carry out different analysis of the power generator.



Figure 1: AEL-TI- Smart Grid Power System Application, with Automatic Control Generation, Transmission Lines and Loads with SCADA

7.1.2 Description of the unit

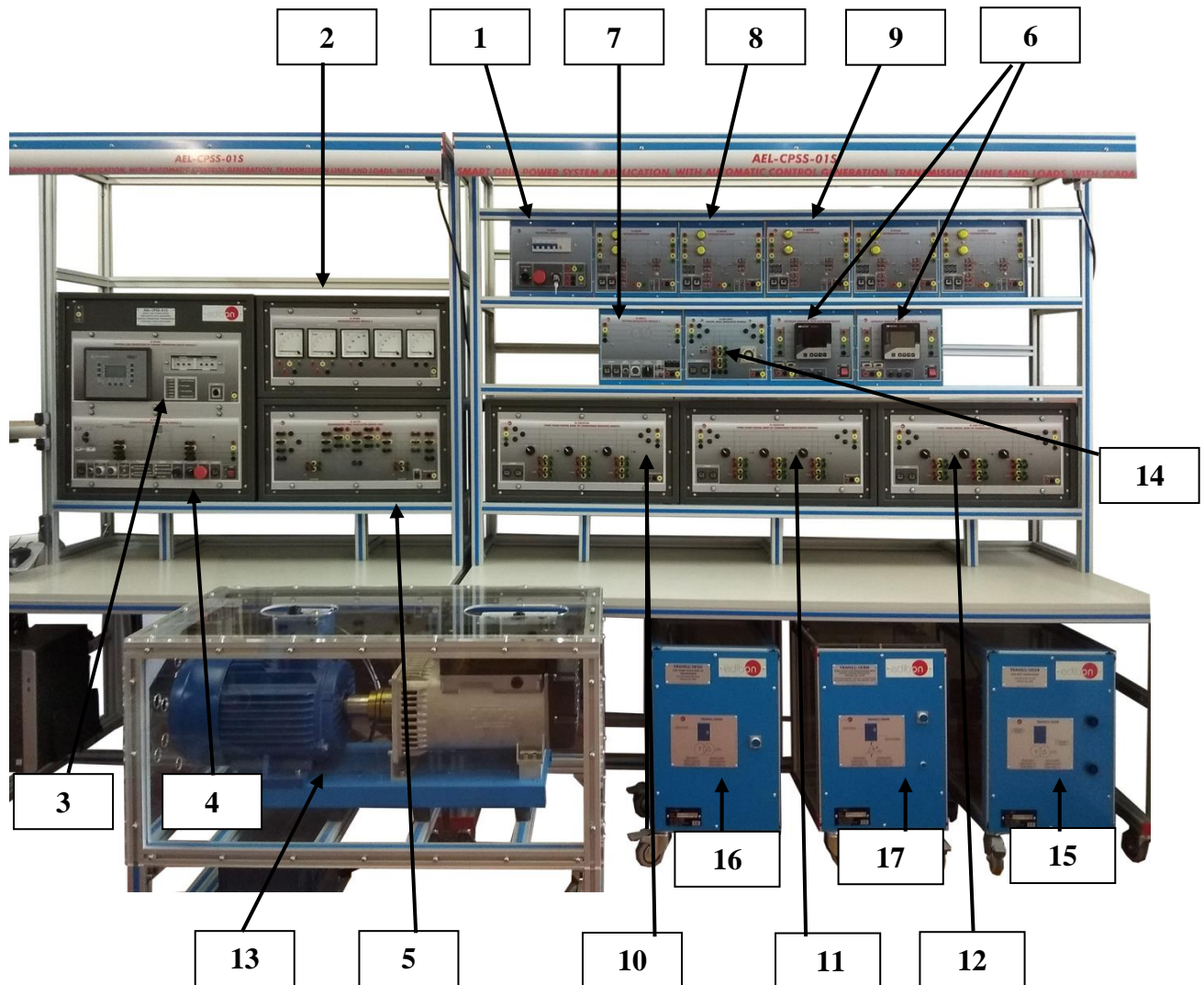


Figure 2: AEL- CPSS-01S modules

The following list contains the references of each element numbered and a brief description of its functions in the process.

1. N-ALI01. Industrial Power Supply is used to simulate the national grid and to carry out synchronization operations. In addition, this

module supplies power to both network analysers.

2. N-PPIM2. Instrumentation Module 2 is used to take analogue measurements of active and reactive power, frequency, AC voltage and DC current.
3. N-PPCM1. Control and Protection of Turbine-Generator Group Module 1. This module includes a frequency and voltage controller which allows automatically controlling these parameters. In addition, it is used to alarm and protect the turbine and generator against several faults. Besides, this controller allows automatic the synchronization with the national grid.
4. N-PSUB3. Power Generator Substation Module 3. This module is used to control the power substation switches and synchronous generator and turbine working conditions. In addition, it has several switches to choose different control ways: local control or remote control (SCADA). From local control it is possible to choose manual/automatic frequency and voltage control and the commutation of 52G and 52NET synchronization and mains circuit breakers.
5. N-AE1CD. Transmission Lines Simulation Module is used to simulate how electrical energy is transported and distributed along different length lines thanks to the different configurable electrical parameters.
6. N-EALD. Network Analyzers for Bidirectional Smart Metering (Smart Meter Simulators) is used to take measurements of the principal parameters involved in the energy flux.

7. N-REG16. Voltage Regulation Module 1. This module allows to control the voltage regulation of the TRANS3/5KRM transformer. It consists of a commutator to increase or decrease the output voltage of the transformer. Additionally it includes two signal connectors to control the voltage regulation remotely.
8. N-BUS08. Distribution bus bar module. This module allows understanding the most important operations carried out in maneuver power substations. This module represents a double bus bar with two disconnectors and one circuit breaker in order to carry out the opening and closing of them.
9. N-BUS09. Coupling bus bar module. This module allows understanding the most important operations carried out in maneuver power substations. This module represents a coupling bus bar with two disconnectors and one circuit breaker in order to carry out the coupling of two bus bars.
10. N-CAR35T3D. 3 x 300W Three-Phase Configurable Resistors Module. It is used to study the active power consumption by the load in delta and star connection. This module includes a series of jumpers for an easy delta connection. In addition, this module can be controlled from the SCADA Control System.
11. N-CAR36T3D. 3 x 300VAr Three-Phase Configurable Inductances Module. It is used to study the consumption of the loads in delta and star connection. This module includes a series of jumpers for an easy delta connection. In addition, this module can be controlled from the SCADA Control System.

- 12.N-CAR19T3D. 3 x 300VAr Three-Phase Configurable Capacitors Module. It is used to study the consumption of the loads in delta and star connection. This module includes a series of jumpers for an easy delta connection. In addition, this module can be controlled from the SCADA Control System.
13. GMG4.5K3PH. Three-Phase Synchronous Generator-Motor Group. It is used for power generation. It consists of a three phase induction motor of squirrel cage used as prime mover. This motor drives the three-phase synchronous generator at its nominal regimen in order to produce electricity.
- 14.N-ERP-MF01. Digital Faults Simulation Module is used to inject faults in different points of the unit to test the back-up protections of the generator motor group controller . It consist of power connections which can be configured to inject single phase, two phase and three phase short circuits.
- 15.TRANS3/5KGR. Grid Transformer 400/400 VAC, 5kW. This transformer provides galvanic isolation between the application and de laboratory network. It is always necessary that users are going to inject faults to avoid that the laboratory protections do not trip.
- 16.TRANS3/5KSU. Step-Up Power Transformer 400/400 VAC, 5kW. This transformer is used to be connected at the output of the generator in order to simulate the same conditions of a power substation.
- 17.TRANS3/5KRM. Three-Phase Autotransformer with Motor Voltage Regulator, 400/400 VAC, 5kW. This transformer is used in power distribution in order to compensate the voltage drop in the

transmission line connected before it.

In order to fully understand the global functionality of the AEL-TI-, this diagram shows simply and clearly the connection of the main elements of the Smart Grid:

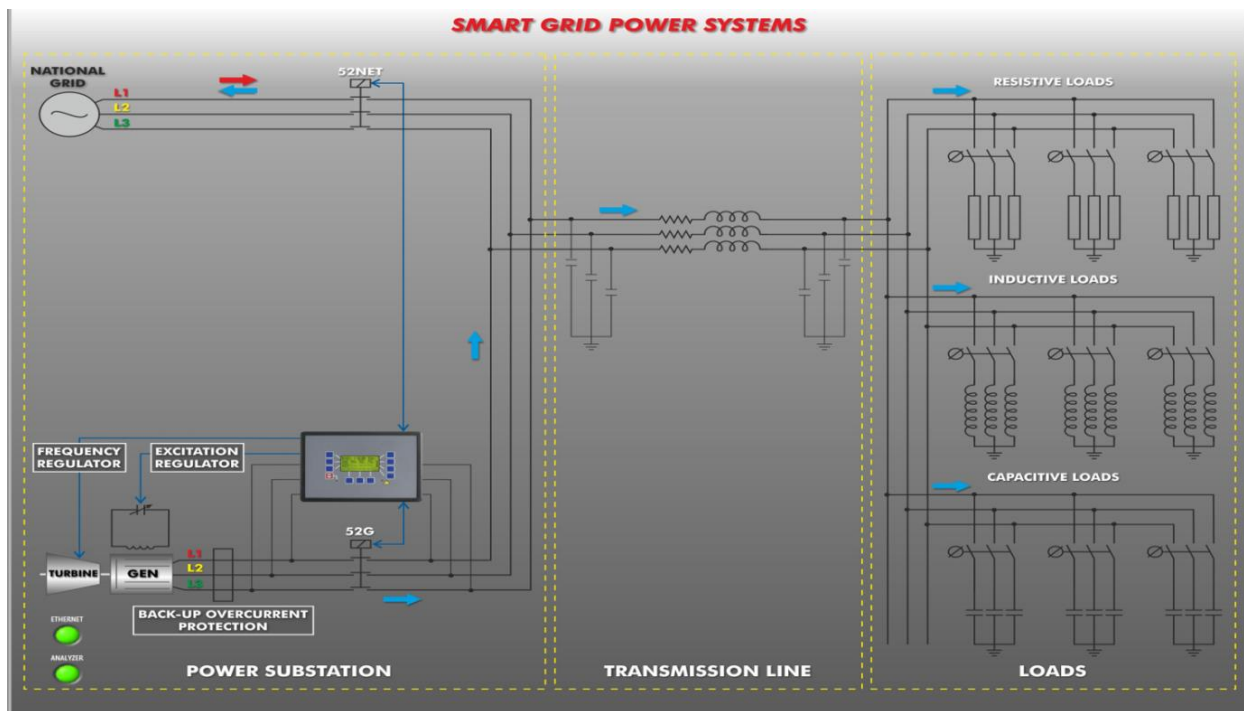


Figure 3: Diagram of AEL- CPSS-01S

7.1.2.1 N-ALI01. Industrial Power Supply



Figure 4: N-ALI01 module

The power supply module allows supplying to the rest of modules. It consists of a single-phase voltage and a three-phase voltage (for industrial installations) with the format of an industrial switch and terminals for the phases L1, L2, L3, line L, neuter N and ground GND.

A removable two-position switch (ON-OFF) carries out the function of main switch.

When module is connected to the network and of the state of the

magnetothermics is activated and the emergency mushroom stop is switched on, the red light on the emergency shutdown gets lighted, regardless of the position of the key.

The other red light, placed on the security key, will be lighted just in case there is voltage in the output terminals (that is, if the protection is completely activated and the emergency switch is off).

The protection of the four-pole differential automatic protection of 240V/30mA/25A (tested) and a four-pole automatic magnetothermic switch of 230/400V-16A/6kA are in charge of the unit's security. Switches are placed on the back part of the panel. There is also an emergency shutdown button that immediately interrupts the current.

The N-ALI01 module has the following elements:

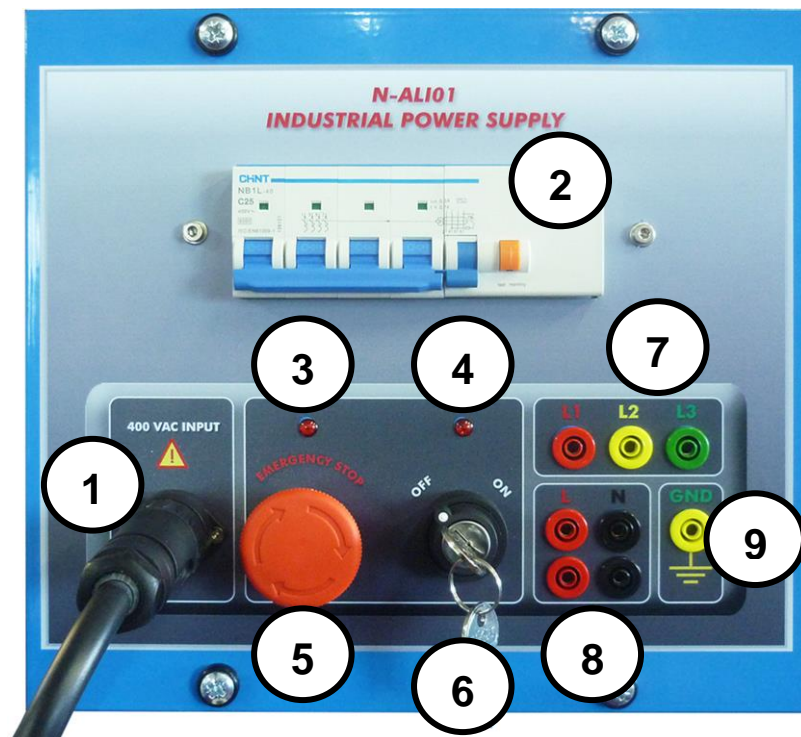


Figure 5: N-ALI01 elements

- 1. 400VAC input connector:** The module includes a power supply cable in order to connect the module to the grid.



Figure 6: Power supply cable

- 2. Differential protection:** The 4 poles differential switch of 240V/30mA/25 A (with test) and the 4 poles magneto-thermal switch of 230/400V-16A/6kA are in charge of the safety of the unit.
- 3. Connected power supply indicator:** This lamp indicates that the module is plugged and the magnetothermal protection is activated and the emergency stop mushroom is switched on.
- 4. Active outputs indicator:** This light will be activated if all the protections of the unit are working. When this happens, the supply module is ready to be used.
- 5. Emergency stop mushroom:** The safety mushroom pushbutton is used when the power supply of the circuit needs to be cut immediately when facing an emergency situation.

- 6. Safety key:** The key has two positions: ON and OFF. The laboratory teacher in charge can remove the key in OFF position to prevent students from operating the module. Check that the “outputs ON” LED indicator is lit when the magnetothermal circuit breaker is activated; the safety mushroom push button deactivated and select the ON position with the safety key.

- 7. Three-phase terminals:** These are the three-phase outputs at 400VAC.

- 8. Single-phase terminals:** These are two single-phase outputs at 230VAC.

- 9. Ground terminal:** This terminal must be connected because if there is any failure in the circuit this is detected automatically by the residual-current circuit breaker. The ground terminal is connected to the module frame for safety purposes.

7.1.2.2 N-PPIM2. Instrumentation Module 2



Figure 7: N-PPIM2 module

This module consists of five analogue meters which show the main electrical parameters of the generator:

- 1. Three-Phase wattmeter:** This component allows measuring the generation of active power that the generator supplies to the application or injects to the electrical grid.
- 2. Three-Phase varmeter:** This component allows measuring the generation of reactive power that the generator supplies to the application or injects to the electrical grid.
- 3. Voltmeter:** This component allows measuring the AC voltage between the output terminals of the generator that supplies to the system.

- 4. Frequency meter:** This component allows measuring the frequency of the generator.

- 5. DC ammeter:** This component allows measuring the excitation current of the generator.

7.1.2.3 N-PPCM1. Control and Protection of Turbine-Generator Group Module 1

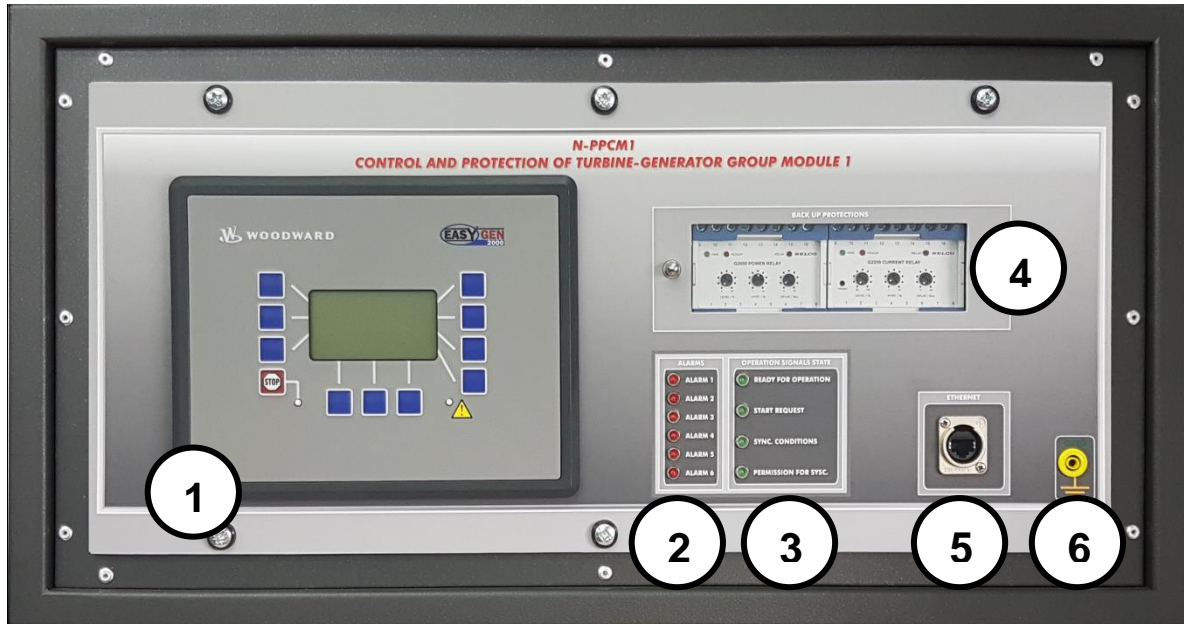


Figure 8: N-PPCM1 module

- 1. Automatic Speed and Voltage Controller:** It is used to control, protect and monitor the power plants functions based on electrical generators.

This module has the following characteristics:

- It allows connecting up to 16 electrical generators in parallel-island, with distribution of active and reactive load and start/stop in function of the load demand.

NOTE: it is required as many modules as generators to be coupled.

- It allows connecting a generator in parallel with the electric

network.

- It has analogical outputs to control different voltage and frequency regulators available in the market.
- It enables a three-phase measurement of the voltage in the network and the generator.
- It enables a three-phase measurement of the current and power of the generator.
- It enables a single-phase measurement of the current of the network.

Besides, the automatic controller includes the following protections:

- Generator: maximum/minimum voltage (59/27), maximum/minimum frequency (81O/U), voltage asymmetry, detection of dead busbars, overvoltage (32), load unbalance (46), negative sequence power/reduced power (32R/F), overcurrent by defined curve (50/51), inverse time overcurrent (IEC255), measured ground fault (50N/51N), phase rotation, switches fault.
 - Network: maximum/minimum voltage (59/27), maximum/minimum frequency (81O/U), vector jump, phase rotation.
- 2. Alarms:** it consists of six red configurable lights to notify any type of trouble. Each led alarm is related to an alarm type:
- **Alarm 1. Generator Reverse Power:** it is activated when the controller detects negative-sequence power in the

generator.

- **Alarm 2. Generator Overcurrent:** it is activated when the controller detects an overcurrent in the generator.
- **Alarm 3: Over/undervoltage:** it is activated when the relay detects an overvoltage or undervoltage in the generator.
- **Alarm 4: Inverse Time Overcurrent:** it is activated when a suddenly overcurrent appears.
- **Alarm 5: Generator Over/underfrequency:** it is activated when the relay detects an overfrequency or underfrequency in the generator.
- **Alarm 6: Shutdown alarms:** this indicator will warn the user when any alarm mentioned before and many others configured in the controller are activated.

NOTE: If any alarm is activated, the turbine cannot operate.

3. Remote control signal states: it is composed of four green lights that show the state of generator and turbine:

- **Ready for operation:** this indicator light indicates that the motor-generator group is ready to work. This light will blink always that any alarm is turned off.
- **Start request:** this indicator light indicates that the user has sent a request from the control panel or SCADA to start the generator.

- **Synchronization conditions:** this indicator is activated when the controller detects synchronization conditions, that is to say, the phase $\Delta\delta$, voltage ΔV and frequency Δf differences between generator and network are smaller than a previously preset percentage. When this light is turned on the user has permission to close the generator circuit breaker 52G.

If the generator is working in stand-alone mode (52NET open), the synchronization conditions light will be turned on when the generator reaches 50Hz and 380 VAC.

- **Permission for synchronization:** this indicator is turned on when the user gives permission for synchronization.
4. **Back-up protections:** these protections allow protecting the alternator against overcurrent and reverse power. The relays have already been configured in such a way that the user **MUSN'T VARY THE POTENTIOMETERS.**
 5. **Ethernet:** this connection allows communicating the controller with the Woodward Toolkit configuration software. The controller is perfectly configured in Edibon and there is high risk of the machine works bad if the user change any parameter. Edibon supplies the communication cable for technical support only.
 6. **GND terminal.**

7.1.2.4 N-PSUB3. Power Generator Substation Module 3

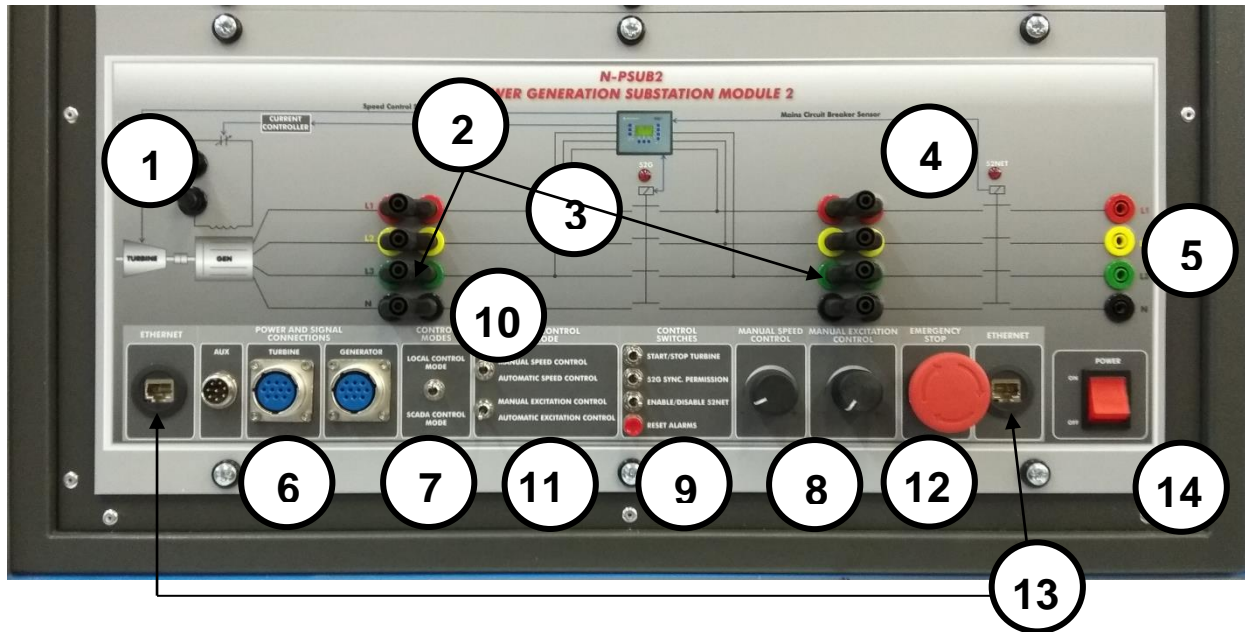


Figure 9: N-PSUB module

This module simulates the usual operations carried out in a power generation substation.

1. **Current controller:** this element is incorporated in the excitation circuit of the alternator or generator. The excitation current is controlled via a signal generated by the Speed-Voltage controller in order to obtain the correct conditions of generation voltage. It has two terminals to measure the excitation current of the rotor alternator.
2. **Measurement points:** there are 8 terminals corresponding to L1, L2, L3 and N. These terminals can be directly linked or used for the connection of measurement instrumentations and other

elements such as transformers. .

3. **52G status indicator:** it is a red light to indicate that circuit breaker is closed.
4. **52NET indicator:** it is a red light to indicate that circuit breaker is closed.
5. **Output terminals:** they are L1, L2, L3 and N terminals that allow connecting the generation substation with the laboratory network.
6. **Power and Signal Connections:** this block consists of the following three connections that will be described from left to right:
 - **Auxiliary:** this connector is used by EDIBON for commissioning the module. In normal operations this connector does not work.
 - **Turbine:** this is an IP44 3PN+E 32A 400V connecting plug to provide power supply to the turbine.
 - **Generator:** this is an IP44 3PN+E 32A 400V connecting plug to provide power supply to the generator.
7. **Control modes:** it consists of a switch in order to select between the two control and operation modes:
 - **Local control mode:** the user can work physically with the whole switches of this module.
 - **SCADA control mode:** on this position, all switches of the

module are disabled. The application can only be controlled from the computer and SCADA.

8. Local control mode: if the user has chosen a local control mode, he has 4 options to control the turbine and generator via 2 switches that will be described from top to bottom:

- Speed control switch: the user can choose between a manual speed control and automatic speed control that lets the Speed-Voltage controller adjust it.
- Excitation control switch: the user can choose between a manual excitation control and automatic excitation control that lets the Speed-Voltage controller adjust it.

9. Control switches: this is composed of 4 switches in order to carry out several manoeuvres:

- Start/stop turbine: it put in operation the turbine if any alarm is activated.
- 52G synchronization permission: the user gives permission to synchronize the generator with the grid or in stand-alone.
- Enable/disable 52NET: the user gives permission to work with the national grid.
- Reset alarms: push button to reset the active alarms. It is required to press two times to reset any alarm.

10. Manual speed control: this is a potentiometer that allows varying the turbine speed in order to have different conditions of

generation.

11. Manual excitation control: this is a potentiometer that allows varying the excitation of the generator in order to have different conditions of generation.

12. Emergency stop: the safety mushroom pushbutton is used when the power supply of the circuit needs to be cut immediately when facing an emergency situation.

13. Ethernet: this connection allows connecting the module with the computer and other modules for transmitting the data signals. This cables are always necessary to work with the SCADA.

14. ON/OFF switch: this switch provides power supply to the module.

7.1.2.5 N-AE1CD. Transmission Lines Simulation Module

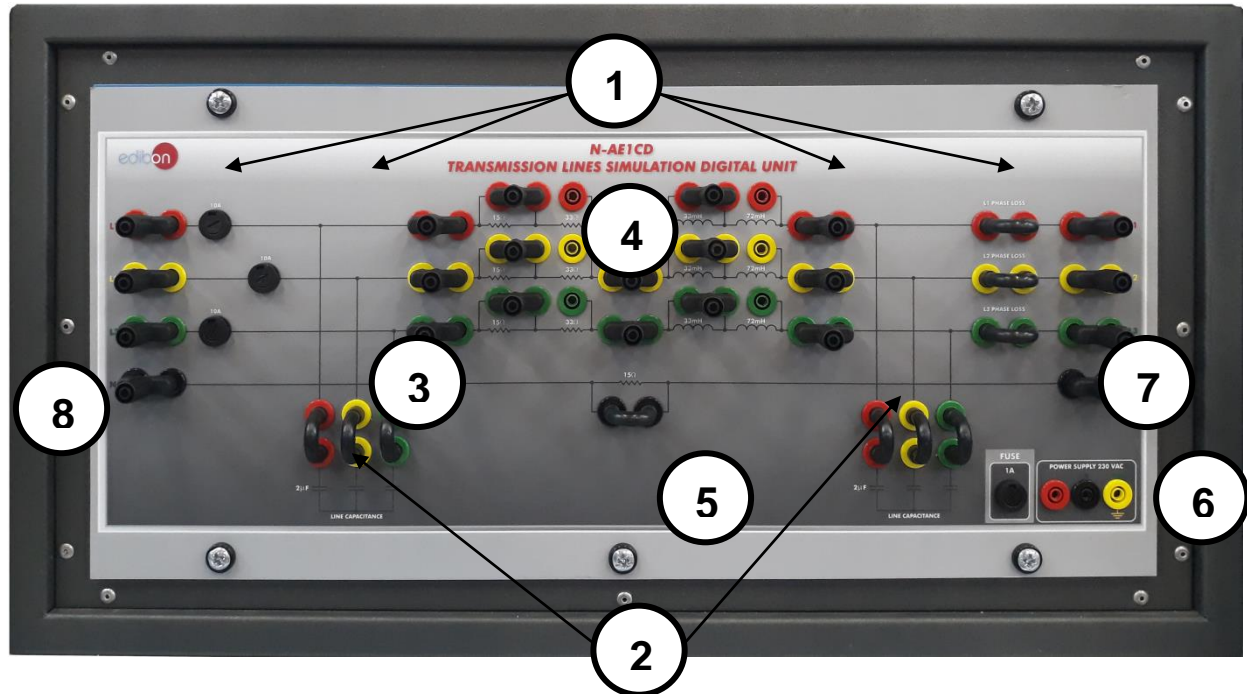


Figure 10: N-AE1CD module

This module allows studying how electrical energy is transported and distributed along hundreds of kilometres. The transmission line module is designed according to the concentrated parameters theory with variable inductances, capacitances and resistances.

- 1. Capacitance of the electrical line:** it consists of six capacitors of $2\mu\text{F}$ which can be included or not by means of jumpers.
- 2. Resistance of the electrical line:** it consists of two resistors per line of 33 and 15 Ohms that can be connected in series or independently, so the possible combinations are the following: 15, 33 and 48 Ohms.

- 3. Inductance of the electrical line:** it consists of two inductances per line of 33 mH and 72 mH that can be connected in series or independently, so the possible combinations are 33 mH, 72 mH and 105 mH.
- 4. Neutral resistance:** it consists of a 15 Ω resistor that allows reducing the fault current in earth faults.
- 5. GND terminal.**
- 6. Output terminals.**
- 7. Input terminals.**
- 8. Phase loss terminals :** they can be used to produce line unbalances on purpose through the use of the jumpers, to test the unbalanced loads protection of the controller.
- 9. 230 VAC+ GND power supply terminals.**
- 10.Fuses:** 10 A fuses to protect the module.

7.1.2.6 N-EALD. Network Analyzer Unit with Computer Data Acquisition

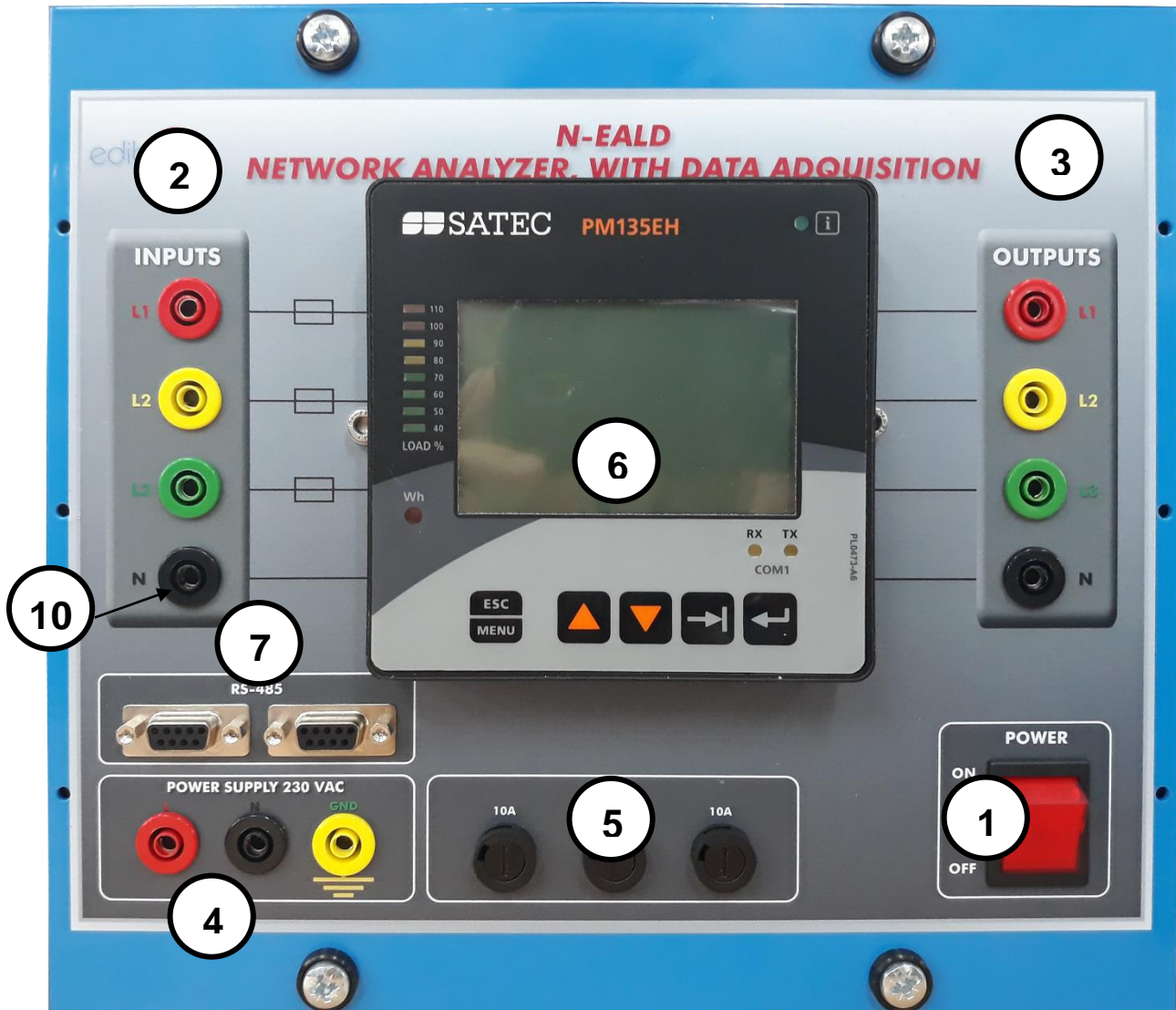


Figure 11: N-EALD module

The Network Analyzer Unit with Computer Data Acquisition is used to analyze the electrical parameters of the network: active, reactive and apparent power and energies, currents and frequencies.

1. ON-OFF Switch.

- 2. Input Terminals:** Input connection with the measurement point.
- 3. Output terminals:** Output connection with the measurement point.
- 4. Supply terminals:** These terminals are used for the module supply of 230VAC.
- 5. Fuses:** Three fuses of 10 A to protect the module.
- 6. Network Analyzer Display:** The display shows voltages, currents, active, reactive and apparent powers, frequencies and energy measurements.
- 7. RS-485 Communication port:** Two RS-485 Communication port which allow communicating with computer to transfer the measured information.

For more information about this module, please consult the user's manual of the N-EALD.

7.1.2.7 N-REG16. Voltage Regulation Module 1

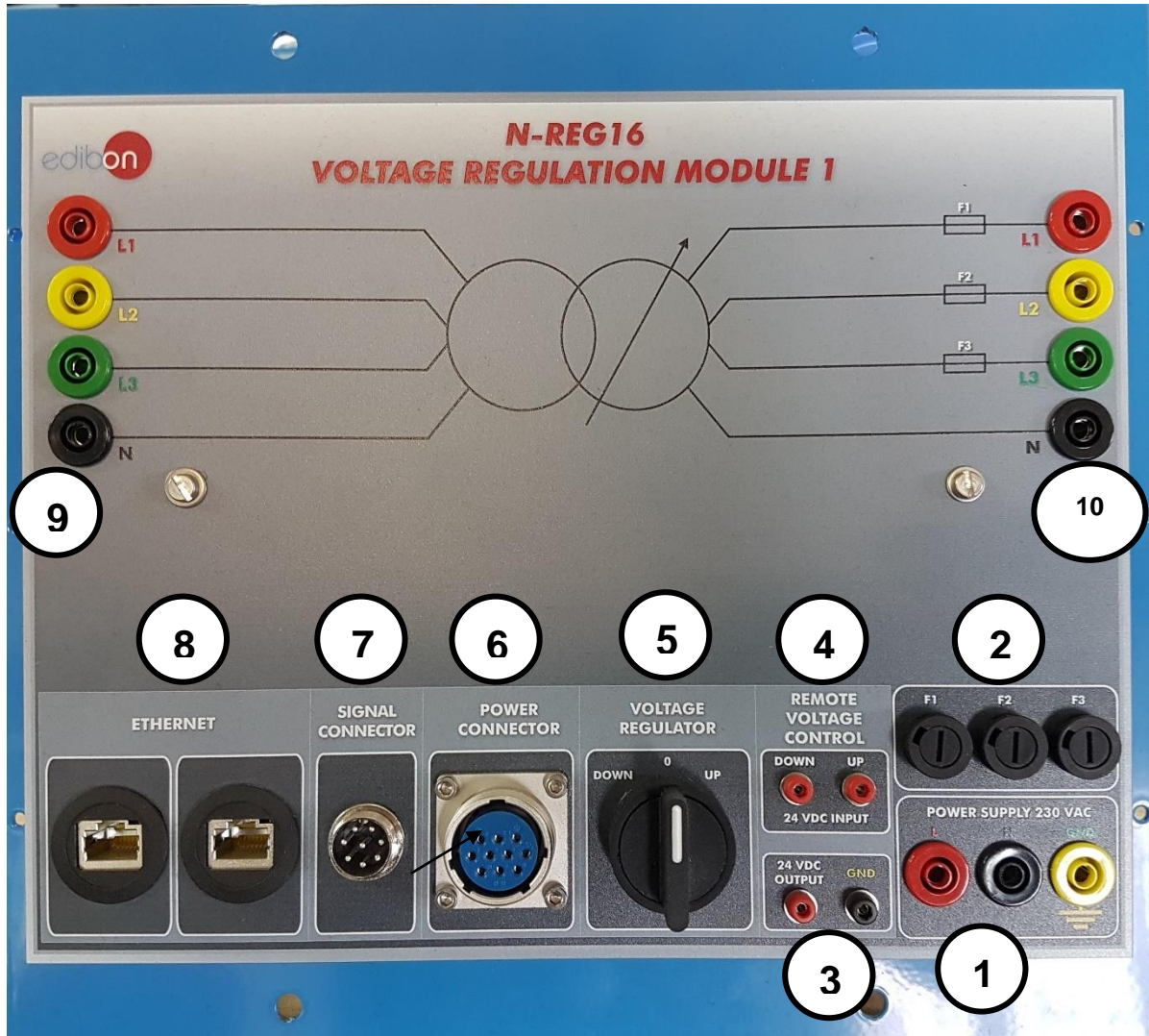


Figure 12: N-REG16 module

This module is used to access to the distribution transformer terminals and to control de voltage regulation.

L1, L2, L3 and N left terminals are connected to the primary winding of the distribution transformer.

L1, L2, L3 and N right terminals are connected to the secondary winding

of the distribution transformer.

On the other hand, the Voltage regulator commutator allows the user to control manually the output voltage. To do this, the commutator controls a motor installed in the shaft of the transformer.

Additionally, this module has two 24 VDC input signals used to control the same as Voltage regulator commutator.

Finally, this module includes two ethernet connectors used for remote control.

The N-REG16 module consists of:

- 1. 230 VAC + GND Power supply terminals.**
- 2. F1, F2, and F3 Fuses:** These fuses protect the three lines of the distribution transformer.
- 3. 24 VDC output:** These terminals are used as auxiliary signal for UP and DOWN commands.
- 4. 24VDC input:** These terminals receive 24 VDC in order to control UP and DOWN voltage with an external element such as relay that enables and disables this signal.
- 5. Voltage Regulator:** This commutator has three positions. Left position send a command to the motor of the distribution transformer to reduce the output voltage. If the user releases the commutator it comes back to the center position and the motor stops. Right position sends a command to the motor of the distribution transformer to increase the output voltage.

- 6. Power Connector:** This connector supplies power to the input and output terminals of the distribution transformer.
- 7. Signals connector:** This connector sends UP and DOWN signals to control the motor of the distribution transformer.
- 8. Ethernet connectors.**
- 9. L1, L2, L3, N power input terminals:.** These terminals supply power to the primary winding of the distribution transformer.
- 10.L1, L2, L3, N power output terminals:** These terminals supply power to the secondary winding of the distribution transformer.

7.1.2.8 N-BUS08. Distribution bus bar module

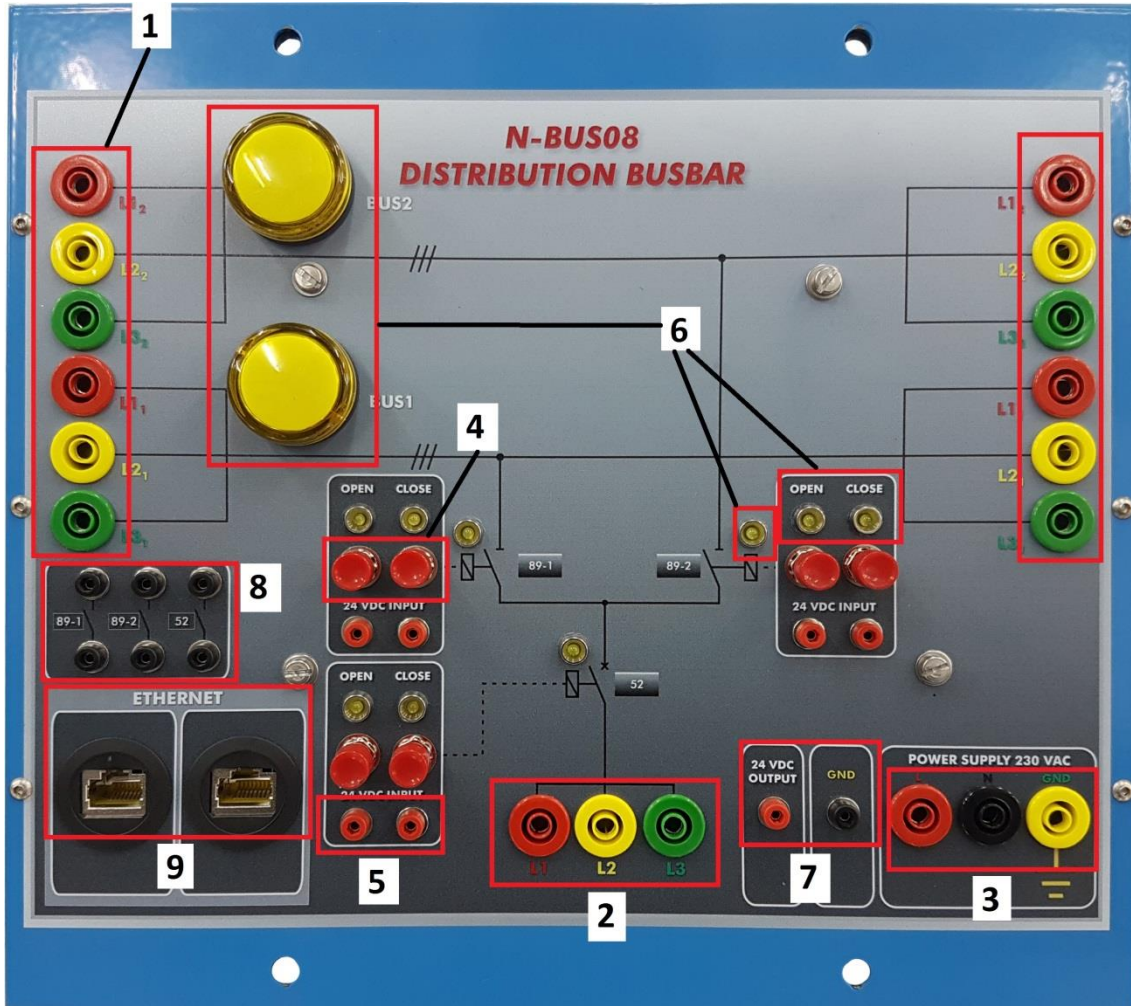


Figure 13: N-BUS08 module

This module works as a three phase double bus bar with two disconnectors and one circuit breaker. This one can work with similar bus bar modules and it can be connected to transmission lines, power generators, loads, network analyzers, etc.

El N-BUS08 consists of the following elements:

1. Three Phase Double Power terminals: These terminals are used to be

coupled to other bus bars. Thus the user can realize extended configurations with several ingoing and outgoing feeders.

- 2. Three Phase Power Terminals:** These terminals are used to be connected to power generators, transmission lines, loads, network analyzers, etc.
- 3. 230 VAC + GND Power supply terminals.**
- 4. Open and close push buttons:** These push buttons are used to work in local control mode. Each push button enables and disables the disconnectors and circuit breakers. Disconnectors are named as 89 and circuit breakers are named as 52.
- 5. 24 VDC input signal connectors:** These connectors allow open and close the disconnectors and circuit breakers via 24 VDC signal. This signal can be the own of the module or other signal with the gnd terminal connected with this module.
- 6. State indicators light:** The lights located in the busbars indicate the presence of voltages in the busbars. On the other hand, the lights located over the push buttons indicate the presence of 24VDC remote signal to open and close the circuit breakers and disconnectors. Finally, the lights located over the coil symbol indicate the actual state of the circuit breakers and disconnectors.
- 7. 24VDC and GND output terminal:** This terminal is used to open and close commands of circuit breakers. This terminal can be wired with auxiliary contacts for logic commutations.
- 8. Auxiliary contacts:** These are circuit breakers which are opened and

closed depending on the state of 89-1, 89-2 and 52 disconnectors and circuit breaker respectively.

9. Ethernet connections: These connectors allow connect this module with other modules and be able to control it from a PC and the SCADA Control System.

7.1.2.9 N-BUS09. Coupling Bus Bar Module

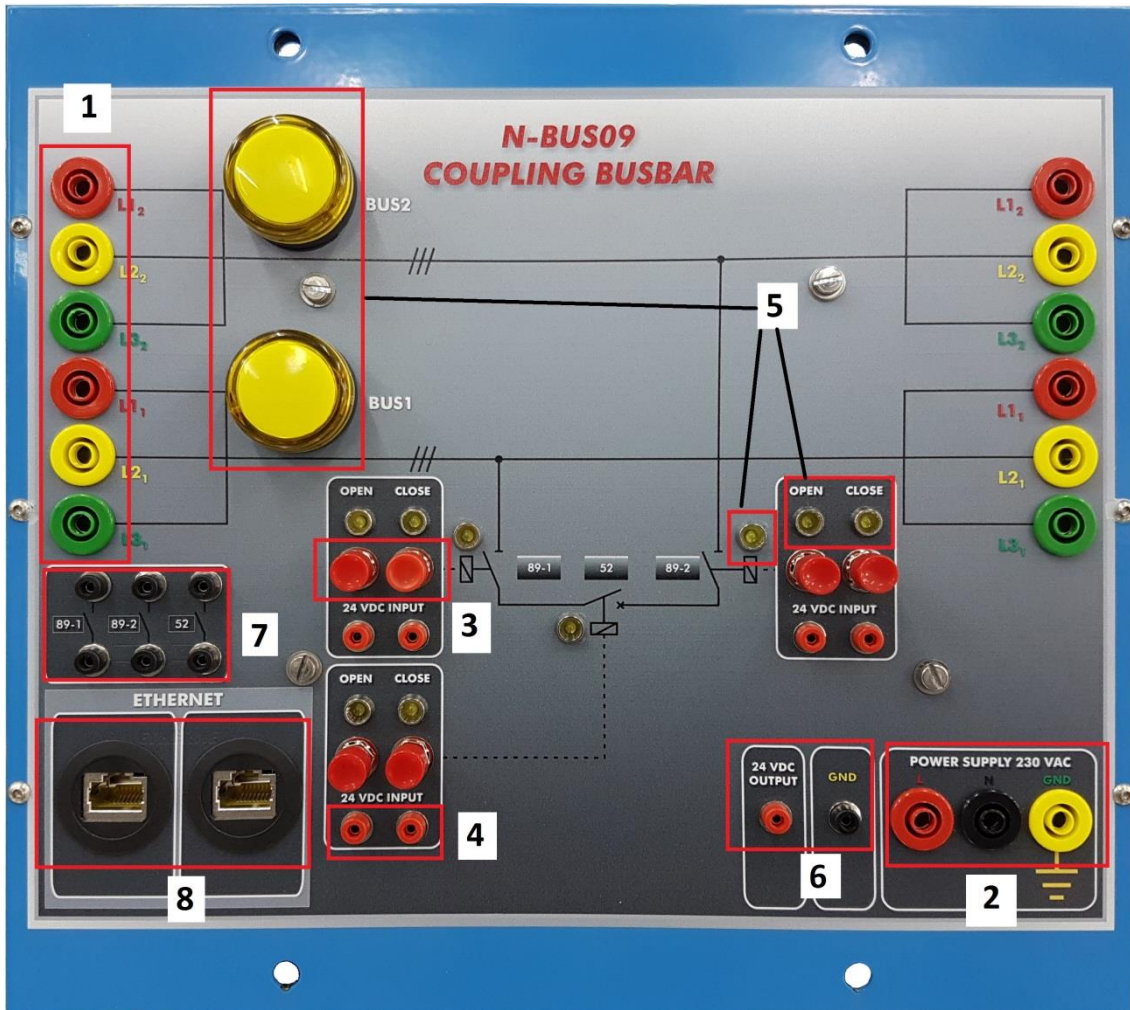


Figure 14: N-BUS09 module

This module works as a three phase coupling bus bar with two disconnectors and one circuit breaker. This one can work with similar bus bar modules.

El N-BUS09 consists of the following elements:

- 1. Three Phase Double Power terminals:** These terminals are used for coupling of two busbars.

- 2. 230 VAC + GND Power supply terminals.**
- 3. Open and close push buttons:** These push buttons are used to work in local control mode. Each push button enables and disables the disconnectors and circuit breakers. Disconnectors are named as 89 and circuit breakers are named as 52.
- 4. 24 VDC input signal connectors:** These connectors allow open and close the disconnectors and circuit breakers via 24 VDC signal. This signal can be the own of the module or other signal with the gnd terminal connected with this module.
- 5. State indicators light:** The lights located in the busbars indicate the presence of voltages in the busbars. On the other hand, the lights located over the push buttons indicate the presence of 24VDC remote signal to open and close the circuit breakers and disconnectors. Finally, the lights located over the coil symbol indicate the actual state of the circuit breakers and disconnectors.
- 6. 24VDC and GND output terminal:** This terminal is used to open and close commands of circuit breakers. This terminal can be wired with auxiliary contacts for logic commutations.
- 7. Auxiliary contacts:** These are circuit breakers which are opened and closed depending on the state of 89-1, 89-2 and 52 disconnectors and circuit breaker respectively.
- 8. Ethernet connections:** These connectors allow connect this module with other modules and be able to control it from a PC and the SCADA Control System.

7.1.2.10 N-ERP-MF01. Digital Fault Simulator Module

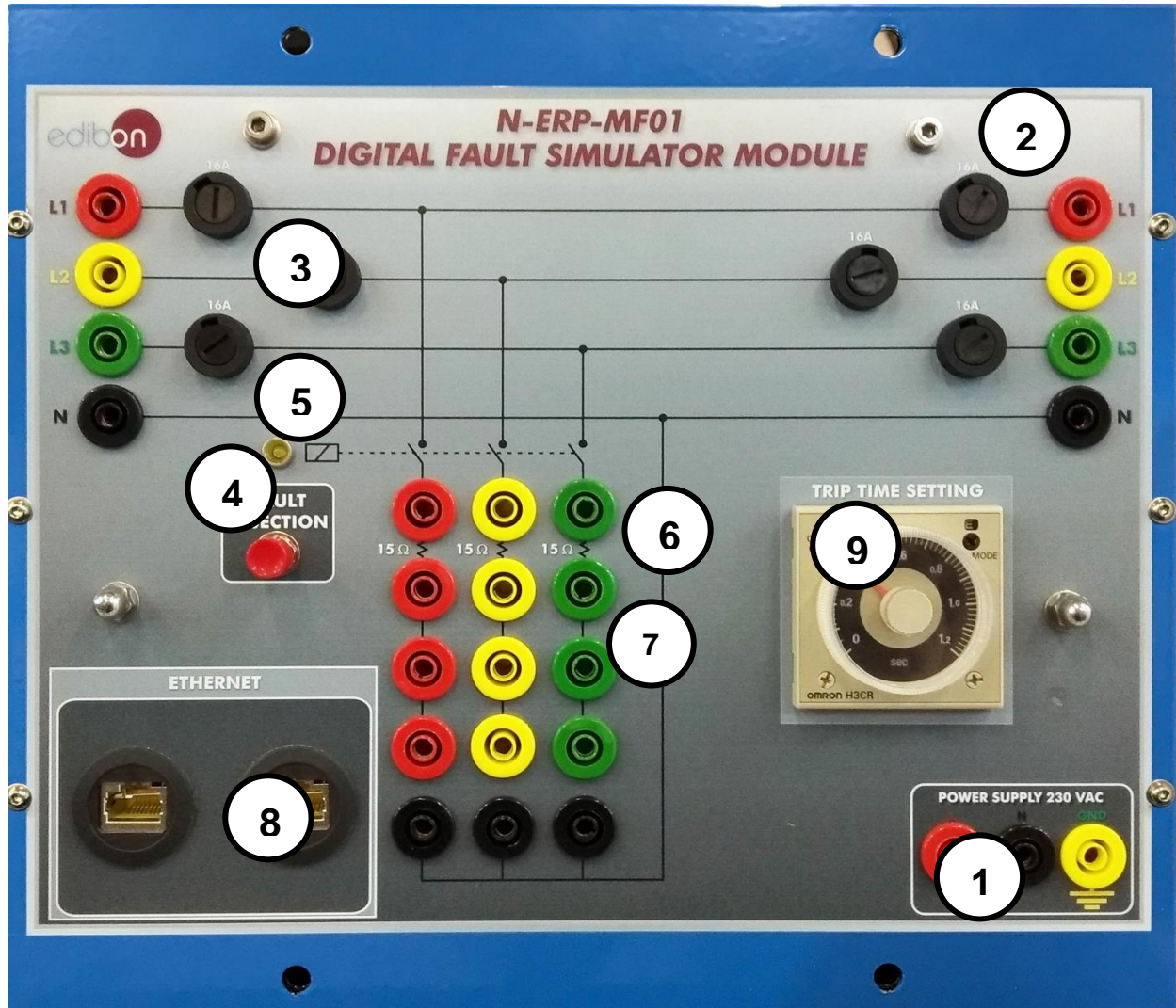


Figure 15: N-ERP-MF01 module

This module is designed to inject faults in any point of the power system. For this purpose, the module includes a series of connections and a trip timer. The connections allow set the type of fault to be injected and the timer allows setting the fault time injected in the power circuit.

The N-ERP-MF01 consists of the following elements:

1. 230 VAC + GND Power supply terminals.

2. **Three-Phase power terminals:** These terminals must be wired in the point where the fault is injected.
3. **Fuses.**
4. **Fault injection push button:** This push button sends a signal to the timer. The timer enables the circuit breaker.
5. **Indicator lamp:** This lamp indicates when the breaker is enabled.
6. **Fault resistances:** These resistances allow configure the faults with or without short circuit impedance.
7. **Fault configuration terminals:** These terminals allow configuring the type of fault. The fault can be three pole, two pole or single pole short circuit. The configuration of the type of short circuit is carried out with the provided jumpers.
8. **Ethernet connections:** These connectors allow connect this module with other modules and be able to control it from a PC and the SCADA Control System.
9. **Trip time setting:** Allow setting the trip time of the fault to inject

7.1.2.11 N-CAR35T3D. Three-Phase Digital Bank of Commutable Resistors

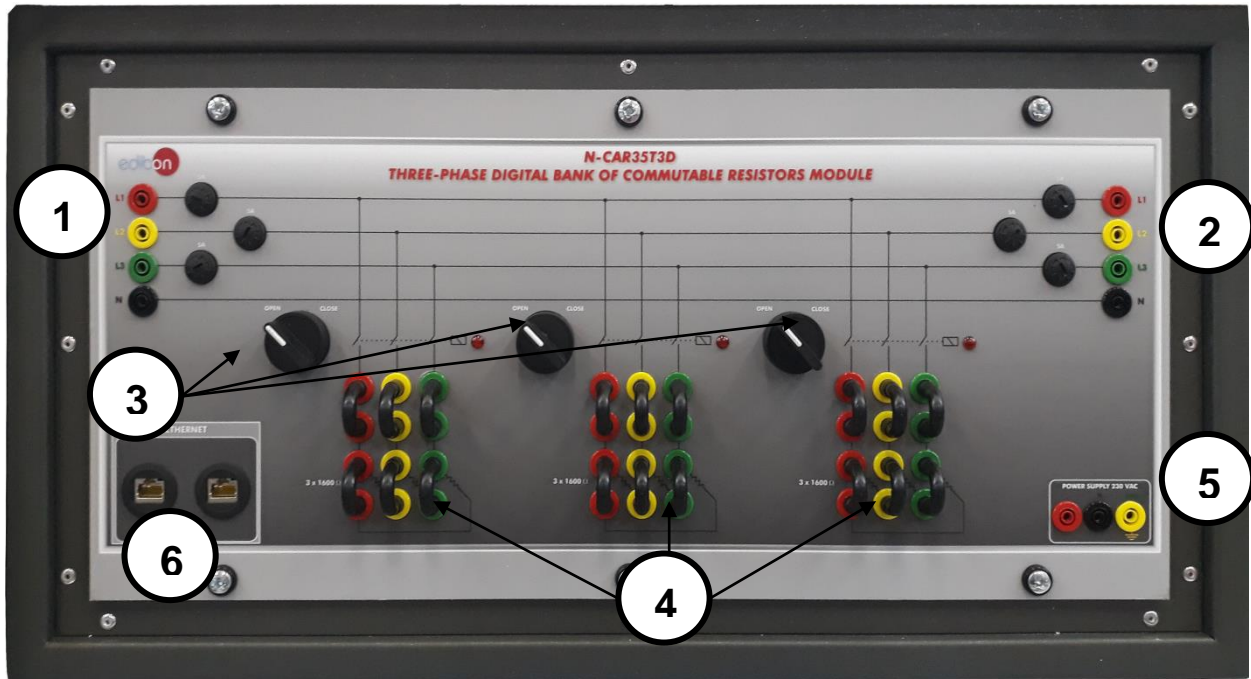


Figure 16: N-CAR35T3D module

1. **Input terminals:** input terminals L1, L2 and L3 with neutral N of the line to connect with the rest of modules.
2. **Output terminals:** output terminals L1, L2 and L3 with neutral N of the line to connect with the rest of modules.
3. **Selector switch:** it consists of a switch with two positions in order to connect and disconnect the resistor Banks:

Position OPEN → resistor Bank disconnected.

Position CLOSED → resistor Bank connected.

4. **Resistors Bank:** it consist of three Banks of three resistors of 1600 Ω each one that can be wired to perform a star or delta connection.
5. **230 VAC + GND Power supply terminals.**
6. **Ethernet connections:** These connectors allow connect this module with other modules and be able to control it from a PC and the SCADA Control System.

7.1.2.12 N-CAR36T3D. Three-Phase Digital Bank of Commutable Inductances Module

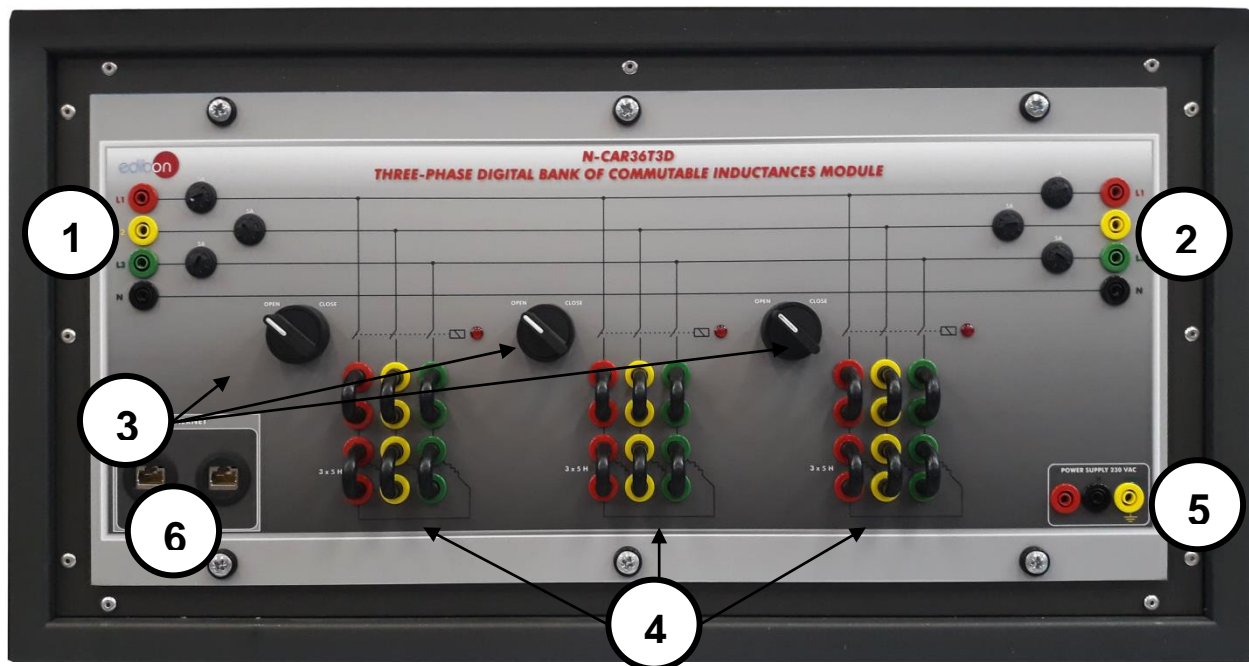


Figure 17: N-CAR36T3D module

- 1. Input terminals:** input terminals L1, L2 and L3 with neutral N of the line to connect with the rest of modules.
- 2. Output terminals:** output terminals L1, L2 and L3 with neutral N of the line to connect with the rest of modules.
- 3. Selector switch:** it consists of a three-pole switch with two positions in order to connect and disconnect the inductance Bank:

Position OPEN → inductance Bank disconnected.

Position CLOSED → inductance Bank connected.

4. **Resistors Bank:** it consist of three Banks of three inductances of 5 H each one. These inductances can be configured in star and delta.
5. **230 VAC + GND Power supply terminals.**
6. **Ethernet connections:** These connectors allow connect this module with other modules and be able to control it from a PC and the SCADA Control System.

7.1.2.13 N-CAR19T3D. Three-Phase Digital Bank of Commutable Capacitors Module

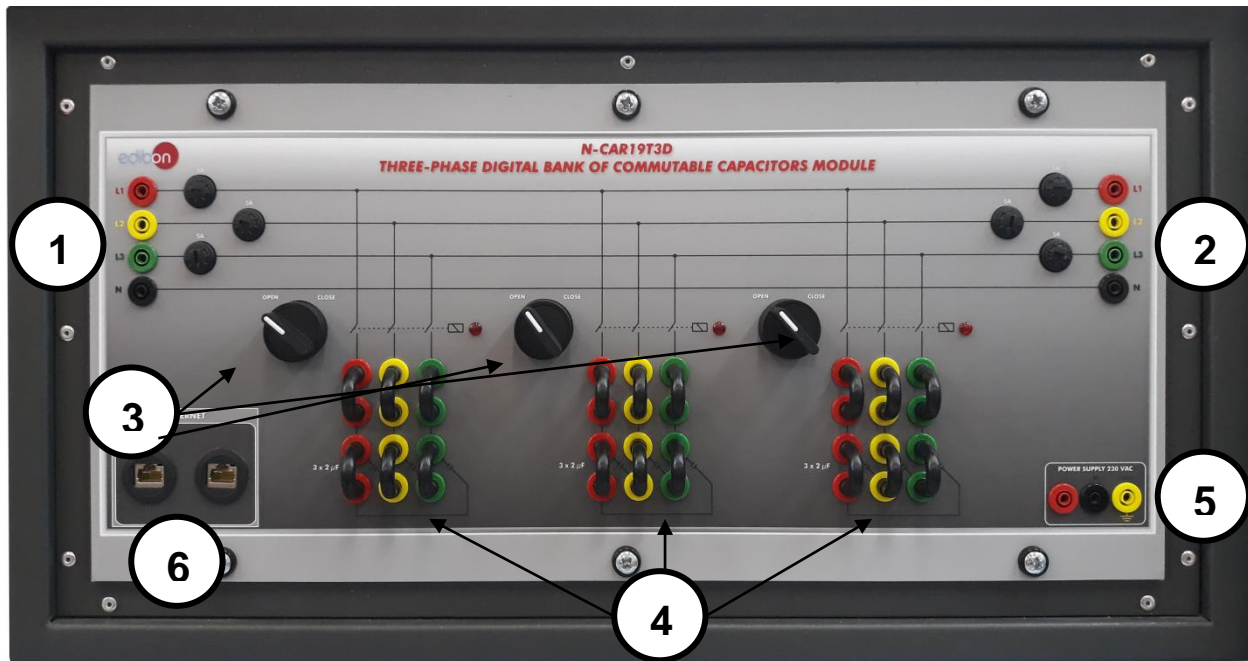


Figure 18: N-CAR19T3D module

1. **Input terminals:** input terminals L1, L2 and L3 with neutral N of the line to connect with the rest of modules.
2. **Output terminals:** output terminals L1, L2 and L3 with neutral N of the line to connect with the rest of modules.
3. **Selector switch:** it consists of a three-pole switch with two positions in order to connect and disconnect the capacitors Bank:

Position OPEN → capacitor Bank disconnected.

Position CLOSED → capacitor Bank connected.

- 4. Capacitors Bank:** it consist of three Banks of three capacitors of $2\mu\text{F}$ each one. These capacitors can be configured in star and delta.
- 5. 230 VAC + GND Power supply terminals.**
- 6. Ethernet connections:** These connectors allow connect this module with other modules and be able to control it from a PC and the SCADA Control System.

7.1.2.14 TRANS3/5KGR . 5 KW Three-phase Grid Transformer

The TRANS3/5KGR is a 5KW three-phase transformer with start/triangle connection that provides galvanic protection to our power system. It is essential to have this type of isolation to avoid damage to the grid in case of undesired faults.

It is a transformer with $r = 1/1$ transformation ratio.

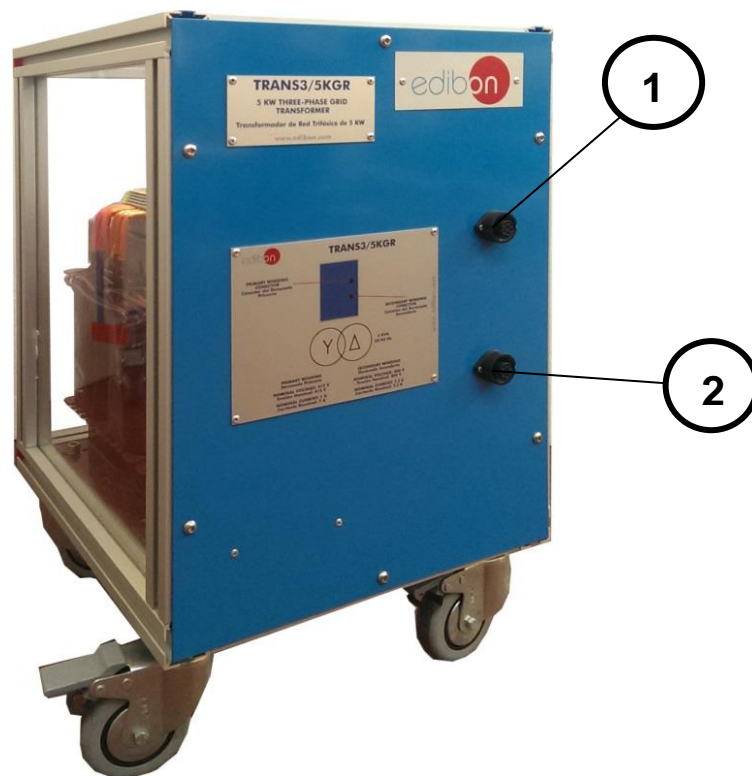


Figure 19: TRANS3/5KGR

1. Primary winding: 400 VAC star connection by a hose containing four wires (three phases and the neutral).
2. Secondary winding: 400 VAC delta connection by a hose containing three wires (three phases, no neutral).

7.1.2.15 TRANS3/5KSU. 5 KW Three-Phase Step-up Transformer

The TRANS3/5KSU is a 5KW three-phase transformer with star/triangle connection to simulate the voltage increase from generation value to transportation values. It is in fact a transformer with $r = 1/1$ ratio.



Figure 20: TRANS3/5KSU.

1. Pin connector: Terminal with a main hose splitted in two of them, one for the primary winding with 400 VAC star connection (four wires for the three phases and the neutral) and the other one for the secondary winding with 400 VAC delta connection (three wires for the three phases, no neutral).

7.1.2.16 TRANS3/5KRM. 5 KW Three-phase Autotransformer with Motor Voltage Regulator:

The TRANS3/5KRM is a 5KW three-phase transformer with star/triangle connection to compensate the drop voltage in the transmission line and keep constant the output voltage to the loads. It is in fact a transformer with $r = 1/1$ ratio.



Figure 21: TRANS35KRM

- 1. Main terminal:** 400 VAC star/delta connections directly connected with a power hose to the N-REG16 for power supply.
- 2. Signal terminal:** Connected to the N-REG16 signal connector for the motor of the distribution transformer to receive signals from the voltage regulator.

7.1.2.17 GMG4.5K2PH. 4, 5 kW Generator-Motor Group

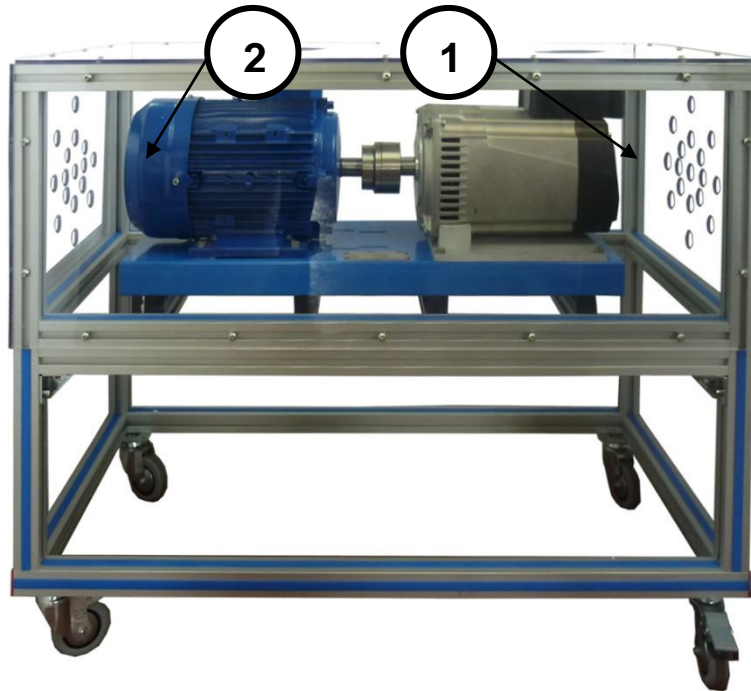


Figure 22: GMG4.5K3PH generator-motor group

The motor-generator group enables the student to simulate an electric power production plant. For safety reasons, the rated power of our generator is 4.5KVA.

The GMG4.5K3PH consists of the following elements:

1. **Main motor and frequency controller:** this motor is a three-phase induction motor of squirrel cage used to move the generator and simulate any type of turbine. It has a rated power of 5 KVA to 3000 rpm. The induction motor is driven by the frequency controller. The frequency controller controls the speed of the main motor. It is supplied from Power Generation Substation Module and receives control signals from Control and Protection of Tubine-Generator

Group Module.

2. **Three-phase generator:** it is a synchronous three-phase generator with independent excitation and brushes. It is used to generate electric power. It has a rated power of 4.5KVA to 3000 rpm and rated excitation current of $I = 4$ A.

7.1.3 Description of the process

The AEL-TI- has been designed to demonstrate how a smart grid works. The motor simulate a turbine which is coupled to the shaft of the alternator. This motor-generator group supply power to the smart grid and can work in isolated operation or in synchronism with the grid. In the operation in parallel with the grid the user will learn the premises to carry out the synchronization with the electrical grid while in isolated operation the user will learn about power transmission, distribution and consumption by isolated loads.

The application provides several generation protections to work safely and see exceptionally how the protections operate. The motor is protected by the frequency controller in order to not exceed the nominal current. The motor-generator group controller, the Easygen, has two back-up protection relays: overcurrent and reverse power relay. Besides, it has several protection to generator, motor and network such as: maximum/minimum voltage (59/27), maximum/minimum frequency (81O/U), voltage asymmetry, detection of dead busbars, overvoltage (32), load unbalance (46), negative sequence power/reduced power (32R/F), overcurrent by defined curve (50/51), overspeed/subspeed (12), inverse time overcurrent (IEC255), measured ground fault (50N/51N), phase rotation, switches fault and vector jump.

The power generation substation where the generator is connected allows carrying out several manoeuvres such as the control of the motor-generator group through speed and excitation and the synchronization between the generator and the national grid.

Additionally, this application includes a module with analog meters in order to analyse the behaviour of the generator. These analog meters are active

power meter, reactive power meter, voltmeter and DC meter. These are very useful because they can detect current and voltage oscillations in the power substation.

When working in isolation mode the electric power generated by the substation is transmitted with the transmission line module up to the loads modules. The transmission line parameters can be set in order to simulate different conditions such as length or capacitive effect variations. Similarly, resistive, inductive and capacitive loads can be commutated to increase or decrease the energy consumption. Additionally, several network analysers are included to be connected upstream and downstream of the transmission line or in the output of the power generator. It allows measuring the electrical parameters in the generation and the energy losses in the transmission lines. The user can change the concentrated parameters of the line with variable inductances, capacitances and resistances and see the effects of these changes.

The consumption loads are divided into resistive, inductive and capacitive loads which are configurable in order to the user can carry out delta or star connection.

Before loads, this application includes a series of bus bars with double bus bar topology. These bus bars provide to the user the experience and the understanding of switching power substations. With these modules it is possible realise practices of opening and closing of circuit breakers and disconnectors, energy distribution, maintenance operations with coupling bus bar, etc.

The AEL-TI- application can work in local or remote mode. This means that in local mode the user can control the modules physically from the panels. In addition, in local mode, the user can chose automatic or manual frequency and voltage control. If automatic control is selected the Automatic Voltage and

Frequency Controller controls the motor-generator group. In the other hand, if manual control is selected, the user can control the current excitation and speed with the potentiometers located in the right side of the power substation module.

Remote mode uses SCADA technology to control all variables from the PC. This mode disables all switches of the module with the exception of emergency stop mushroom.

The following picture shows a representative diagram of the smart grid: generation, transmission and consumption:

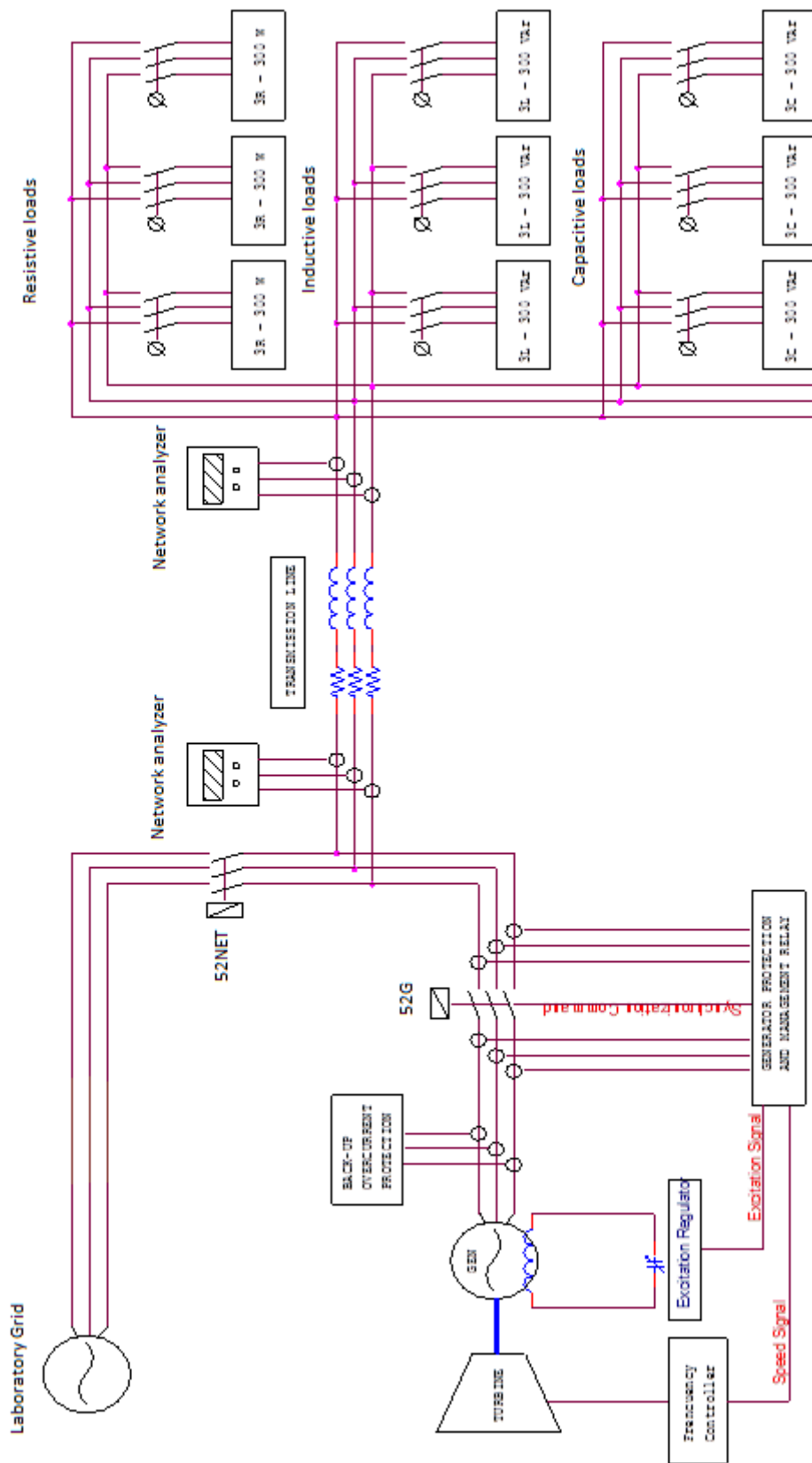
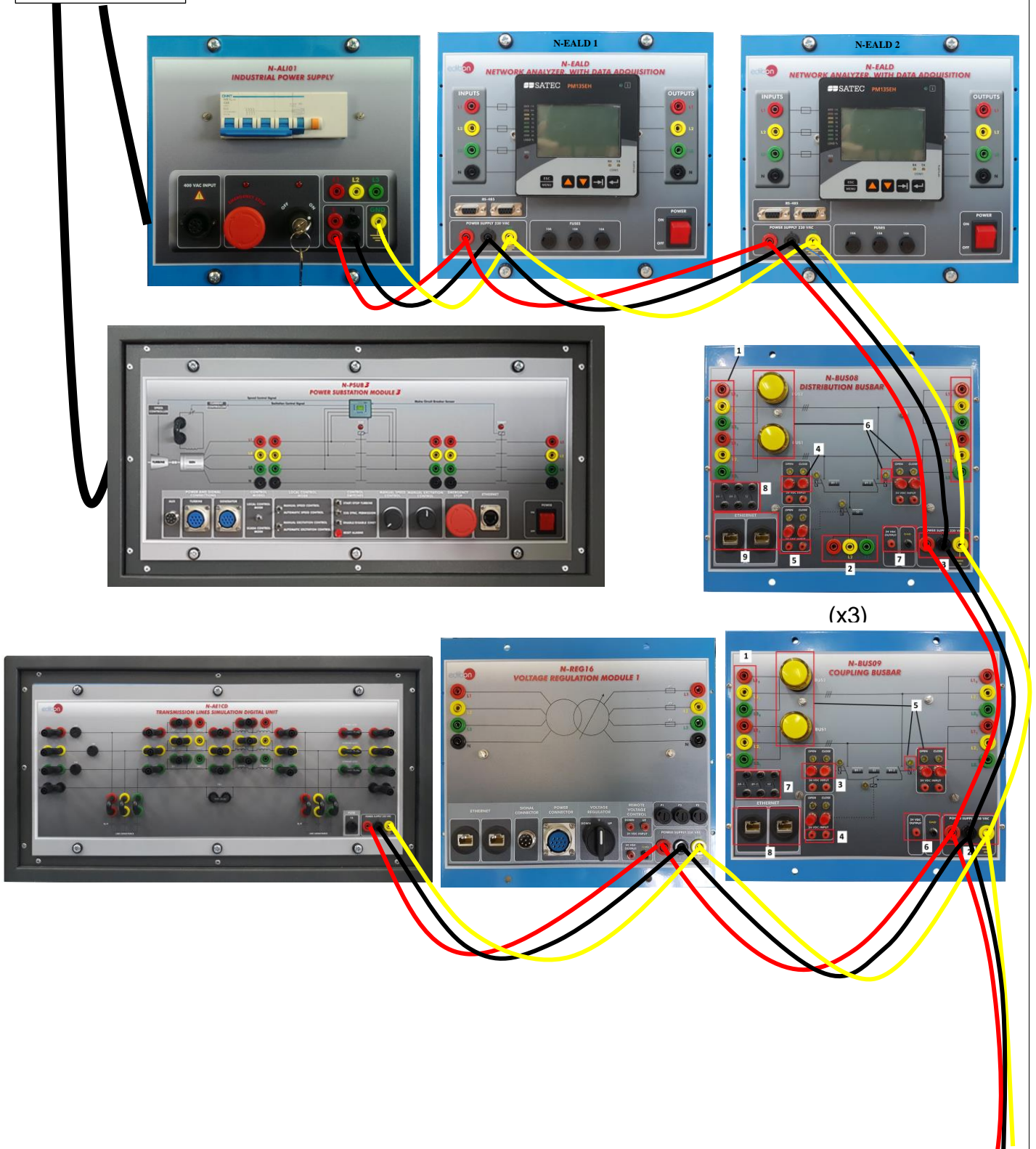


Figure 23: AEL-TI- electrical diagram

7.1.3.1 Cable assembly of the AEL-TI- modules

7.1.3.1.1 Power supply wiring

Three-phase
Power supply



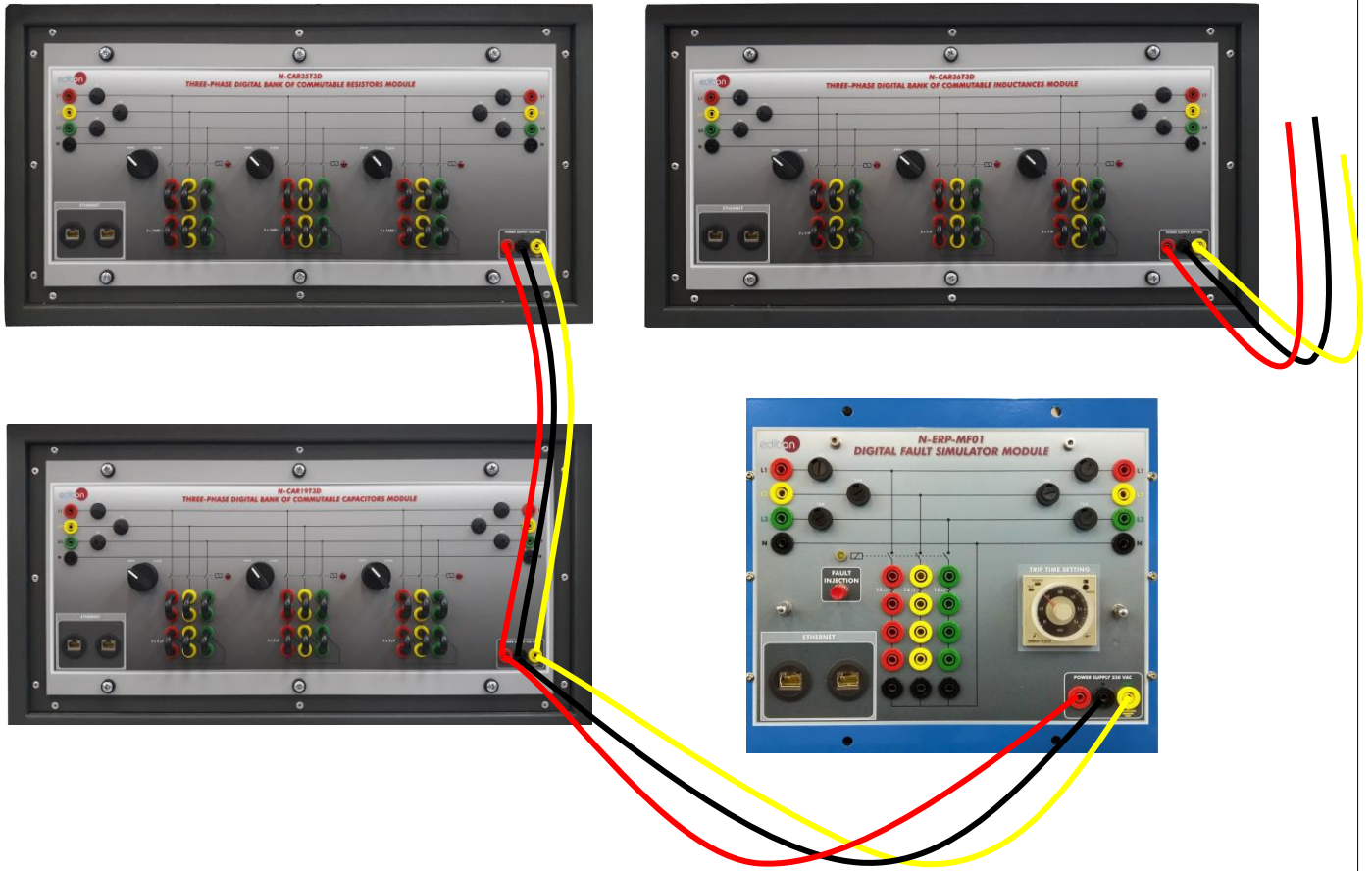


Figure 24: Power supply wiring

7.1.3.1.2 Generator measuring instruments wiring

The instrumentation module (N-PPIM2) can be wired as it is shown in the picture below to measure the electrical parameters of the generator.

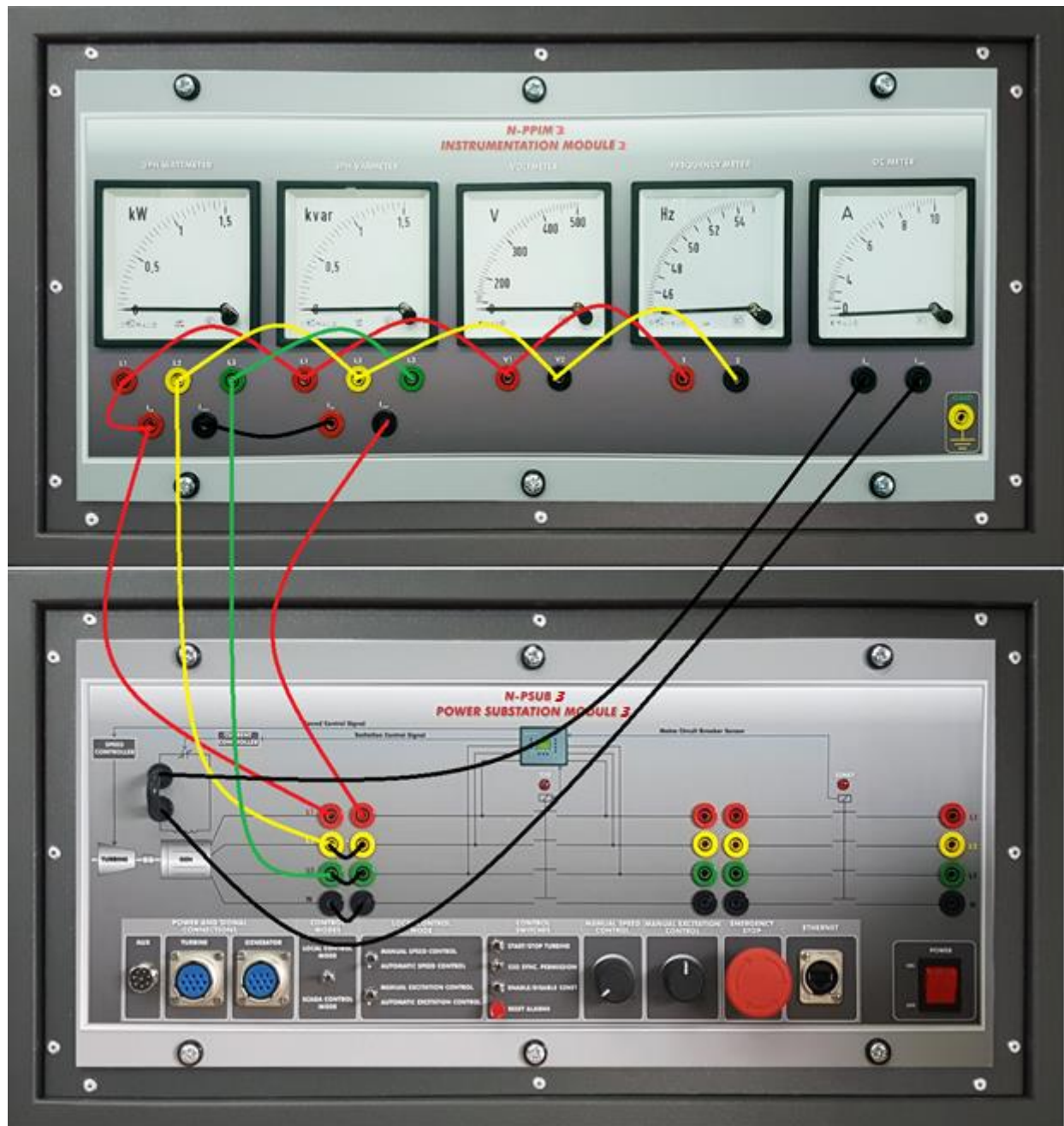


Figure 25: Instrumentation module 2 wiring

7.1.3.1.3 Stand-alone configuration wiring

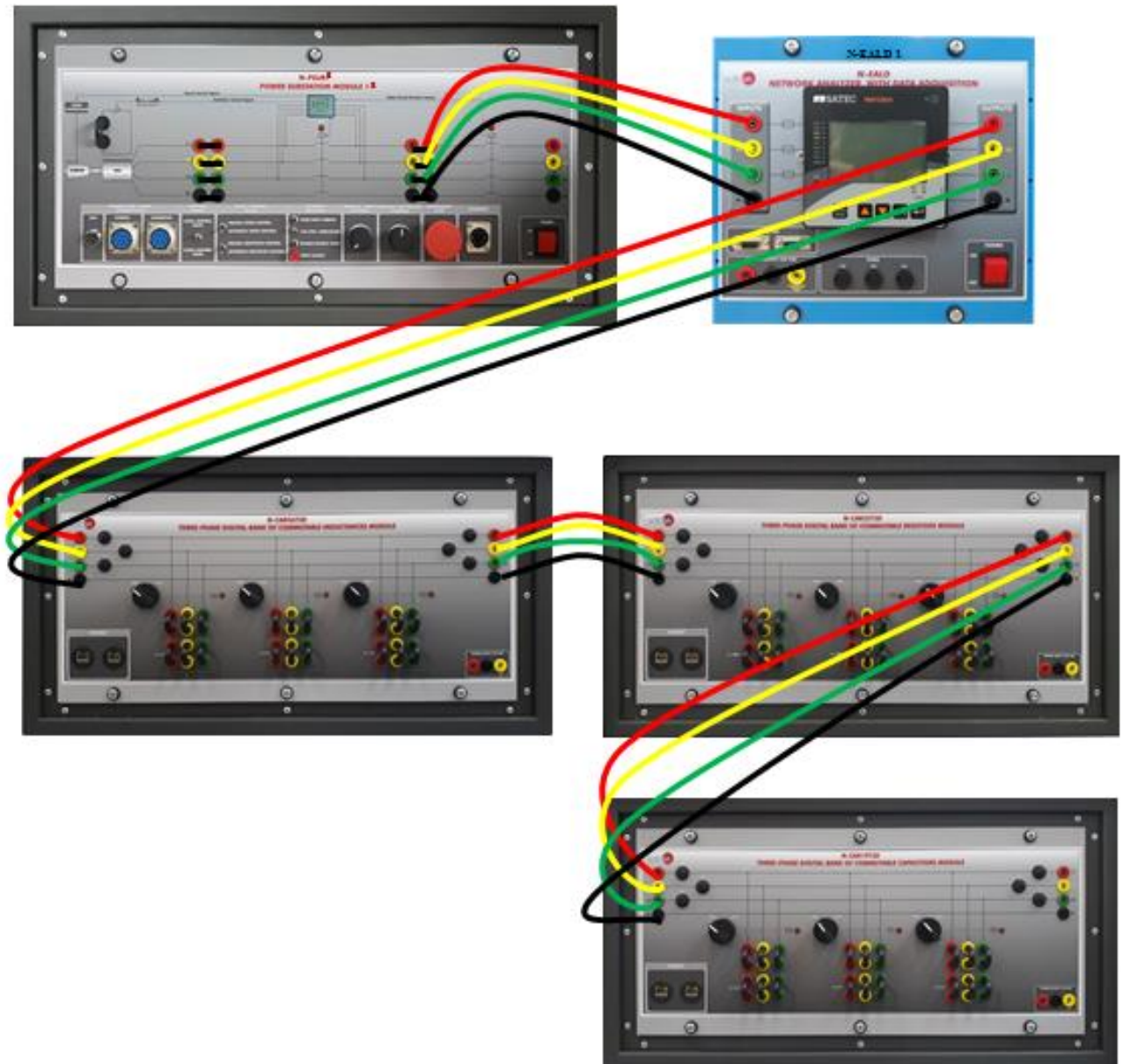


Figure 26: Example of stand-alone configuration wiring

7.1.3.1.4 Synchronization of the generator with the grid wiring.

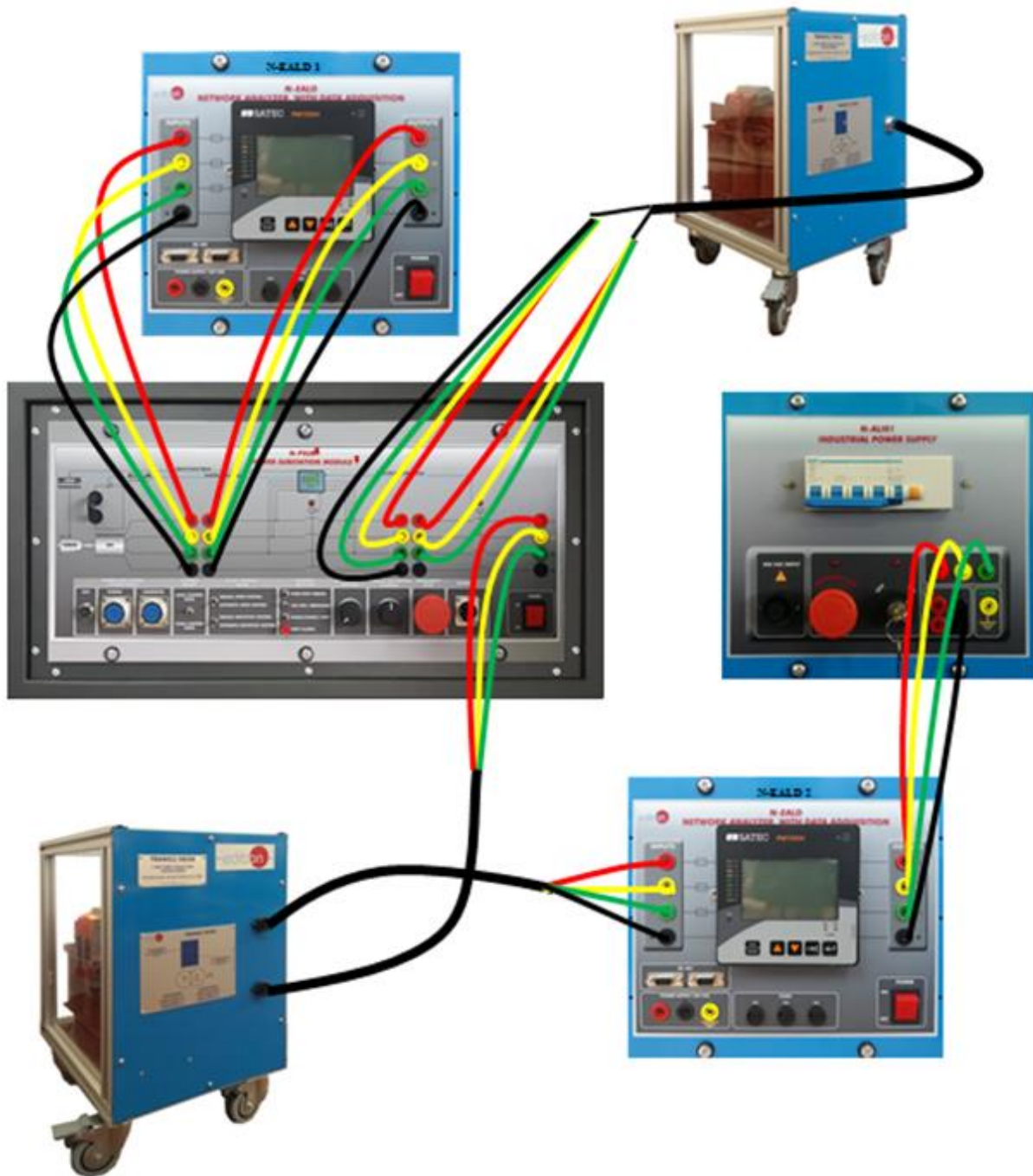


Figure 27: Example of synchronization of the generator with the grid

7.1.3.1.5 Stand-alone configuration with transmission line and loads wiring

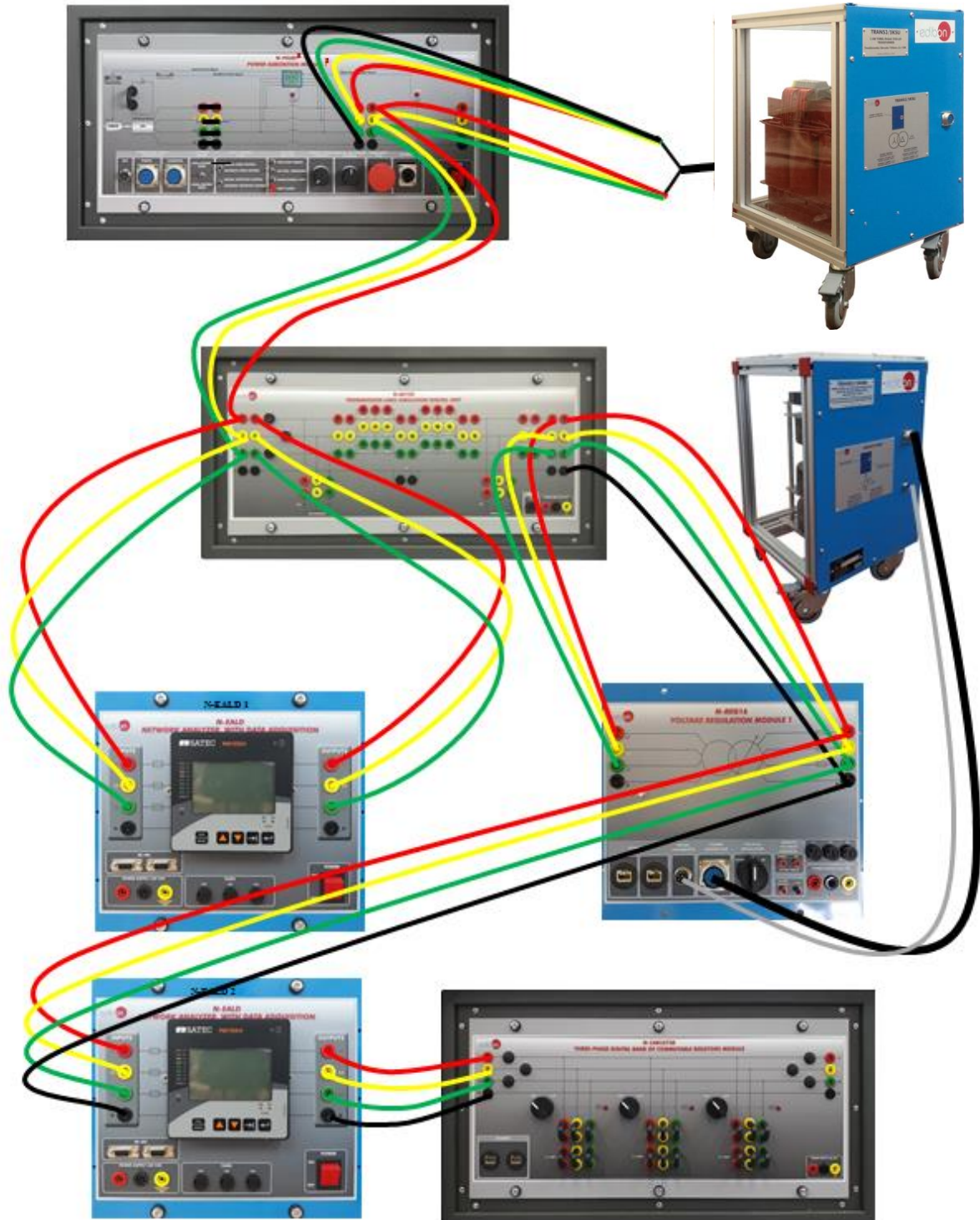
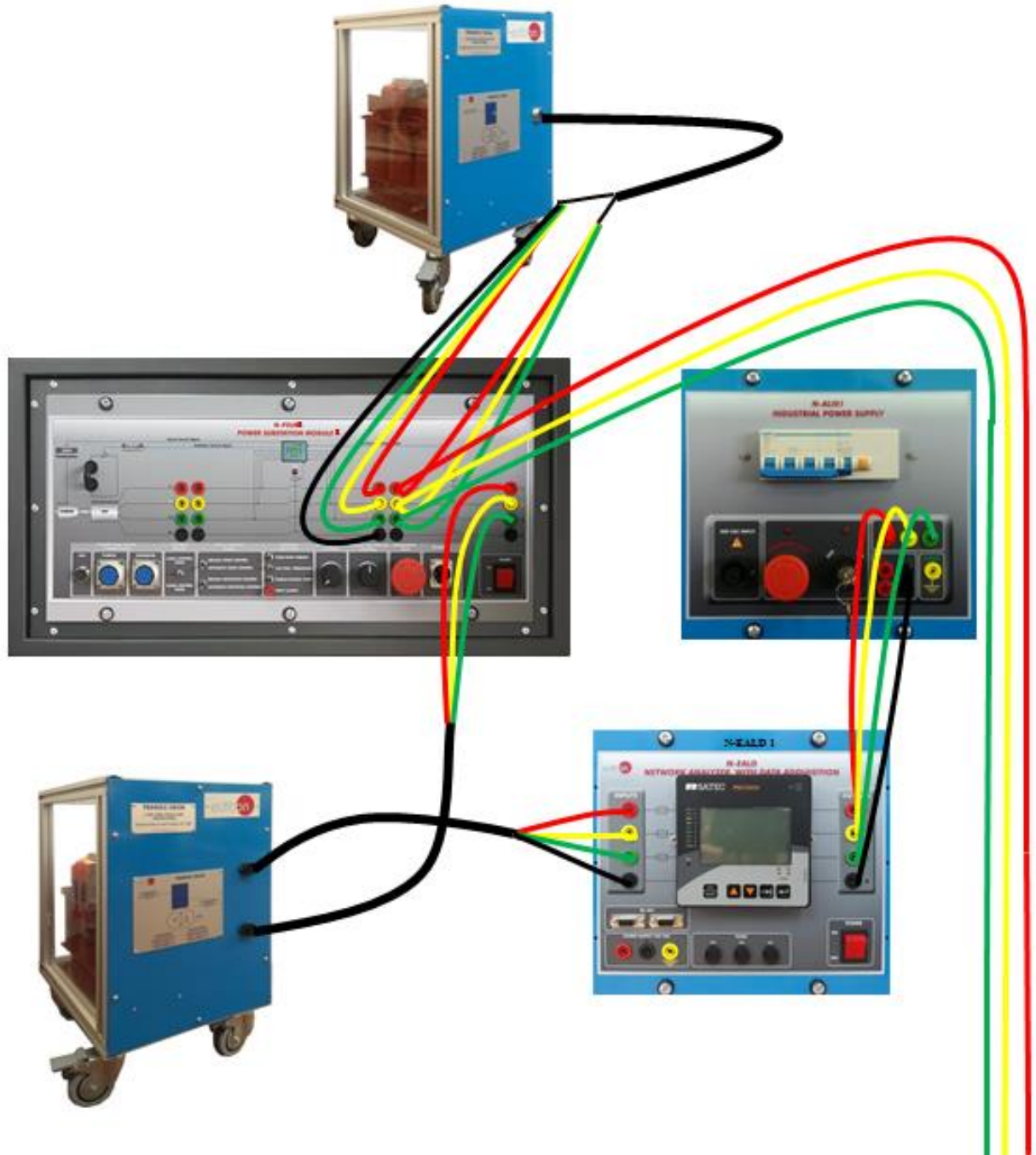
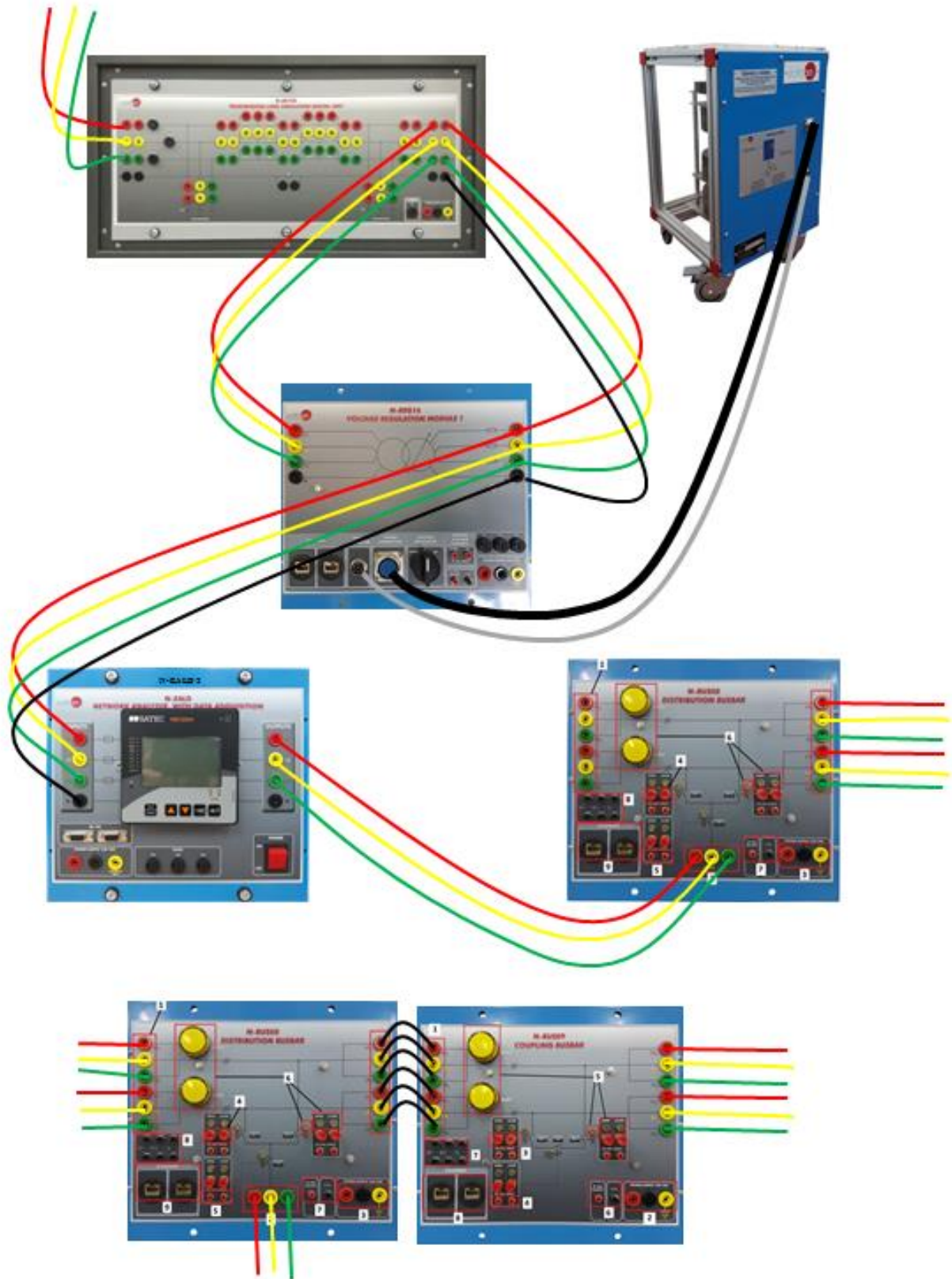
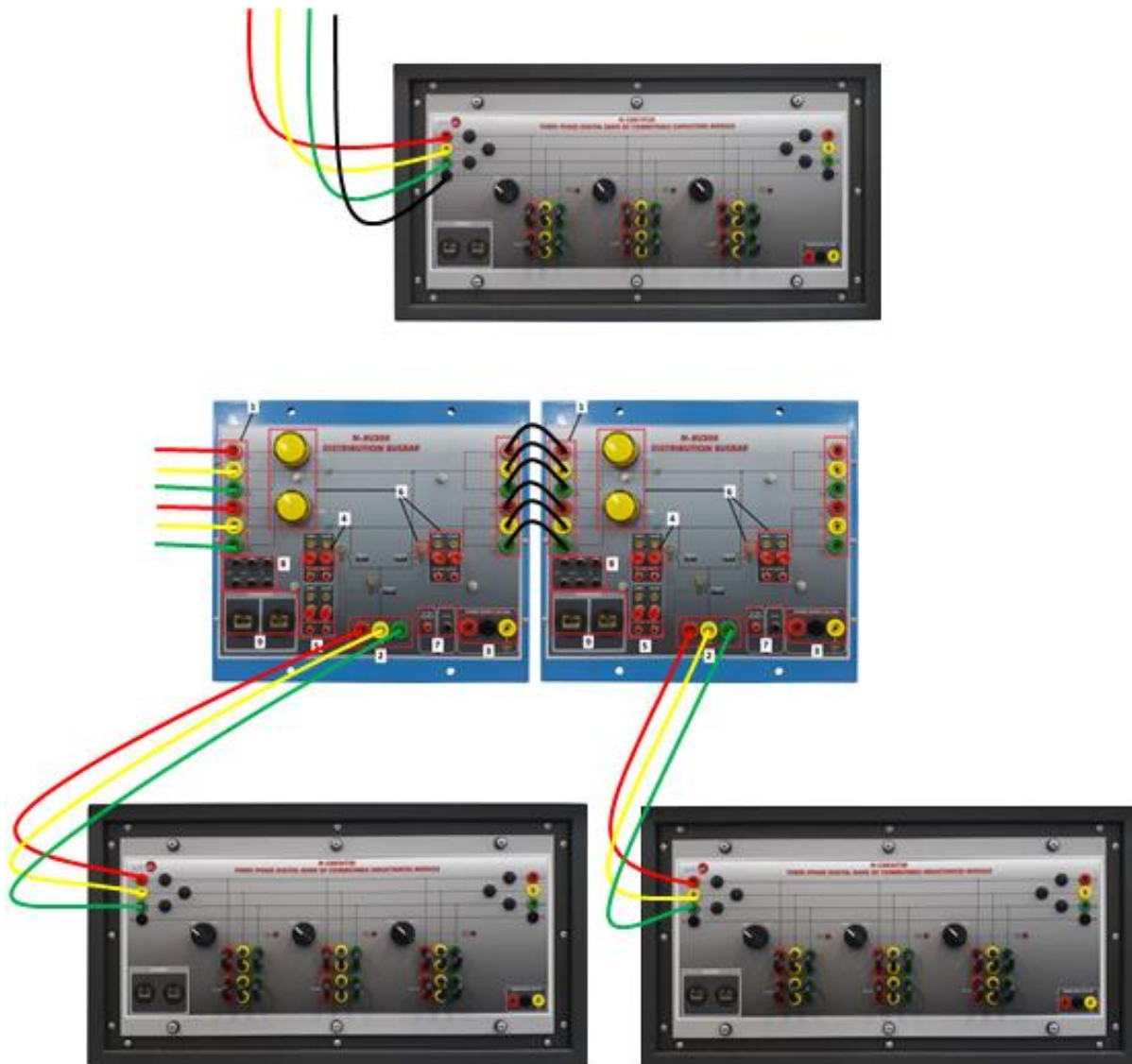


Figure 28: Example of stand-alone configuration along with transmission line and loads wiring

7.1.3.1.6 Synchronization with the grid along with transmission line and distributed loads







29: Example of synchronization with the grid along with transmission line and distributed loads

7.1.4 Practical possibilities

The following are some practical exercises possibilities:

- 1.- Stand-alone manual control of voltage and frequency of the generator.
- 2.- Stand-alone automatic control of voltage and frequency of the generator.
- 3.- Synchronization operations with the synchronous generator and the grid.
- 4.- Stand-alone operation with transmission line and loads.
- 5.- Automatic synchronization with the grid along with transmission line and distributed loads.
- 6.- Digital faults simulation in stand-alone operation.

Practical exercises possibilities with SCADA:

- 1.- Stand-alone manual control of voltage and frequency of the generator with the SCADA system.
- 2.- Stand-alone automatic control of voltage and frequency of the generator with the SCADA system.
- 3.- Automatic synchronization operations with the synchronous generator and the grid with SCADA system.
- 4.- Stand-alone operation with transmission line and loads with SCADA system.

- 5.- Automatic synchronization with the grid along with transmission line and distributed loads with SCADA system.

- 6.- Digital faults simulation in stand-alone operation with SCADA system.

7.1.5 Specifications

7.1.5.1 N-ALI01: Industrial Power Supply

Supply voltage: 400 VAC, 3PH+N+G.

ON-OFF removable key.

Output voltage connections:

Three-Phase + Neutral: 400 VAC.

Single-Phase: 230 VAC.

Three-Phase supply hose with IP44 3PN+E 32A 400V connecting plug.

Differential magnetothermal: 4 poles, 25A, 300mA AC 6KA

7.1.5.2 N-PPIM2: Instrumentation Module 2

Three-Phase wattmeter:

Measured range: 0 - 5 kW

Three-Phase varmeter:

Measured range: 0 - 5 kVar

Voltmeter:

Measured range: 0 - 500 VAC

Frequency meter:

Measured range: 45 - 55 Hz

DC meter:

Measured range: 0 - 5 A

7.1.5.3 N-PPCM1: Control and Protection of Turbine-Generator Group Module 1

Automatic speed and voltage controller (easygen):

Enables to connect up to 16 electric generators in parallel-island with distribution of active and reactive load and start/stop in function of the load demand.

Enables to connect a generator in parallel with the grid.

Enables different switches control modes, such as opening, closing and synchronization.

Analogical outputs to control voltage and frequency regulators.

Three-phase measurement of the grid and the generator voltage.

Three-phase measurement of the generator intensity and power.

Single-phase measurement of the grid intensity.

Protection system:

Generator:

Maximum/minimum voltage (59/27), maximum/minimum frequency (81O/U), voltage asymmetry, detection of dead busbars, overvoltage (32), load unbalance (46), negative sequence power/reduced power (32R/F), overcurrent by defined curve (50/51), inverse time

overcurrent (IEC255), measured ground fault (50N/51N), phase rotation, switches faults.

Network:

Maximum/minimum voltage (59/27), maximum/minimum frequency (81O/U), vector jump, phase rotation.

Six alarms:

Alarm 1: Reverse power

Alarm 2: Overcurrent

Alarm 3: Over/undervoltage

Alarm 4: Inverse Time Overcurrent

Alarm 5: Over/under frequency

Alarm 6: Shutdown Alarms

Four operation signals:

Ready for operation

Start request

Synchronization conditions

Permission for synchronization

Back-up protections:

Current relay.

Reverse Power relay.

Ethernet connection: RJ45 communication port. This communication port is only for technical support from Edibon.

7.1.5.4 N-PSUB: Power Generation Substation Module 3

Supply voltage: 400 VAC, 3PH+N.

ON / OFF switch.

Power and signal connections:

Auxiliary connection.

Three-phase turbine supply hose with IP44 3PN+E 32A 400V connecting plug.

Three-phase generator supply hose with IP44 3PN+E 32A 400V connecting plug.

Three switches to choose between the different modes:

Local and remote control mode.

Manual and automatic speed control.

Manual and automatic excitation control

Three control switches to:

Start and stop the turbine.

Give permission to synchronize the generator with the grid.

Give permission to synchronize the generator with the national grid.

Two potentiometers to regulate:

Turbine speed.

Generator excitation.

Emergency stop button.

Two circuit breakers.

Different terminals points to measure.

Ethernet connection: two RJ45 communication port for SCADA remote control.

7.1.5.5 N-AE1CD: Transmission Lines Simulation Digital Module

Power supply voltage: 230 VAC +GND

Line Voltages: 400 VAC + N

Three-phase line with variable parameters.

Concentrated parameters line.

Two capacitances Banks between line and ground composed by three capacitances of 2 μ F.

Resistance of the line that can be wired independently:

One resistor of 15 Ω .

One resistor of 33 Ω .

Inductance of the line with several values: 32 mH, 72 mH.

Neutral resistor of 15 Ω .

Fuse: 1 A

7.1.5.6 N-EALD: Network Analyser Unit with Computer Data Acquisition

ON-OFF switch.

Power supply voltage: 230 VAC +GND

Input terminals: Input connection with the measurement point.

Output terminals: Output connection with the measurement point.

Digital outputs: Three digital outputs are used for pulses or alarms, or for combining both.

RS-485 Communication port.

Fuses: 3x10 A

Network Analyser Display. It shows:

Active, reactive and apparent power

Active, reactive and apparent energies

Lines and phase currents

Line and phase voltages

Frequencies

Power Factor

7.1.5.7 N-REG16: Voltage Regulation Module 1

230 VAC+GND Power Supply terminals.

24 VDC output terminal

24 VDC input terminal (up voltage).

24 VDC input terminal (down voltage).

Slide commutator with three positions.

Power connector.

Signal connector.

Fuses: 3 x 10 A

Input power terminals:

Power input connections: L1, L2, L3, N.

Output power terminals:

Power output connections: L1, L2, L3, N.

Ground Terminal.

7.1.5.8 N-CAR35T3D: Three-Phase Digital Bank of Commutable Resistors

Configurable Star and Delta connections.

Three banks with three-phase resistors of 1600 Ω each one.

Nominal voltage: 400 VAC.

Nominal power: 3 x (3 x 300) W.

7.1.5.9 N-CAR36T3D: Three-Phase Digital Bank of Commutable Inductances Module

Configurable Star and Delta connection.

Three Banks with three-phase inductances of 5 H each one.

Nominal voltage: 400 VAC.

Nominal power: 3 x (3x300) VAr.

7.1.5.10 N-CAR19T3D: Three-Phase Digital Bank of Commutable Inductances Module

Configurable Star and Delta connection.

Three Banks with three-phase capacitors of 2 μ F each one.

Nominal voltage: 400 VAC.

Nominal power: 3 x (3 x 300) VAr.

7.1.5.11 TRANS3/5KSU 5 KW Step-up transformer

5KVA step-up transformer.

Rated power: 5KVA.

Voltage in primary winding: 400VAC star.

Voltage in secondary winding: 400VAC delta.

7.1.5.12 TRANS3/5KGR 5 KW Grid Transformer

5 KVA grid transformer.

Rated power: 5KVA.

Voltage in primary winding: 400VAC star.

Voltage in secondary winding: 400VAC delta.

7.1.5.13 TRANS3/5KRM.Three-Phase Autotransformer with Motor Voltage Regulator.

5 KVA distribution autotransformer.

Rated power: 5 KVA

Voltage in primary winding: 400VAC star.

Voltage in secondary winding: 400VAC delta.

Signal connection to receive step up and down signals from the voltage regulator module.

7.1.5.14 GMG4.5K2PH. 4,5 kW Generator-Motor Group

Nominal power: 4,5 kVA.

Power factor: 0,8

Nominal output voltage: 3x 400 VAC.

Frequency: 50/60 Hz.

Speed: 3000 rpm.

Nominal output current: 8 A.

Nominal excitation current: 4 A

7.1.6 Dimensions and weight

- 4000 x 840 x 2010 mm. approx.
- 180 Kg. approx.

7.1.7 Required services

Electrical supply: single phase, 380 V/50 Hz. or 220 V/60 Hz, 6 kW.

7.2 THEORY

7.2.1 Smart Grids

Over the last two decades, the electric system has grown due to the emergence of new factors which are decentralizing the energy generation. Before this decentralization, the electrical grid was a unidirectional energy flux from the generation plants to the consumers.

Although the transmission and distribution power lines have always been in continuous development, currently there are new challenges to address such as improving the energy efficiency, incorporating the renewables energies, and reducing the polluting emissions or developing energy storage technologies.

The way to carry out all these advances is an electrical grid where the electricity is bidirectional and the homes or the enterprises can be consumers or become in small generation groups. This advanced grid is called Smart Grid.

The development of a Smart Grid requires a combination of the electric, information and telecommunication systems. These systems must facilitate, securely and efficiently, the integration between all properties of the Smart Grid: remote management, active management of the demand, distributed generation, grid automated management and development of electrical mobility.

The Smart Grid concept can be defined by 4 fundamental pillars: Smart Network (SN), Smart Operation (SO), Smart Metering (SM) and Smart Generation (SG). These technologies have been used for years, however, the recently improvement of the telecommunication and information technologies have caused the massive implementation in the electrical grid.

The Smart Network refers to the automation of the electrical grid, establishing a distributed intelligent between the different control and protection units and the control centers which operate in the grid.

The Smart Operation is defined as the efficient management of the grid thanks to the Smart Network, which provides a greater knowledge about the consumption in each point of the system.

The Smart Metering is used to collect information about the consumption in real time of all points of the grid. In this way, the grid operator can offer an optimum response to the instantaneous consumption in order to improve the system efficiency. An important component is the Smart Meter, defined as a digital meter that collects the information about the energy usage and sends it to the control and operation centers. Due to the Smart Meter reading, the consumer can know how much energy is consuming in real time and can decide between disconnecting from the grid (if he knows the electricity price in that moment) or the energy self-consumption.

The Smart Generation collects the Distributed Energy Resources (DER) in order to improve the generation response to the demand. The integration of renewables energies is the solution for the problems of power supply in adverse place.

7.2.2 Synchronous machines

7.2.2.1 Introduction to synchronous machines

A synchronous machine transforms mechanical energy into electric energy, or vice versa. These machines will rotate at constant speed depending on the

frequency of the electric system.

$$n = \frac{60f}{p}$$

Where n is the number of revolutions per second, f the frequency of the currents in the stator and p the number of pole pairs.

7.2.2.2 Introduction to synchronous alternator

The alternator is an electrical generator that transforms mechanical energy into electrical energy. These electrical machines consist of a stator, a rotor and an excitation system.

Normally, the alternator has a DC generator to produce electricity and excite the rotor of the machine. The excitation is the current applied to the rotor in order to establish a magnet fixed polarity. The rotation of the rotor causes that the magnetic field is applied successively to the stator windings. Thus, the magnetic flux in stator windings changes: positive, zero, negative, zero and so on. The flux variation produces an induced voltage in stator windings and this voltage is the evacuated to the AC three-phase grid.

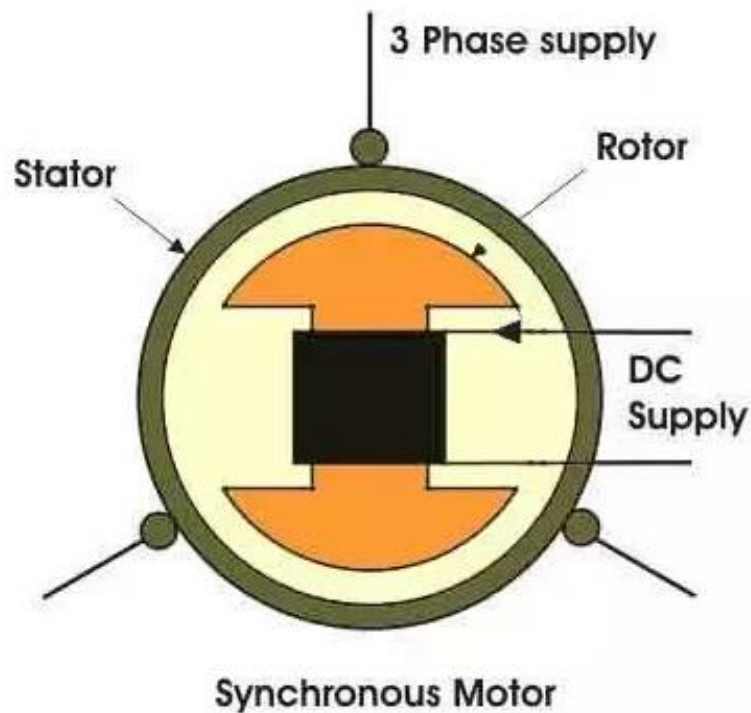


Figure 30: Synchronous motor diagram

7.2.2.3 Conditions required for the synchronization

Some aspects must be taken into account for a correct operation when we connect generators in parallel and prevent any type of problem, such as damaging the generators or losing power. Those aspects are explained next:

1. Equal voltages: if the voltages of the generators are not exactly the same, there will be a great flow of current when the synchronization switch is closed. To avoid this problem, each phase must have exactly the same voltage and phase angle magnitude than the conductor to which it were connected.

In other words, the phase voltage a must be exactly the same as the voltage in the phase a' and so on for the phases $b-b'$ and $c-c'$, being

a , b and c the phases of the generator and a' , b' and c' the phases of the grid.

The line voltages RMS must also be the same.

2. Equal frequencies.

The frequency of the two or more generators must also be the same; otherwise, it could cause serious problems. This can be visualized in the following graphs:

The first graph has 60 Hz and a phase voltage of 120V.

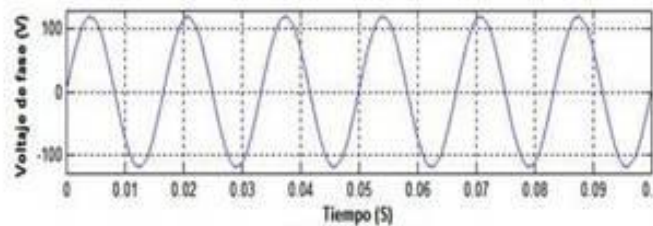


Figure 31: Example of signal with 60Hz and 120V

The following graph has 58 Hz, only 2 Hz lower than the previous one, and the same phase voltage.

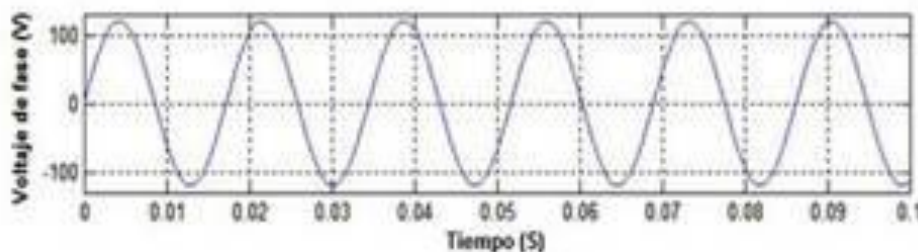


Figure 32: Example of signal with 58Hz

The following graph shows the result of what would happen if the generator is operated at different frequencies (60Hz and 58 Hz).

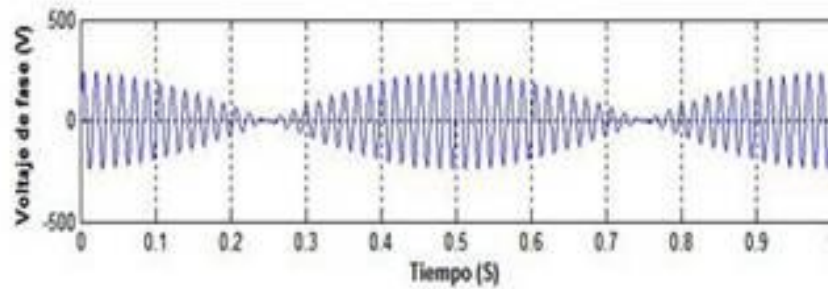


Figure 33: Example of signals combination

As it can be seen in the graph that results from the sum of the waves at different frequencies and same voltage, a totally distorted voltage is obtained at the output with a frequency equal to the difference between the values of the frequencies of the two first waves, which would cause great problems in the load.

3. Phase sequence: both generators, in our case, the grid and the motor-generator group, must have the same phase sequence.

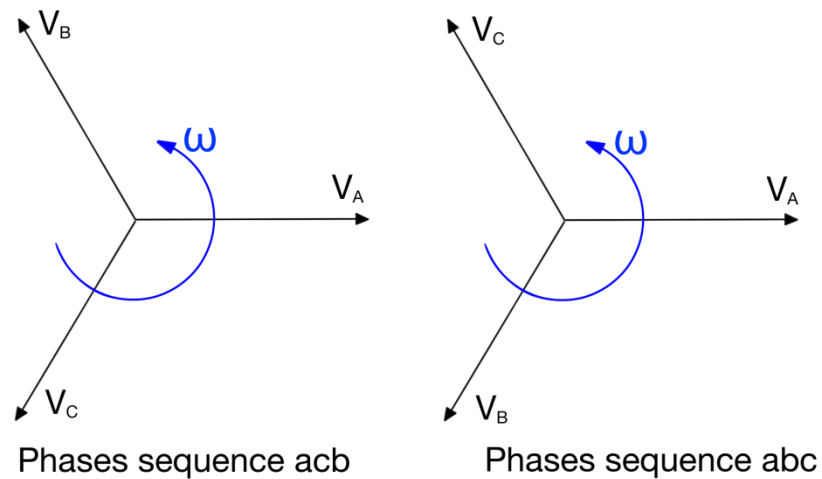


Figure 13: Phase sequences

The phase angles of the two phases must be equal, the sequence at which the

phase voltage reaches its peak in the grid in the generator will be the same. If the phase sequence is different, then a couple of voltages will be in phase, the other two pairs of voltages will be outphased by 120° . If generators are connected in this way, there will be no problem with the phase a, but great currents will flow in the phases b and c, damaging both machines.

7.2.2.3.1 Procedure to put the generator in parallel with the grid

Some steps and precautions must be followed to put the generator in parallel with the grid and obtain an optimal operation with these synchronous machines.

1. Start the generator to be connected: at this point, start the generator and set it to its synchronous speed (equaling this way $f_{gen} = f_{red}$) and equaling the value of their voltages. Other condition is the phase sequence of the generator, which must be compared to the phase sequence of the electrical system. Some methods are indicated below to make sure that these conditions and previous conditions are fulfilled.
2. Phase sequence: other condition is the phase sequence of the generator, which must be compared to the phase sequence of the power system. Some methods are indicated below to make sure that these conditions and previous conditions are fulfilled.

There are many ways to check this. One of them is to connect a small induction motor alternatively to the terminals of the generator and then to the terminals of the grid. If the motor rotates in the same direction both times, then the phase sequence is the same in both

generators.

If the motor rotates in opposite directions, then the phase sequences are different and two of the conductors of the generator must be reversed. A simpler way of measuring the sequence is by using a sequence meter.

3. Synchronization of the generator with the grid.

7.2.3 Power Transmission and Distribution Lines

The transmission system is the group of lines, substations and units used to transport electricity from generation points to consumption centers.

Electrical energy must be transformed to reduce losses by Joule effect before being transported to the consumption centers. It is done by increasing the generation center output voltage using a step-up transformer. After the energy is transformed it passes to the transmission lines.

The transmission lines consist of the conducting element, usually copper, aluminum or steel cables, and the support elements.

The characteristic parameters of the transmission lines are:

- Resistance per unit of length, “R”, which depends on the resistivity of the conductors and the frequency. For high frequencies, the resistance increases due to the skin effect.
- Inductance in series per unit of length, “H”, which is caused by the fact that every conductor through which an alternating current flows has an associated inductance.
- Capacity in parallel per unit of length, “C”, since the line is formed by two or more conductors separated by a dielectric, thus forming a condenser whose capacity depends on the area of the conductors, the separation and the dielectric constant of the material that separate them.
- Conductance in parallel per unit of length, “G”. It is a consequence of the fact that the dielectric has finite resistivity, so that part of the

current is lost in the conductors.

There are several types of energy distribution depending on the electrical diagram formed by the transmission lines:

- Radial: it is characterized by the supply through one end, transmitting the energy radially. Selective protection may be equipped in this type of distribution, but they do not guarantee service in the event of a fault.
- Open loop network: any consumption point may be supplied from two possible electrical paths. Selective protection may be equipped in this type of distribution. Besides, any fault may be isolated without interrupting the service thanks to the alternating path.
- Closed loop or ring network: two of its ends are supplied, being these points inserted in the ring. Its advantages are a safe service and an easy maintenance. However, this type of network is more complicated.

Step up and step down transformers

In real electrical systems energy is generated at a relatively low voltage which is increased in the transformation substations through step-up transformers for efficiency reasons and transferred to the transmission line. Before being transmitted to the distribution lines, whose voltage is coupled to that of the consumption centers, the voltage is decreased in transformation substations through step down transformers

Regulating transformers

In distribution substations there are regulating or distribution transformers to control the voltage of the load. The function of this type of transformer is to keep

the output voltage delivered to the consumption points constant in the event of load fluctuations. It also regulates the reactive power. Therefore, these transformers have a series of outlets in the windings that enable light adjustments up to 7.5% above or below the rated voltage of the transformer.

There are transformers whose outlets cannot be changed when the transformer is supplying energy. It is a problem when the voltage wants to be maintained in the event of load fluctuations. However, there are other transformers whose outlets can be changed while it is supplying power.

Protections in the transmission/distribution system

Protection relays and their associated equipment are compact units that consist of analogical components, discrete solid state components, operational amplifiers and digital micro-controllers connected to the power system to perceive problems.

These relays are used in all parts of the power system to detect faults. An essential objective of all power systems is to keep the continuity of the service and to minimize the scope and cutoff time in the event of a fault.

Objective of the protection system:

The main objective of a protection system is to isolate quickly from the rest of power system the area where the problem has arisen, so that the fault does not affect the rest of the system. There are five basic aspects that characterize a protection relay:

1. Reliability: it assures that the protection will work correctly.
2. Selectivity: capacity to maximize the continuity of the service by

disconnecting the minimum number of systems.

3. Speed: capacity to limit the duration of the faults.
4. Sensitivity: capacity of the system to detect small variations in the surroundings of the equilibrium point.
5. Economy: maximum protection at a minimum cost.

The following protection systems may be found in transmission systems:

Overcurrent relays

Overcurrent relays are the cheapest and simplest way to protect a transmission line. These protection relays need to be adjusted again when the conditions of the power system change. These relays operate in an instantaneous, temporized and directional way (instantaneous/temporized).

These relays do not differentiate between the load current and the fault current, for that reason they are only used when the fault current is higher than the load current.

These relays are normally used in radial lines. Instantaneous time to solve the fault is not required since the faults in these circuits do not affect the stability of the system.

Directional overcurrent relays are used in the transmission lines with supply through both ends.

Reverse Power Relays

Reverse power relays protect and control the generators against those electrical faults which lead to their motorization (for example when the generating frequency is lower than the transmission and distribution one), which would mean the opposite energy flux direction, preventing them from working as a motor and

therefore from consuming power from the grid or the busbars. The motorization of a generator can lead to serious mechanical and electrical damages.

Distance relays

In high voltage lines, current levels are very high when a fault is generated. If the fault is not solved quickly, instability in the power system may appear. The advantages of the distance relay are that they have a wide instantaneous operation area and great sensitivity, they are easy to adjust and coordinate and they are not affected by changes in the configuration of the power system.

A distance relay calculates the impedance as the quotient between the voltage and the current in its location in the power system to determine whether there is a fault inside or outside its operation area.

Due to the fact that in transmission lines the impedance of the line is proportional to its length, it is advisable to use this type of relay to measure the impedance from the location of the relay to a specific point.

In general there are four ways of operation characteristics: impedance, admittance, reactance and polygonal characteristic.

Operations with busbars

Operation substations are usually seen in the distribution system. They enable to connect several circuits (or lines) to direct or distribute the power flow to the different areas of the system.

The operation substations consist of several circuits, such as:

- Switches that allow to control the flow of energy or to isolate lines for maintenance or works and elements with faults. These devices may operate

while the substation is in service.

- Disconnectors to isolate elements for maintenance. These devices must operate without load, for that reason they are usually arranged in series with switches. The disconnectors provide a “visible” disconnection of the line, indispensable to be able to work safely in it.
- Measurement transformers, used for voltage and current measurements.

The substation will have the characteristics mentioned below depending on the arrangement of its equipment:

- Flexibility: capacity to adjust to the different conditions that may arise, such as maintenance and operating changes among others.
- Reliability: capacity to supply energy for a given period of time, even if at least one component of the substation cannot be repaired during the operation.
- Safety: capacity to provide service continuity without cuts during faults in the power equipment, especially switches and busbars.

Several arrangements may be found depending on the position of the equipment that forms the substation, such as switches or disconnectors:

- Simple busbar: it is not reliable, safe nor flexible. Therefore, the service must be interrupted when a revision of the collecting bar wants to be done.

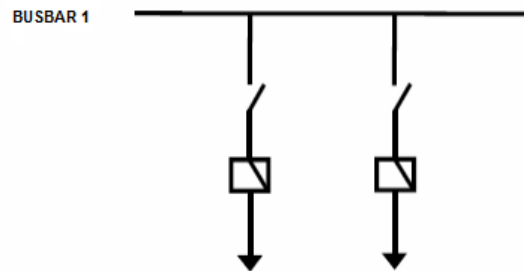


Figure 34

- Main busbar and transfer busbar: they enable the switching using the transfer switch between two parallel bars, keeping the service during the maintenance.

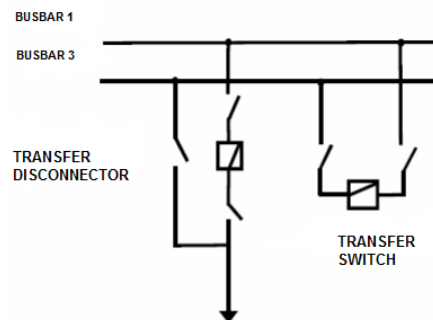


Figure 35

- Double busbar: they enable to separate circuits in each busbar. It offers the possibility to perform maintenance works without interrupting the service. It provides flexibility and reliability.

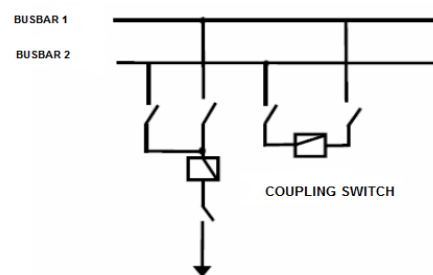


Figure 36.

- Double busbar plus “ByPass” disconnecter: they can work either as a double

busbar or as a main busbar plus transfer but not at the same time. Therefore, they offer flexibility and reliability, but not at the same time.

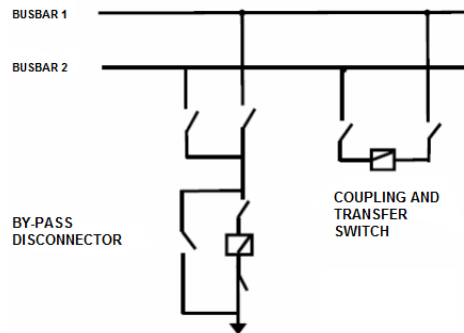


Figure 37

- Double busbar plus transfer disconnector: it is a variation of the double busbar plus transfer disconnector arrangement but with one disconnector less.
- Double busbar plus transfer busbar: it is a combination of the main busbar and transfer arrangement and the double busbar arrangement. It offers reliability and flexibility at the same time.

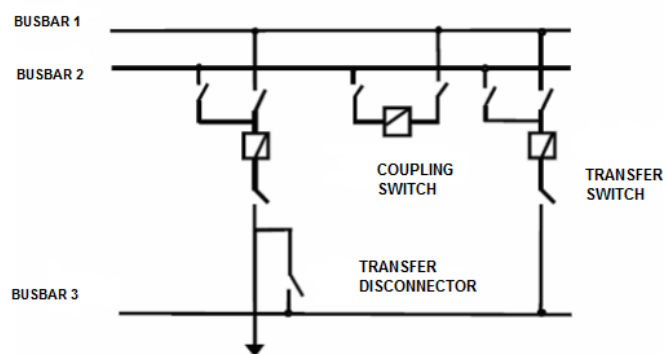


Figure 39

- Ring: this configuration is divided in several parts, each line circuit or transformer has busbar disconnectors at each side, enabling this circuit to be supplied by any of the adjacent busbar disconnectors. When a fault is introduced in

the busbar the substation will be out of service, but once the error is identified, it can be isolated and the service restored.

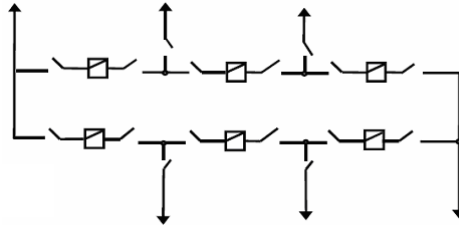


Figure 40

- One and a half switch: it allows to perform maintenance works without cutting the service. A fault will neither cut the service to any circuit. It is safe and reliable but not flexible because it operates with both busbars energized and all the switches closed.

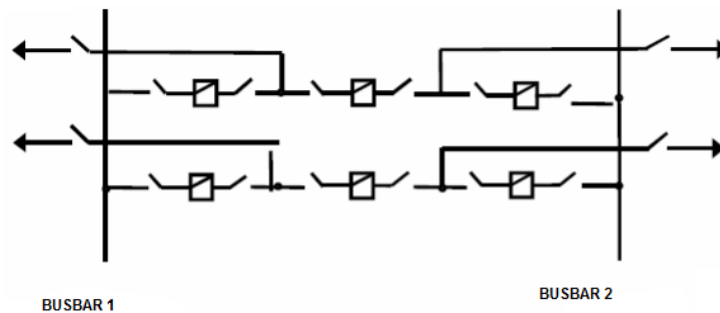


Figure 41

- Double busbar with double switch: the busbars and switches of each circuit are doubled in this arrangement. It is safer in the event of a fault or during maintenance works. It is the most expensive of all arrangements.

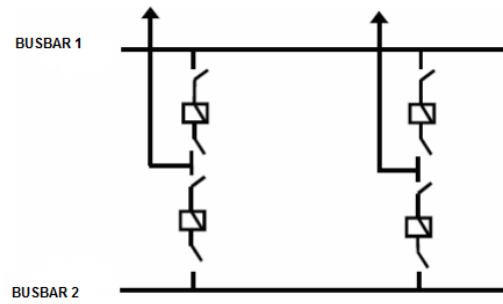


Figure 42

7.2.4 Reactive energy compensation

Reactive energy in power transmission and distribution systems means losses and inefficiency. Furthermore the national grid always demands to generation centers the achievement of a minimum compulsory power factor otherwise penalizations are imposed on them. Thus reactive energy compensation is essential in power systems and can be done in several ways; in this application the user will use mainly different type of loads for this purpose. Let's imagine a three-phase resultant inductive circuit that demands a certain reactive energy so our goal is to increase and correct the power factor to the one we desire which means lowering the phase angle by means of the introduction of a capacitive load that counteracts the action of the inductive one.

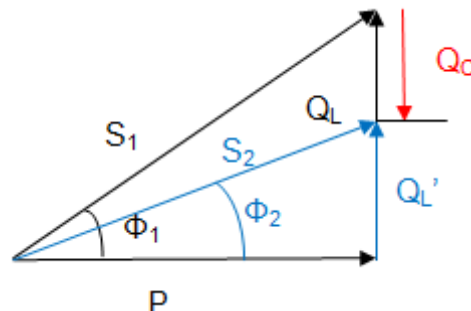


Figure 43. Power factor and reactive energy compensation

As said the objective of the reactive compensation is to reach the desired cosine of phi (power factor). It is known that:

1. The purely inductive reactive power is:

$$Q_L = P \cdot \tan(\Phi_1)$$

2. The desired reactive power is:

$$Q_L' = P \cdot \tan(\Phi_2)$$

3. Therefore, the capacitive reactive power that must be introduced to reach the

desired Q will be:

$$Q_C = Q_L - Q_L' = P \cdot \tan(\Phi_1) - P \cdot \tan(\Phi_2) = P \cdot (\tan(\Phi_1) - \tan(\Phi_2))$$

4. The reactive power that must be provided by each capacitor in a three-phase system with star connected capacitors is:

$$Q_{C1} = Q_C/3 = X_C \cdot (I_{\text{phase}})^2 = X_C \cdot (V_{\text{phase}}/X_C)^2 = V_{\text{phase}}^2/X_C$$

5. The capacity of the capacitor can be obtained this way:

$$C = Q_C/(3 \cdot \omega \cdot V_C^2)$$

Being $V_{\text{phase}} = V_L/\sqrt{3}$ and $\omega = 2 \cdot \pi \cdot f$, being $f = 50$ Hz (frequency of the grid).

6. As a function of these results it has to be analysed the way and number of capacitors that must be connected.

7.3 OPERATION

7.3.1 N-PPCM1. Control and Protection of Turbine-Generator Group Module 1

The N- PPCM1 has the automatic speed and voltage controller of the turbine-generator group which allows regulating the speed of the turbine and the excitation of the generator. This controller is the main protection and management device of the generation system. For this reason, it is very important to know how it works.

7.3.1.1 Navigation guide of automatic speed and voltage controller

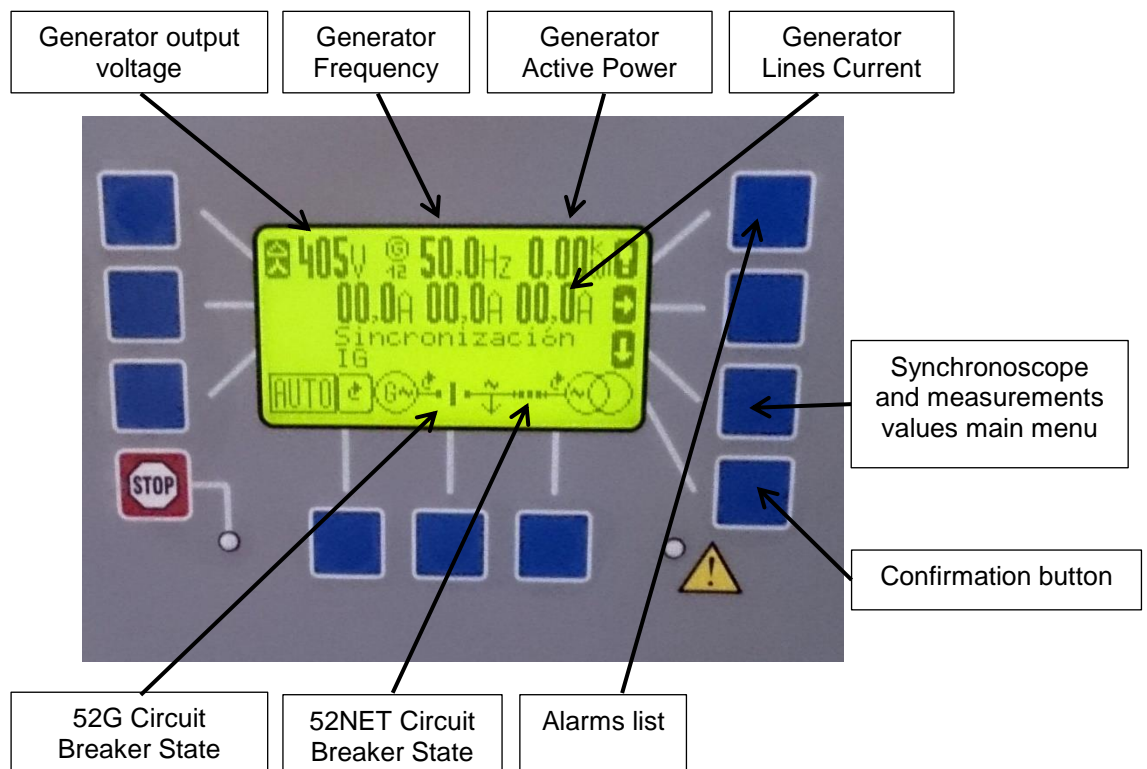


Figure 44: Main window of automatic and voltage controller



Figure 2-1: Front panel and display

Figure 2-1 illustrates the front panel/display of the easYgen-2000 Series with push buttons, LEDs and Liquid Crystal display (LC display). A short description of the front panel is given below.



NOTE



This push button is always active and will stop the engine when pressed, except the operating modes are selected externally. In this case, the AUTO and MAN Mode push buttons are also disabled.

Function blocks

Function blocks

Buttons that have the same function within one screen are grouped into function blocks. The function blocks are defined as:

Display..... Change the method of voltage and power calculations displayed (page 25).

Mode..... Change the mode of operation (page 28).

Operation.... Used to perform manual operation of the genset and the breakers (page 29).

Navigation... Navigation between system and configuration screens, and alarm list (page 29).



Push buttons

The push buttons on the front panel are assigned to softkeys on the display. Each softkey is assigned to a function depending on the mode of operation.



Liquid Crystal Display (LC display)

The display contains softkey characters, measuring values, modes of operation, and alarms. The functionality of the display screens as well as the description of the functions is detailed in the "Navigation" section (page 8).




LED

The left LED 13 indicates that the unit is in STOP mode. The right LED 14 indicates that alarm messages are active / present in the control unit.

Screen "Alarm list"

[all application modes]



This screen appears after pressing the "Alarm" softkey in the starting screen. All alarm messages, which have not been acknowledged and cleared, are displayed. Each alarm is displayed with the alarm message and the date and time of the alarm occurred in the format yy-mon-dd hh:mm:ss.ss. Please note, that self-acknowledging alarm messages get a new timestamp when initializing the unit (switching on). The  symbol indicates that this alarm condition is still present. A maximum of 16 alarm messages can be displayed. If 16 alarm messages are already displayed and further alarm messages occur, these will not be displayed before displayed alarm messages are acknowledged and thus deleted from the list.



Return to the starting screen.



Scroll up to next alarm message.



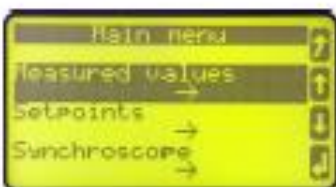
Scroll down to next alarm message.




The selected alarm message (displayed inverted) will be acknowledged. This is only possible, if the alarm condition is no longer present. If the Alarm LED is still flashing (an alarm is present, which has not yet been acknowledged as 'Seen'), this softkey resets the horn and acknowledges the alarm as 'Seen'.

Screen "Main Menu"

[all application modes]



This screen appears after pressing the  softkey two times.



Return to the starting screen.



Scroll up to next menu item.



Scroll down to next menu item.



Enter menu item.

Measured values

Display the measured values screen.

Setpoints

Display the setpoints screen.

Synchroscope

Display the synchroscope screen.

Sequencing

Display the sequencing screen.

Counters and service

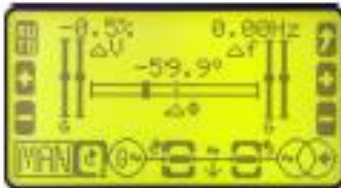
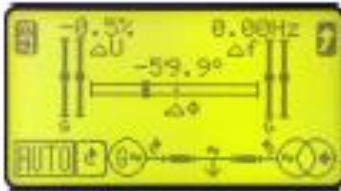
Display the counters and service screen.

Diagnostic










Display the diagnostic screen.

Screen "Synchroscope"

[all application modes]

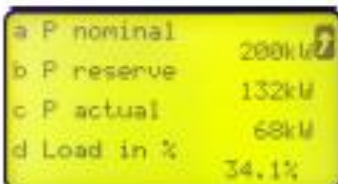







This screen appears after pressing the "Synchroscope" softkey in the "Main menu" screen. The square symbol indicates the actual phase angle between mains and generator. A complete left position of the square symbol means -180° and complete right position means $+180^\circ$. The frequency and voltage differences are indicated on the top of the display.





-  Return to "Main menu" screen.
-  Change into AUTOMATIC operating mode.
-  Change into MANUAL operating mode.
-  Change into STOP operating mode.
-  Operating mode MANUAL: Raise voltage/frequency.
-  Operating mode MANUAL: Lower voltage/frequency.
-  Operating mode MANUAL: start/stop engine.
-  Operating mode MANUAL: open GCB/MCB.
-  Operating mode MANUAL: close GCB/MCB.

Screen "Sequencing"

[all application modes]

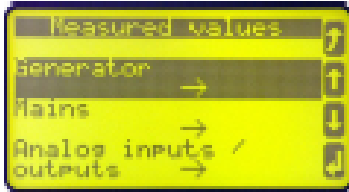


This screen appears after pressing the "Sequencing" softkey in the "Main menu" screen. The sequencing screen shows all gensets participating in load sharing and load dependent start/stop. The operation mode of each genset as well as the state of its GCB is shown on this screen. The symbol  above the generator number indicates AUTOMATIC operating mode,  indicates MANUAL, and  indicates STOP. The field below shows whether the respective GCB is closed () or open (). The bottom field displays the actual load dependent start/stop values. If this device is not participating in load dependent start/stop, "LD start stop Off" is displayed here.





-  Return to "Main menu" screen.
-  Scroll down to genset 09 through 16 display.
-  Scroll up to genset 1 through 08 display.
-  Display the second screen on the left hand side.

Screen "Measured values"

[all application modes]



This screen appears after pressing the "Measured values" softkey in the "Main menu" screen.

-  Return to the "Main menu" screen.
-  Scroll up to next menu item.
-  Scroll down to next menu item.
-  Enter menu item.

Generator

Display the generator indication screen.

Engine (J1939)

Display the Engine (J1939) interface screen.

Mains

Display the mains indication screen.

Analog inputs/outputs

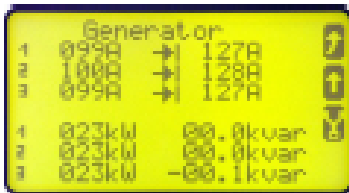
Display the analog inputs and outputs indication screen.

Discrete inputs/outputs





Display the discrete inputs and outputs indication screen.

Screen "Generator"

[all application modes]



This screen appears after pressing the "Generator" softkey in the "Measured values" screen. All measured generator values are displayed in this screen.

-  Return to "Measured values" screen.
-  Scroll down display screen to additional generator values.
-  Scroll up display screen to main generator values.
-  Reset the maximum value display.

V..... Voltage

A..... Current

kW.... Real power





Kvar. Reactive power

Screen "Mains"

[all application modes]



This screen appears after pressing the "Mains" softkey in the "Measured values" screen. All measured generator values are displayed in this screen.

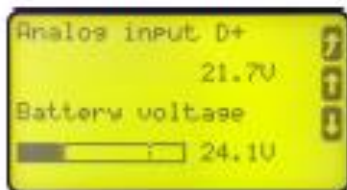
-  Return to "Measured values" screen.
-  Scroll down display screen to additional mains values.
-  Scroll up display screen to main mains values.
-  Reset the maximum value display.

V Voltage
 A Current
 kW Real power
 kvar .. Reactive power




Screen "Analog inputs/outputs"

[all application modes]

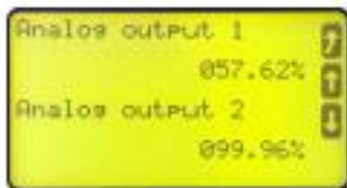
"Analog inputs" screen:



These screens appear after pressing the "Analog inputs/outputs" softkey in the "Measured values" screen. The analog inputs and outputs are displayed. The analog outputs are displayed as a percentage of the selected hardware range, i.e. 50 % of a 0 to 20 mA output refer to 10 mA.

-  Return to "Measured Values" screen.
-  Scroll up display screen.
-  Scroll down display screen.

"Analog outputs" screen:










Screen "Language / clock configuration"

[all application modes]



This screen appears after pressing the "Language / clock configuration" softkey in the "Parameter" screen.






-  Return to the "Parameter" screen.
-  Scroll up one parameter.
-  Scroll down one parameter.
-  Select the parameter to be configured with this softkey. Change the parameter using the  softkey. Confirm the change with the  softkey or exit parameter configuration without any changes using the  softkey.

Screen "Display configuration"

[all application modes]



This screen appears after pressing the "Display configuration" softkey in the "Parameter" screen. The contrast and brightness of the display may be configured here.








-  Return to the "Parameter" screen.
-  Increase contrast/brightness.
-  Decrease contrast/brightness.
-  Lamp test
-  Pressing and holding the STOP button for at least 10 seconds restores the default settings for contrast and brightness in case the settings have been adjusted in a way that the display can't be read anymore.

Screen "Enter password"

[all application modes]



This screen appears after pressing the "Enter password" softkey in the "Parameter" screen. Only the password may be entered using this screen. The code levels are only displayed depending on the entered password.

-  Return to the "Parameter" screen.
-  Scroll up one parameter.
-  Scroll down one parameter.
-  Select the parameter to be configured with this button. Change the parameter using the  softkey. Confirm the change with the  softkey or exit parameter configuration without any changes using the  softkey.

7.3.1.2 Back-up Protection relays



Back-up protections parameters are established and the user must not vary the potentiometers.

7.3.2 N-PSUB3 : Power Generation Substation Module 3

The Power Generation Substation Module allows carrying out the main maneuvers to control the turbine-generator group. The switches included in this panel send the orders to the N-PPCIM1 in order to control the actions of the generator-motor group.

7.3.2.1 Local mode



Figure 45: Local mode control buttons

This operation mode can be selected with the control modes switch and enables the next group switches “local control mode” and “control switches”. Local control mode switches group allows the following functions:

- Manual / Automatic Speed Control.

The manual operation enables the potentiometer called Manual Speed Control to regulate the turbine speed, which is the same as regulate the turbine frequency. The automatic operation lets the controller adjust the turbine speed according to demand conditions.

- Manual / Automatic Excitation Control.

In the second one, the manual operation enables the potentiometer called Manual Excitation Control to regulate the generator excitation. On the other hand, the automatic operation lets the controller adjust the generator excitation according to demand conditions.

- Control switches group:

Besides the mechanical control of motor-generator group, the Control Switches block has four switches to carry out typical maneuvers of a generation substation:

- Start/Stop turbine: the user put in operation the turbine and the generator begins to rotate for the shaft coupling.
- 52G synchronization permission: the user gives permission to the automatic controller (easygen) for synchronizing the generator with the grid when voltage, phase sequences and frequency are properly. The internal circuit breaker will be closed depending on the 52NET switch state:
 - Disable 52NET: the automatic controller hasn't a reference which to compare and when the line voltage (400 VAC)

and frequency (50/60 Hz, depends on the country) take these values the internal circuit breaker is closed.

- Enable 52 NET: the automatic controller senses the presence of the national grid. The controller will close 52G internal circuit breaker when the reference coincides with the generator instantaneous values. The conditions that have to be accomplished:
 - Equal voltages.
 - Equal frequencies: depends on the national grid of the country.
 - Equal phase sequence.
- Enable/disable 52NET: the user closes the circuit breaker that will synchronize the generator with the national grid and a signal is automatically sent to the automatic controller to detect the electrical parameters of the national grid.
- Reset alarms: the user reset the active alarms pressing the push-button twice.

7.3.2.2 Remote mode

This operation mode can be selected turning the Control Modes switch to SCADA Control Mode position. This control mode will be explained in the [SCADA system](#) point.

7.3.1 N-EALD: Network Analyzer Unit with Computer Data Acquisition

The N-EALD has the network analyzer used to display the main parameters of the system such as powers, currents, voltages, etc.



Figure 46: Network analyzer buttons

When using the analyser in measurement mode, we have the following parts of the display:

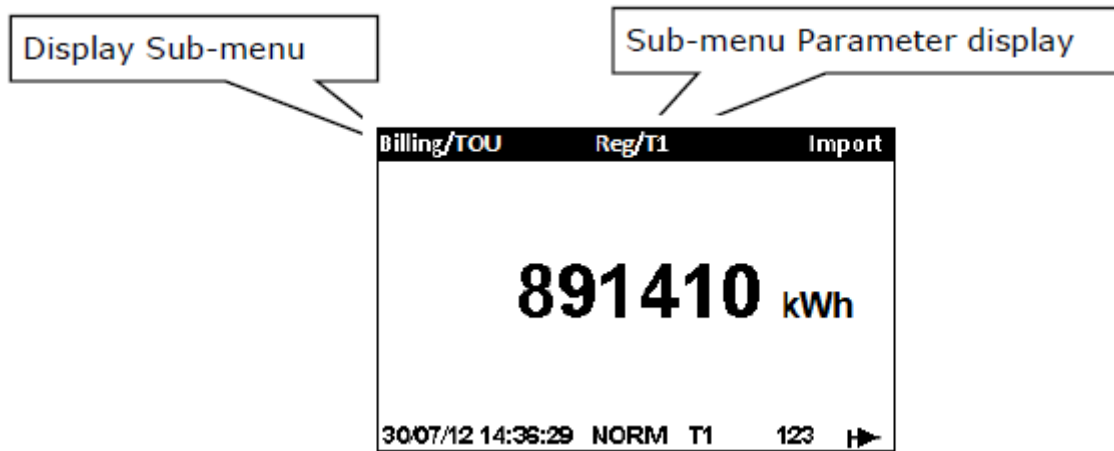


Figure 47: Top bar elements of the display

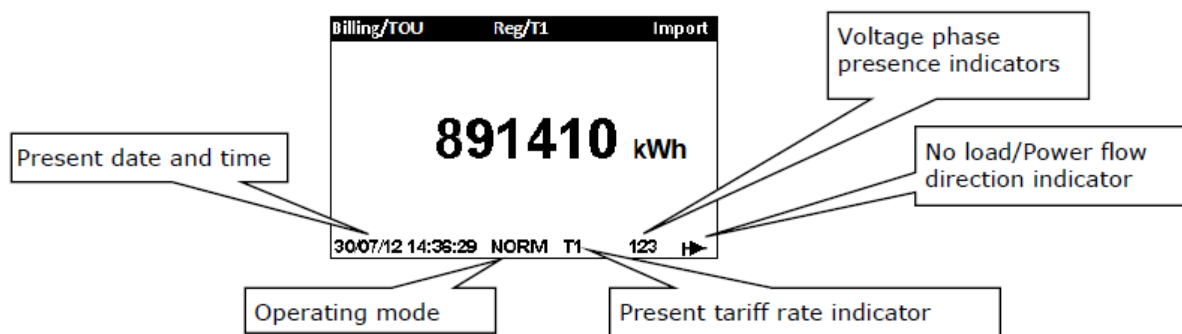


Figure 48: Bottom bar elements of the display

In order to navigate between the data displays you can use the UP/DOWN scroll buttons, for example, you are in voltage L-L measurement and you want to change to L-N values, for that operation you must press the UP button, and to return to the previous one you must press DOWN button.

As it has been explained, each submenu of measurement has different data displays, for example, voltage measurements has; L-L, L-N, THD, etc. The submenus of the measurement menu and data displays you can navigate are the following:

Group (→ to change)	Screens (▲ to go right, ▼ to go left). Underlined = included in Auto Scroll
Voltages	<u>V L-L</u> // <u>V L-N</u> // THD // Ue // Hz // Phase // Demand
Currents	Amps // THD // TDD // K Factor // Unbalance // Demand
Powers	<u>Total</u> // <u>L1</u> // <u>L2</u> // <u>L3</u> // Import Demand // Export Demand
Demands	P Import // P Export // Amps // Volts
Min/Max	V L-L // V L-N // Amps // I neutral // P // PF // Hz
Energy	Import // Export
TOU (Import, Export)	Reg#1 // Reg#2
Harmonics	#3 // #5 // #7 ... #39
Spectrum	V1 // V2 // V3 // I1 // I2 // I3
Waveform	L1 // L2 // L3
Phasor	
Digital I/O	
Diagnostic	
Alarms	
Basic Settings	Page1 // Page2
Device Info	Info // Com

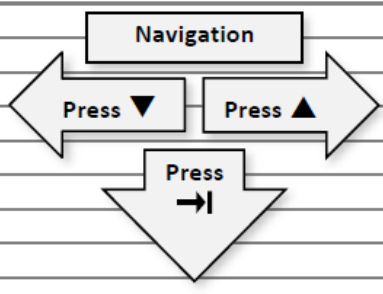


Figure 49: Measurement menu scheme

In order to navigate between groups (voltage, currents, powers, etc) you must press the TAB button, and to navigate between the different screens of each group you can use UP and DOWN buttons.

7.3.2 N-REG16: Voltage Regulation Module 1

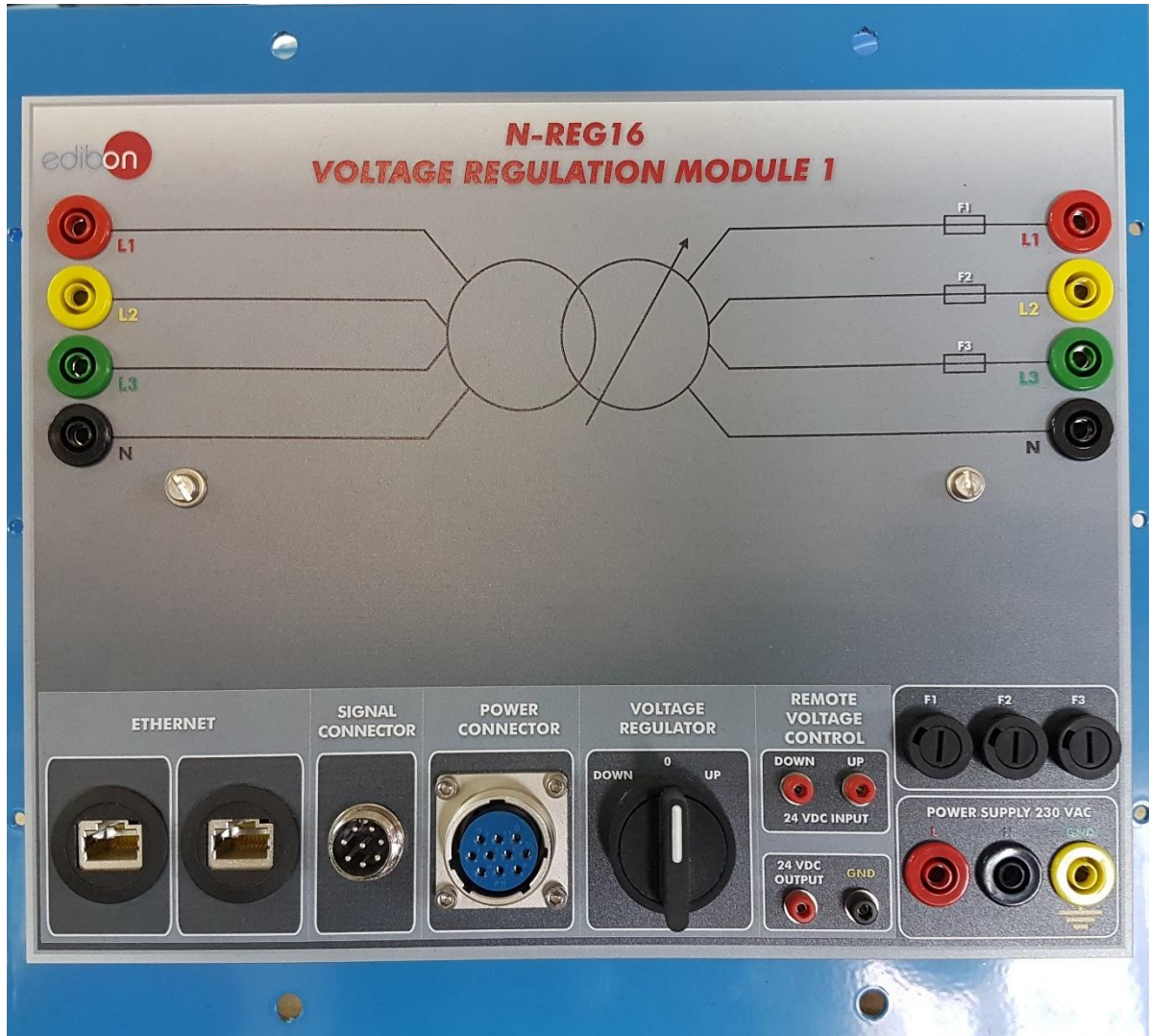


Figure 50: N-REG16 Module

This module allows controlling the output voltage of the three-phase autotransformer whose reference is TRANS3/KRM.

There are three ways to control the voltage regulation:

- 1.- Voltage regulator commutator.



Figure 51

This commutator has three positions:

DOWN: the commutator enables the motor of the autotransformer reducing the output voltage.

0: the commutator disables the motor of the autotransformer and the output voltage is constant. If the user release the commutator, this one comes back to the “0” position.

UP: the commutator enables the motor of the autotransformer increasing the output voltage.

2.- REMOTE VOLTAGE CONTROL connections.



Figure 52

This connections are very useful for remote control.

There are two 24 VDC input connections to increase or reduce the output voltage of the autotransformer. The following picture indicates an example of wiring:

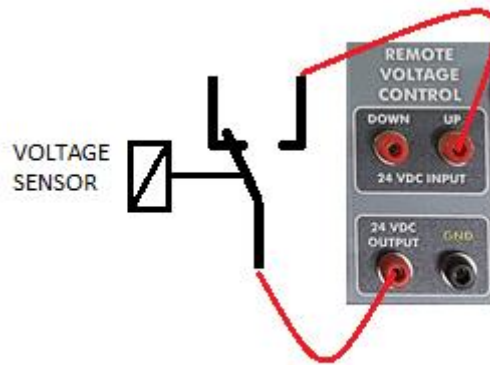


Figure 53

The voltage sensor measures the output voltage of the three-phase autotransformer and close its contact when the voltage level is lower than a set value. On this way the user can realize an automatism to control automatically the voltage.

3.- SCADA Control.

This option is enabled when the user works with a PC and the provided SCADA Control System.

For this purpose the ethernet connectors must be connected to the N-PSUB module and CONTROL MODUES switch must be put in SCADA Control Mode.



Figure 54

7.3.3 N-BUS08. Distribution bus bar module

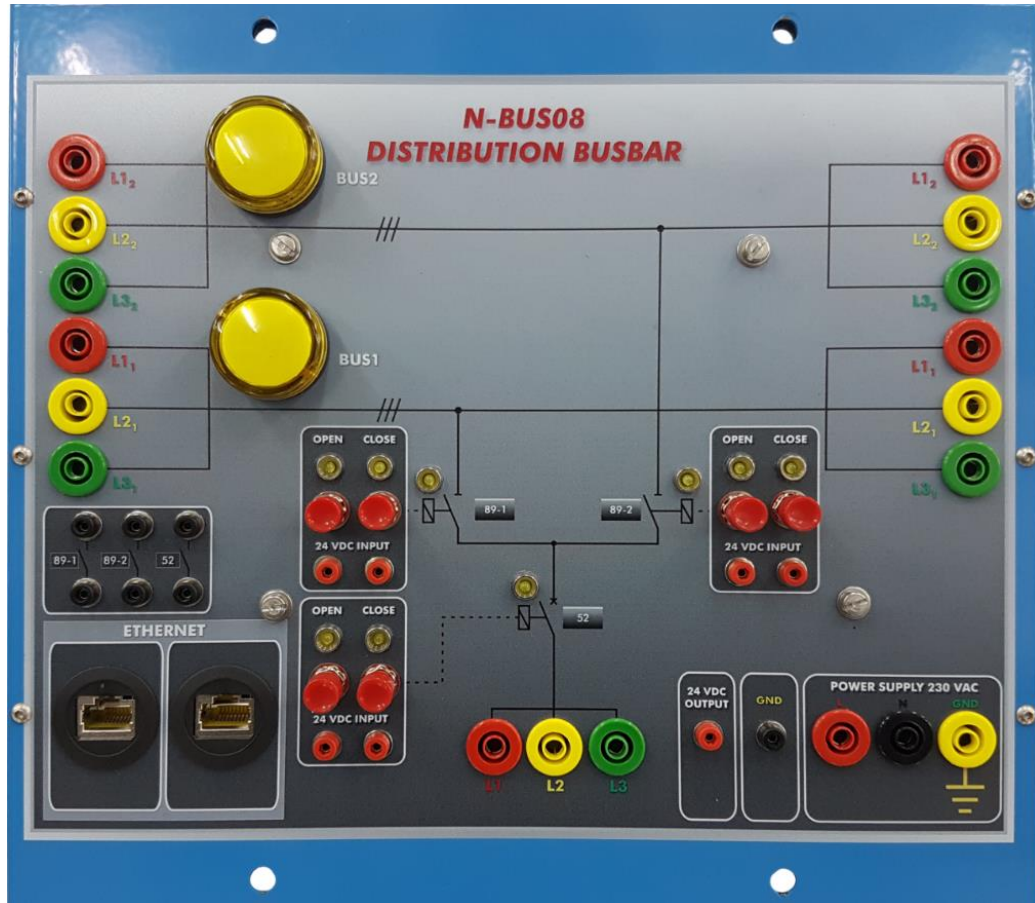


Figure 55: N-BUS08 module

This module allows carry out the same operations of double bus bar power substations. For this purpose, the module includes a series of push buttons and connections for switching operations.

Note that circuit breakers are named as 52 and disconnectors as 89.

There are two modes to control the circuit breakers and disconnectors:

1. Local control mode: this control mode allows switching maneuvers via push buttons. Each push button has the function of open and close the circuit breakers and disconnectors.

Additionally, this module includes 24 VDC digital inputs for logic

operation of circuit breakers and disconnectors. These digital inputs can be wired to an external device such as overcurrent protection relay to provoke the action of the circuit breakers. The following picture shows a wiring example:

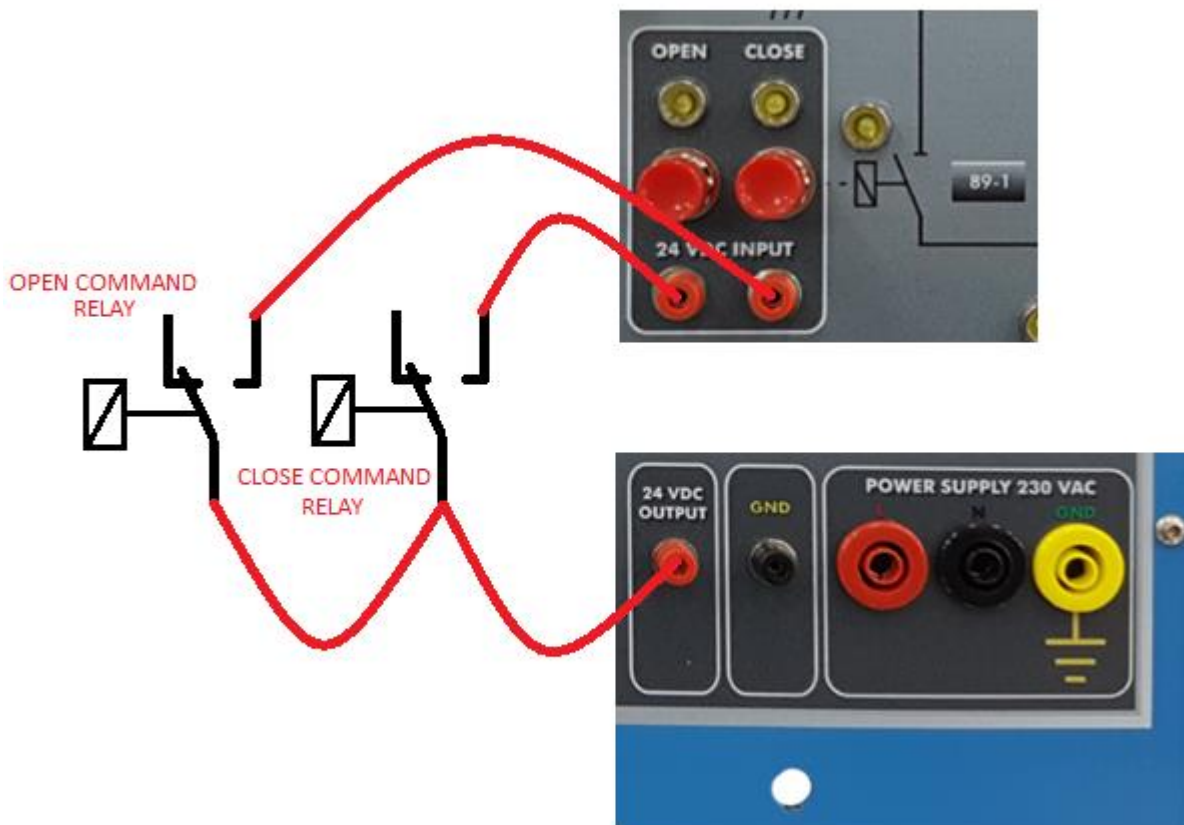


Figure 56

In this example, Open Command Relay and Close Command Relay belong to an overcurrent protection relay. This protection relay sense the current of the power circuit and send signals to the control relays according to the level of sensed current. On this way, the circuit breakers can be opened or closed according to different conditions.

2. Remote control mode: this control mode allows control the switching actions from the SCADA Control System. For this purpose the

module must be connected via ethernet to the rest of the modules. Additionally, the switch of the N-PSUB module must be turned in SCADA Control Mode position:



Figure 57

7.3.4 N-BUS09. Coupling Bus Bar Module

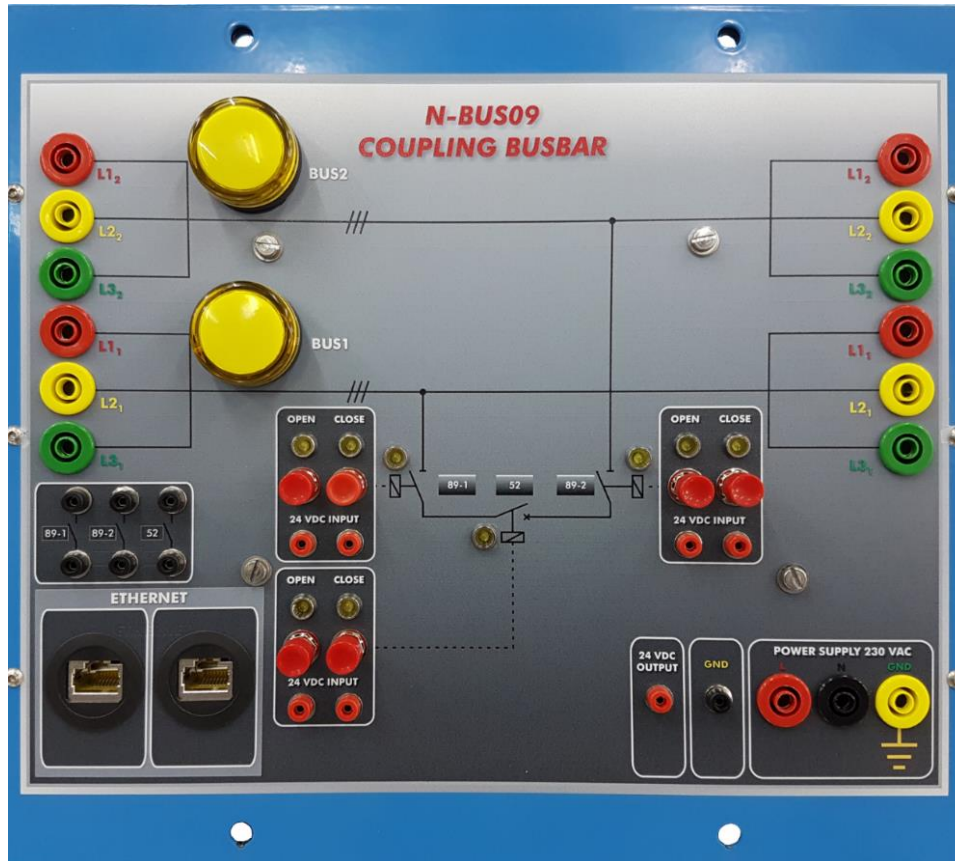


Figure 58: N-BU09 module

This module allows carrying out the change in power distribution busbars simulating real situations such as maintenance operations or unseen faults. For this purpose, the module includes a series of push buttons and connections for switching operations.

Note that circuit breakers are named as 52 and disconnectors as 89. It is important to understand the circuit breakers and disconnectors connection sequences. The user must have in mind that only circuit breakers are able to work in load mode. Thus if the sequence is wrong the application will not let the user open or close the corresponding switches.

There are three modes to control the circuit breakers and disconnectors:

1. Local control mode: this control mode allows switching maneuvers via push buttons. Each push button has the function of open and close the circuit breakers and disconnectors.

Additionally, this module includes 24 VDC digital inputs for logic operation of circuit breakers and disconnectors. These digital inputs can be wired to an external device such as overcurrent protection relay to provoke the action of the circuit breakers. The following picture shows a wiring example:

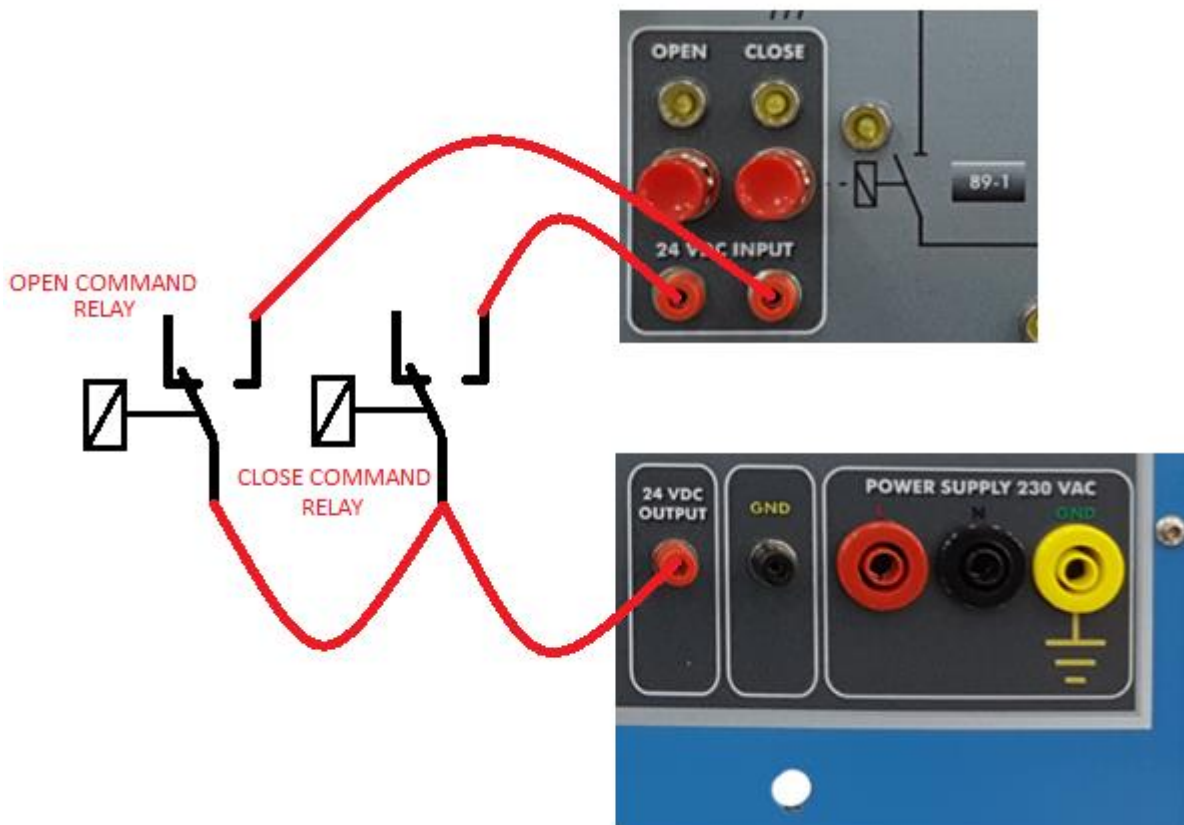


Figure 59

In this example, Open Command Relay and Close Command Relay belong to an overcurrent protection relay. This protection relay sense the current of

the power circuit and send signals to the control relays according to the level of sensed current. On this way, the circuit breakers can be opened or closed according to different conditions.

2. Remote control mode: this control mode allows control the switching actions from the SCADA Control System. For this purpose the module must be connected via ethernet to the rest of the modules. Additionally, the switch of the N-PSUB module must be turned in SCADA Control Mode position:



Figure 60

7.3.5 N-ERP-MF01. Digital Fault Simulator Module

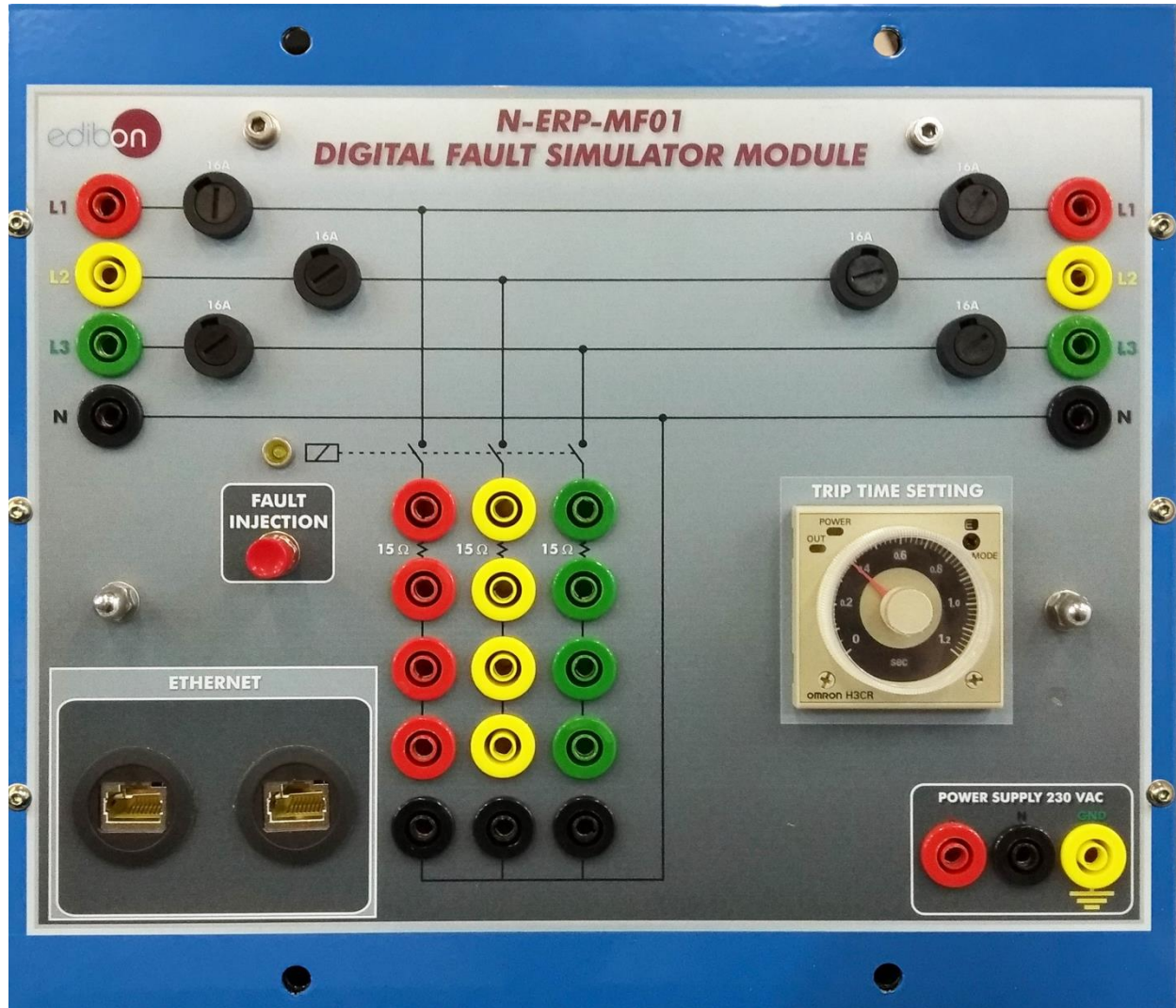


Figure 61: N-ERP-MF01 module

This module is designed for the study of faults in power systems. The user must be carried out the following steps to configure and inject the faults:

1. Decide the type of fault to be injected and set it. There are five possible faults: Single Pole fault, double pole fault, double pole to ground fault, three pole fault and three pole to ground fault. All these faults can be set with or without impedance. The following pictures indicate how set the type of fault:

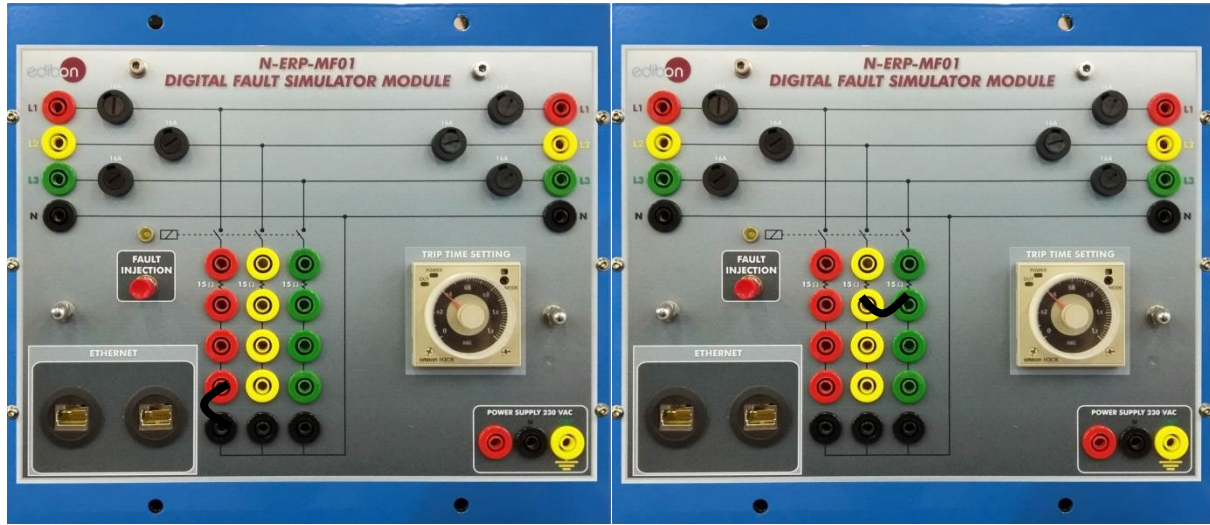


Figure 62: N-ERP-MF01 single pole and two pole setting fault.

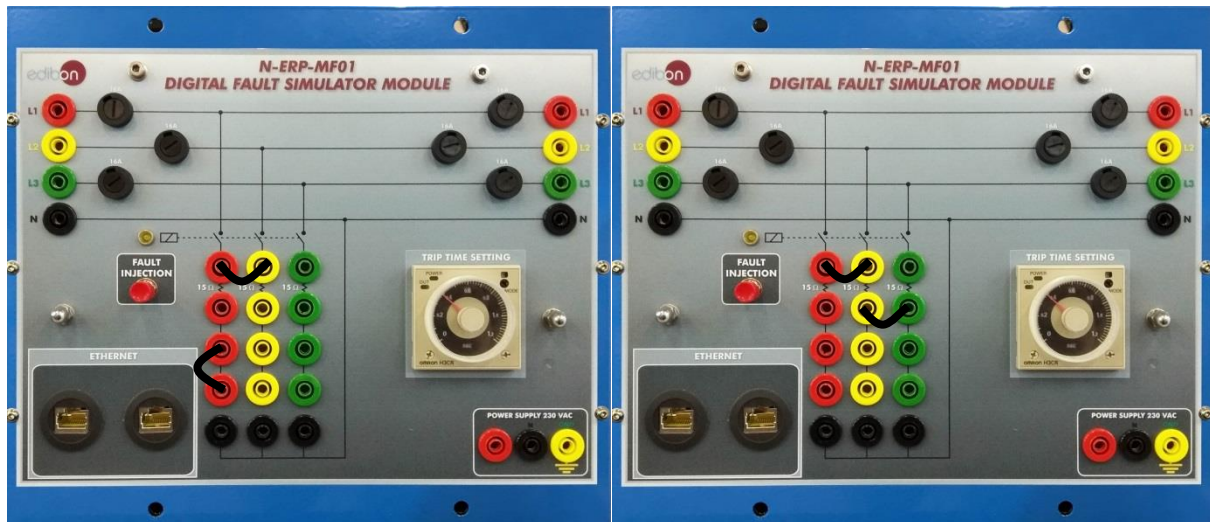


Figure 63: N-ERP-MF01 two pole to ground and three pole setting faults



Figure 64: N-ERP-MF01 three pole to ground setting fault

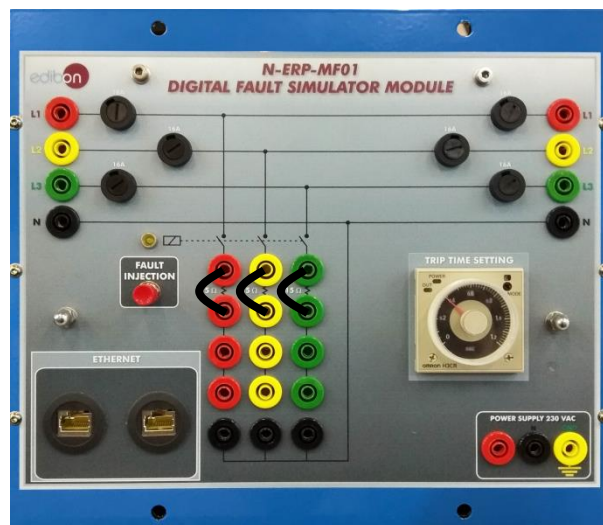


Figure 65: N-ERP-MF01 setting off fault impedance

2. Trip time setting. Rotate wheel of the timer in order to set the fault time. Note that this time must always be lower than 1 second. More fault time may cause serious damage in the unit.
3. Select the point of the fault. In this point the user must wire the L1, L2, L3 and N power connections in the point where the fault is going

to be injected.

4. Fault injection. Press the push button in order to inject the fault. The circuit breaker lamp is turned on and turned off automatically.

NOTE that fault injection can be carried out in remote from the SCADA Control Software:

1. Remote control mode: this control mode allows fault injection from the SCADA Control System. For this purpose the module must be connected via ethernet to the rest of the modules. Additionally, the switch of the N-PSUB module must be turned in SCADA Control Mode position:



Figure 66

7.3.6 N-CAR35T3D. Three-Phase Digital Bank of Commutable Resistors

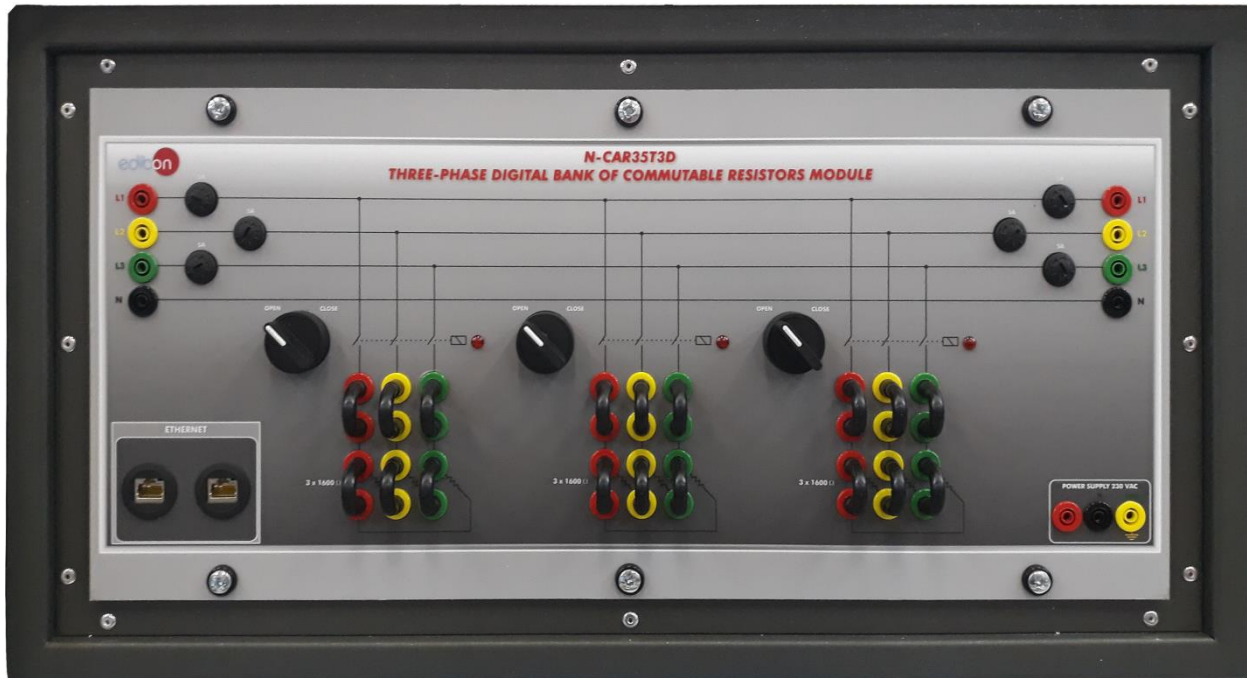


Figure 67: N-CAR35T3D module

This module is designed for the study of active power consumption. The module consists of three phase commutable banks of resistors. Each bank has connected three resistors which can be configured in star and delta. In addition, the module includes three commutators for each Bank.

The module can be used in two modes:

1. Local control mode. This mode allows carry out switching operations with each commutator. The commutators have two positions: OPEN and CLOSE. Close position allows connect the loads to the lines. Open position disconnect the loads.
2. Remote control mode: this control mode allows control the switching actions from the SCADA Control System. For this purpose the module must be connected via ethernet to the rest of

the modules. Additionally, the switch of the N-PSUB module must be turned in SCADA Control Mode position:



Figure 68

:

7.3.7 N-CAR36T3D. Three-Phase Digital Bank of Commutable Inductances Module



Figure 69: N-CAR35T3D module

This module is designed for the study of reactive power consumption. The module consists of three phase commutable Banks of inductances. Each Bank has connected three inductances which can be configured in star and delta. In addition, the module includes three commutators for each Bank.

The module can be used in two modes:

1. Local control mode. This mode allows carry out switching operations with each commutator. The commutators have two positions: OPEN and CLOSE. Close position allows connect the loads to the lines. Open position disconnect the loads.
2. Remote control mode: this control mode allows control the switching actions from the SCADA Control System. For this

purpose the module must be connected via ethernet to the rest of the modules. Additionally, the switch of the N-PSUB module must be turned in SCADA Control Mode position:



Figure 70

7.3.8 N-CAR19T3D. Three-Phase Digital Bank of Commutable Capacitors Module



Figure 71: N-CAR35T3D module

This module is designed for the study of capacitive reactive power. The module consists of three phase commutable Banks of capacitors. Each Bank has connected three capacitors which can be configured in star and delta. In addition, the module includes three commutators for each Bank.

The module can be used in two modes:

1. Local control mode. This mode allows carry out switching operations with each commutator. The commutators have two positions: OPEN and CLOSE. Close position allows connect the loads to the lines. Open position disconnect the loads.
2. Remote control mode: this control mode allows control the switching actions from the SCADA Control System. For this

purpose the module must be connected via ethernet to the rest of the modules. Additionally, the switch of the N-PSUB module must be turned in SCADA Control Mode position:



Figure 72

7.3.9 SCADA system

The SCADA system is used to control and visualize the parameters of the application when the SCADA control mode (remote mode) is activated in the N-PSUB module.

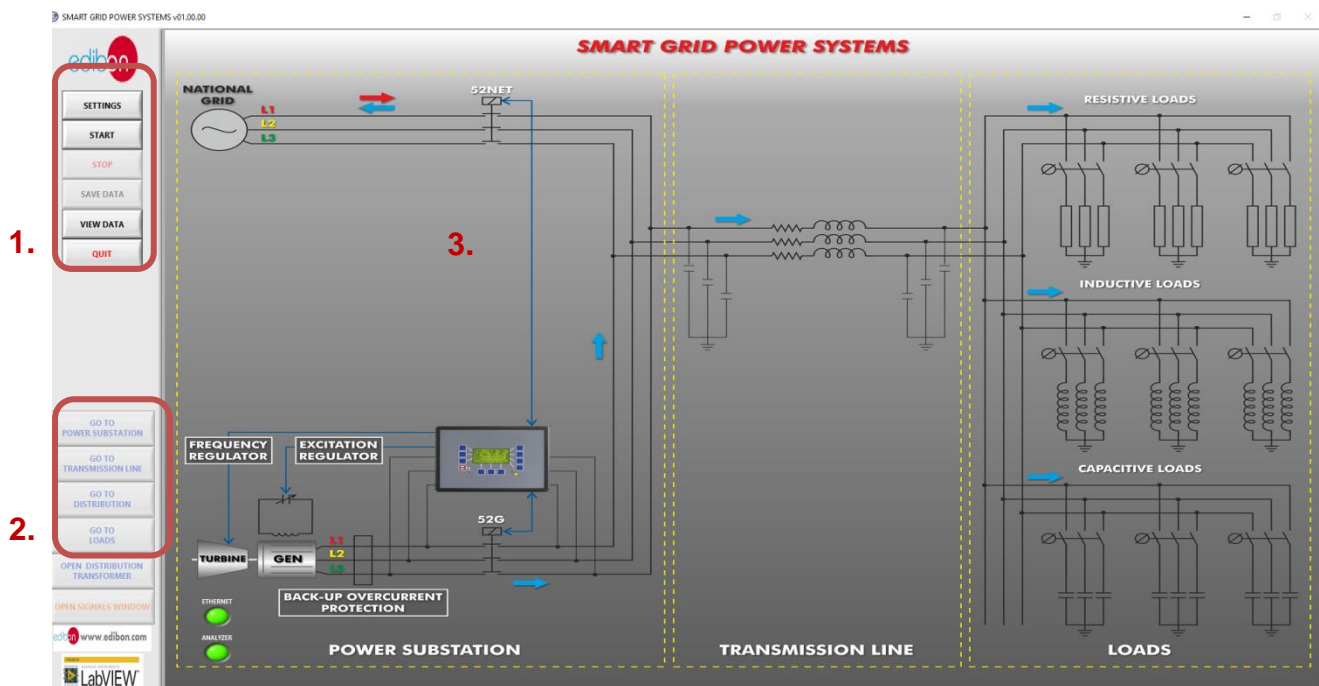


Figure 73: Main screen of SCADA software

The main screen shows a global vision of the application and the parts in which is structured (power substation, transmission line, distribution and loads) and has the main menu to control the SCADA.

The figure shows the parts of this screen:

1. SCADA control menu. It contains the main commands of the system:

- Alarm settings

- Start and Stop of the SCADA System.

- Save data: To save the measured data by creating a file in the PC.

2. Screen navigation menu. In order to be able to navigate through these screens you must start the SCADA system in the control menu. Networks analyzers must be fed and Ethernet wires connected, otherwise the system will not work and an advice will show up on the screen; this can be checked through the green indicators located under the turbine in the diagram. The navigation menu is used to change between the specific screens of the system:

- Power substation screen.

- Transmission line screen.

- Switching distribution screen.

- Loads Screen.

- Signal window.

3. Diagram of the unit showing a power system similar to the hardware.

7.3.9.1 Power substation screen

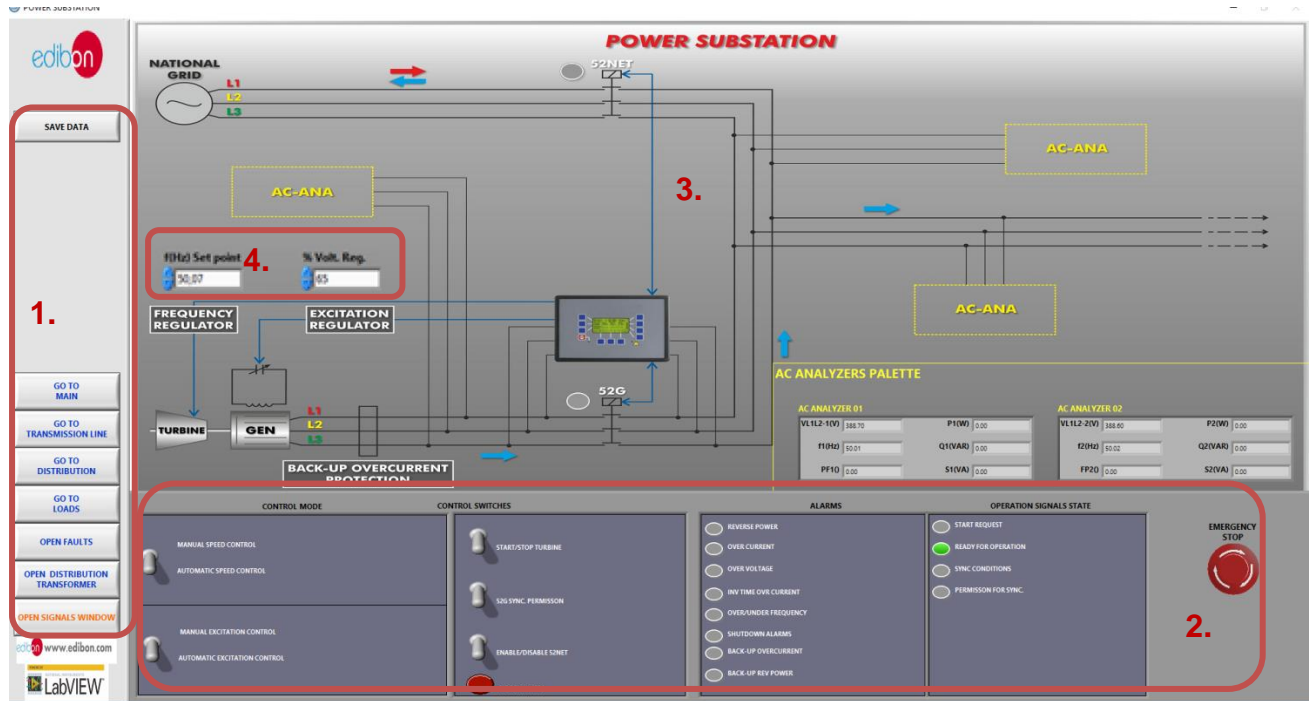


Figure 74: Power substation screen of SCADA software

This screen shows a three-phase diagram where the power generation substation parameters, switches, alarms and operation signals can be visualized.

The figure shows the main parts of this screen:

1. Navigation menu and save data button. To know more about them, go to the main screen description.
2. Power substation control panel. It has the same structure as the N-PSUB and N-PPCM1 modules. Go to the paragraphs “N-PSUB3 : Power Generation Substation Module and N-PPCM1. Control and Protection of Turbine-Generator Group Module 1” to understand how to operate with it.
3. Diagram of the power substation. In the right of the screen has an

“AC analyzers palette” with the measures of the network analyzers. These analyzers can be moved to the positions named as AC-ANA in the three-phase diagram. Note that these movements do not change the real position of the analyzers (the measures will be the same) that only depends on the wiring assembly.

4. Manual control regulators. They appear when the manual control switches are selected in the control panel, one for controlling the generator frequency and the other one for regulating the generator voltage expressed as a percentage of the nominal value.

7.3.9.2 Transmission line screen.

This screen shows a three-phase diagram where the parameters of the transmission line can be visualized. The impedance of each phase line can be modified changing the resistances, inductances and capacitances values. It is important to mention that these values are only informative: a changing in the software values without change the real wiring does not vary the measures.

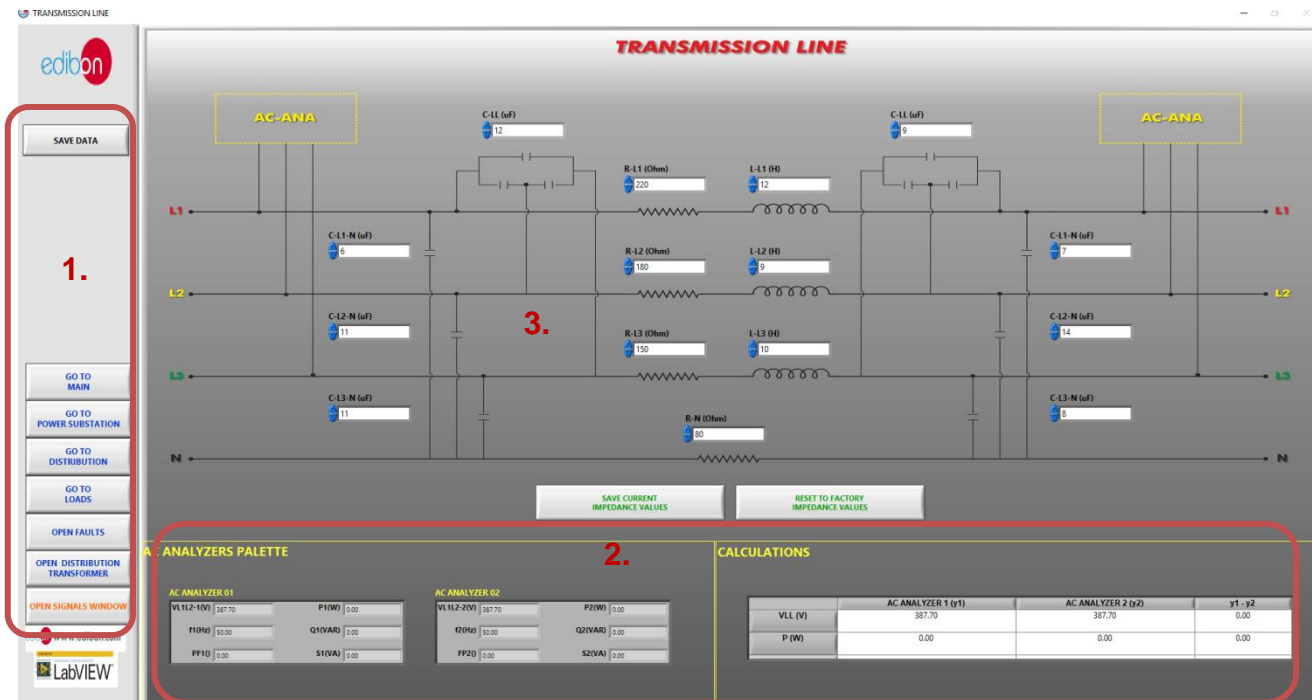


Figure 75: Transmission line screen of SCADA software

The figure shows the main parts of this screen:

1. Navigation menu and save data button. To know more about them, go to the main screen description.
2. AC analyzers palette and calculations. These tables show the measures taken by the analyzers and the different between them with the aim of obtain the line losses. The analyzers can be moved to the positions named as AC-ANA in the three-phase diagram. Note that these movements do not change the real position of the analyzers (the measures will be the same).
3. Diagram of the transmission line. It has two buttons to save the configuration of the transmission line and to reset them to the factory values.

7.3.9.3 Loads screen

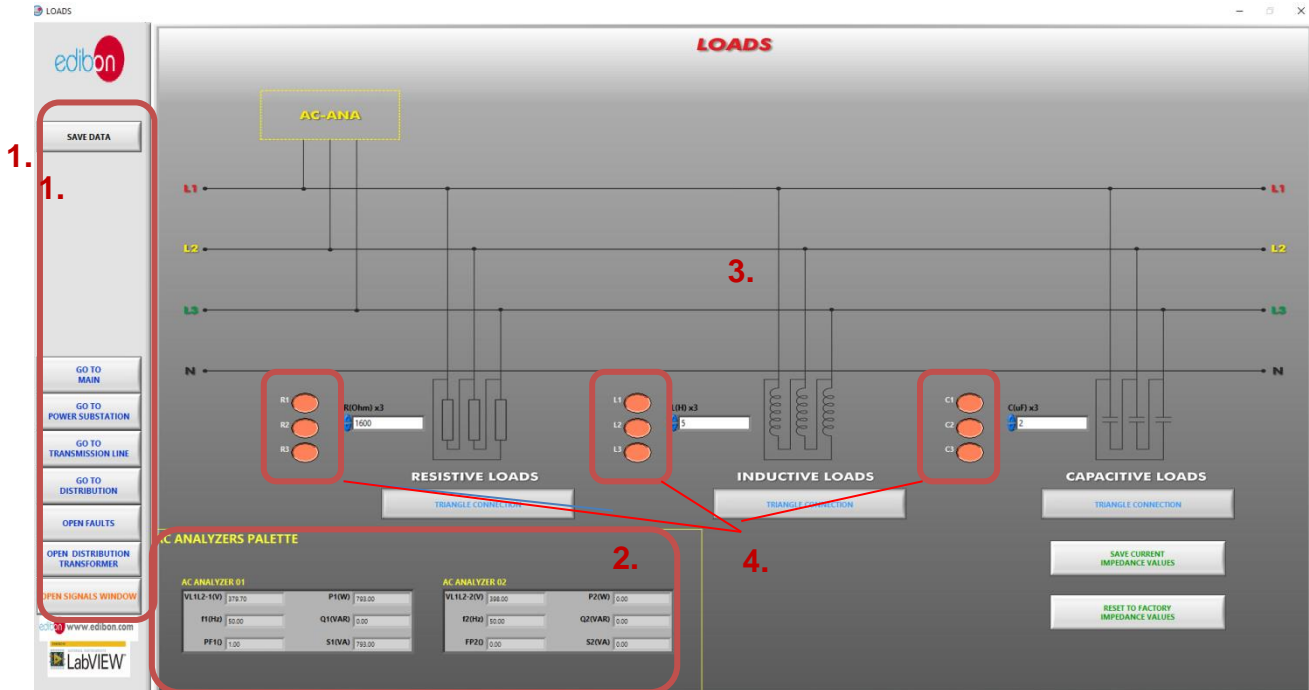


Figure 76: Loads screen of SCADA software

This screen shows a three-phase diagram where the resistive, inductive and capacitive loads can be visualized. These loads are only represented by one bank of each load type. For example, if there are connected two resistor Banks in the real system, the resistor value to introduce in the SCADA software will be $1600/2 = 800 \Omega$. It is important to mention that these values are only informative: a changing in the software values without change the real wiring does not vary the measures.

The figure shows the main parts of this screen:

1. Navigation menu and save data button. To know more about them, go to the main screen description.
2. AC analyzers palette. It shows the measures taken by the

analyzers. The analyzers can be moved to the positions named as AC-ANA in the three-phase diagram. Note that these movements do not change the real position of the analyzers (the measures will be the same).

3. Diagram of the transmission line.
4. Remote switches: Allow load banks remote opening and closing from the SCADA.

7.3.9.4 Open signals window

The signals window is divided in two screens: signal vs time graph and phasor diagram.

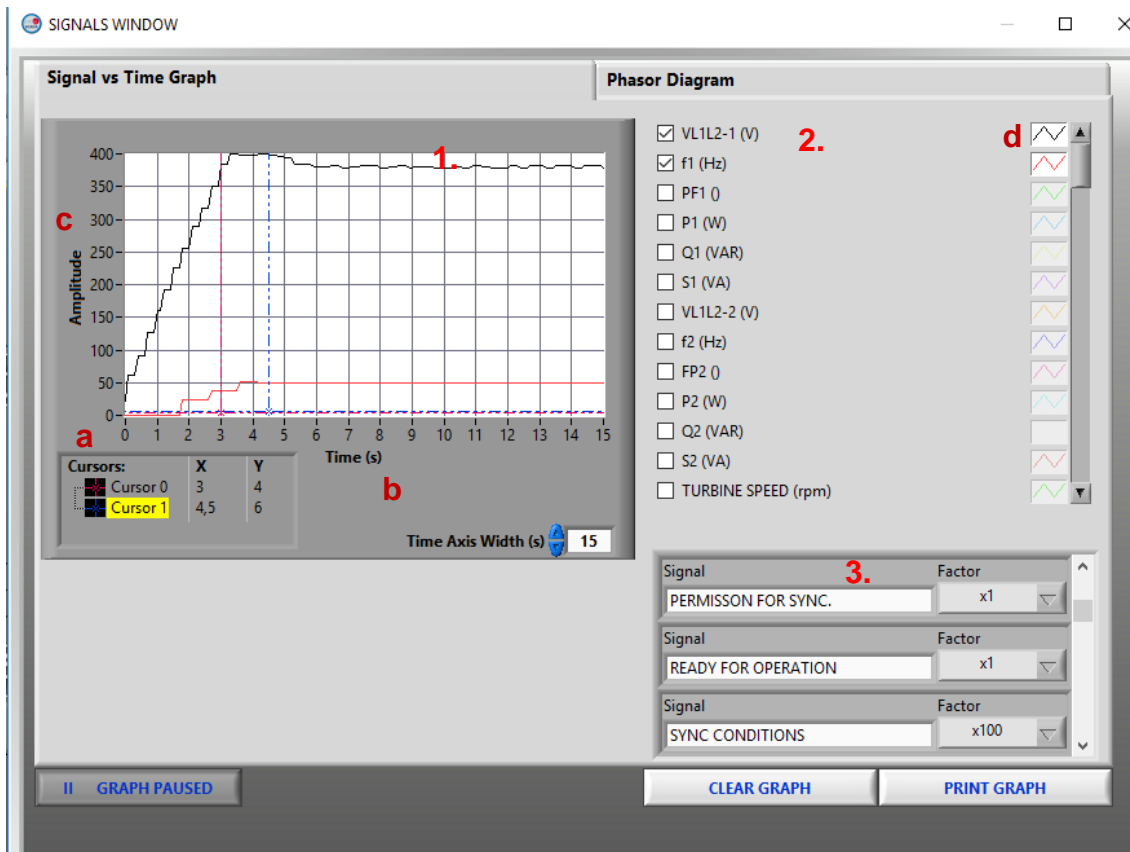


Figure 77: Open signals window. Signal vs time graph

The signal vs time graph has the following sections (see figure):

1. Real time graph. It displays the variables selected and it is possible to take measures using two cursors (a) and modify the time (b) and the amplitude (c) scales. To modify this last scale, click on the upper number and it will allow you to change the value.
2. Variable selector. In this section the variables showed in the real time graph are selected and configured. To modify colors, line widths, line types, etc. do click on the picture placed on the right of the variable (d) and a menu will appear.
3. Multiplier of digital variables. It used to scale the digital variables and visualize them together with the analog signals.

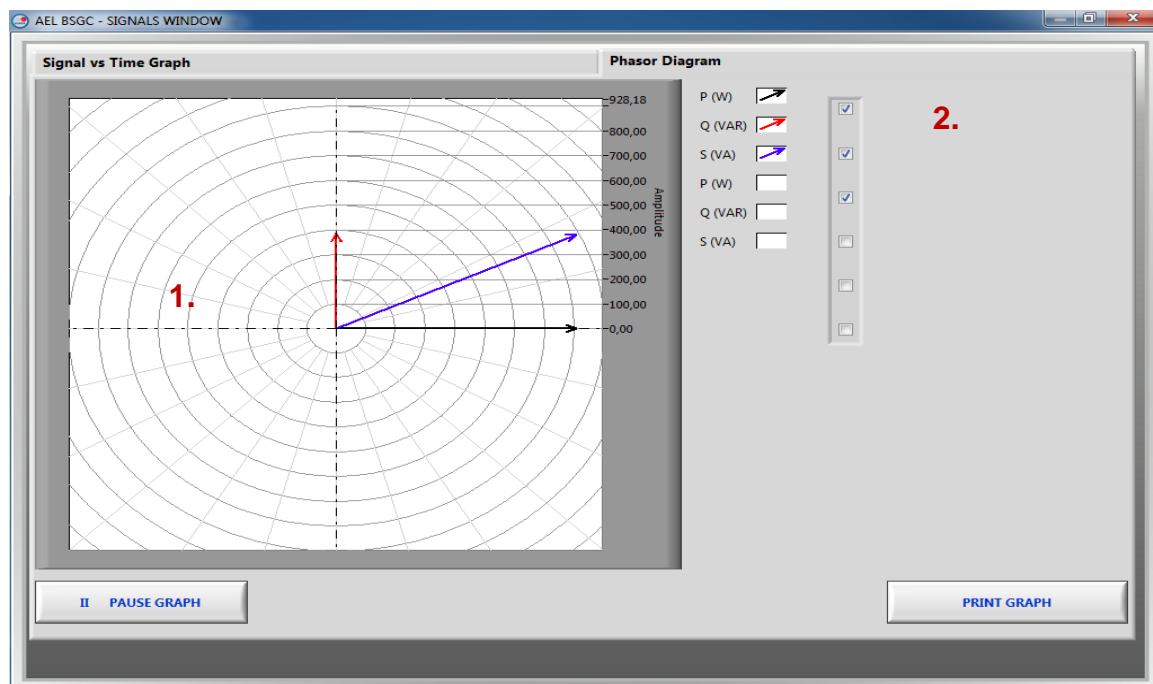


Figure 78: Open signals window. Phasor diagram

7.3.9.5 Distribution transformer screen

This screen shows the diagram to control remotely the UP and DOWN signals from the voltage regulator to the distribution transformer to step up or down the voltage.

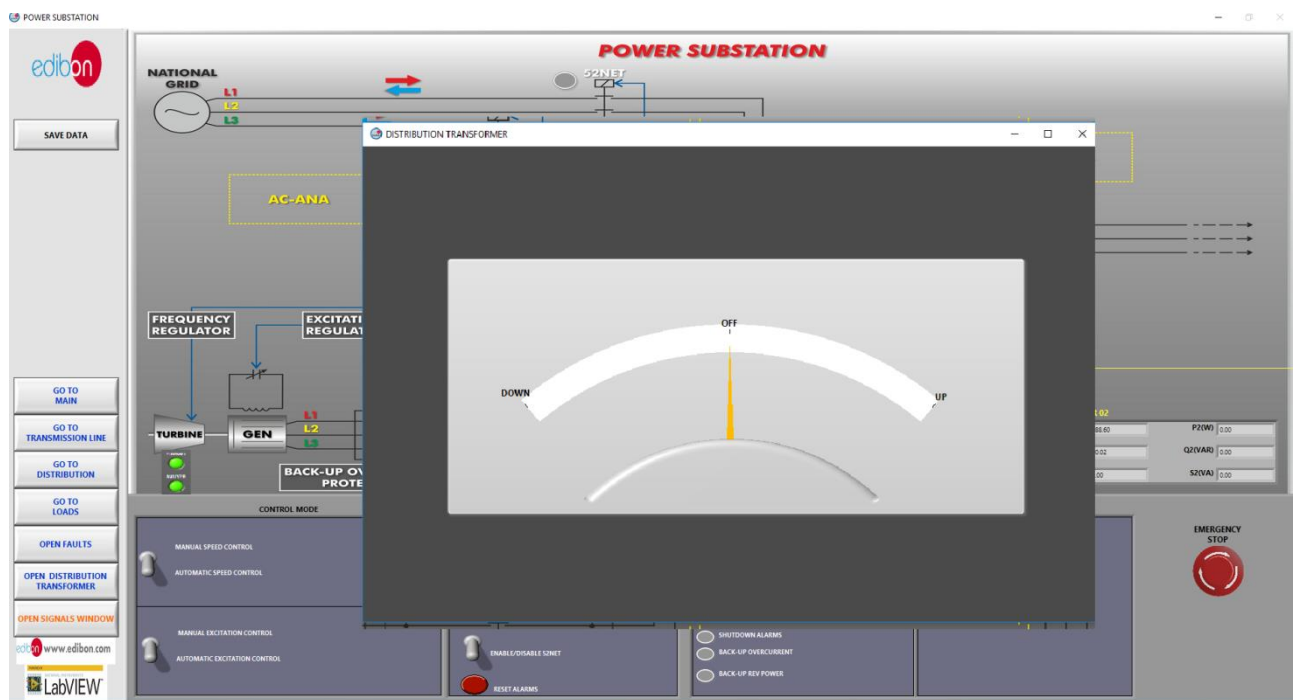


Figure 79: Distribution transformer screen.

7.3.9.6 Faults screen

This screen shows the remote control button to inject the fault chosen. It is important to remind the user that the type of fault will only depend on the real wiring of the digital fault simulator module.

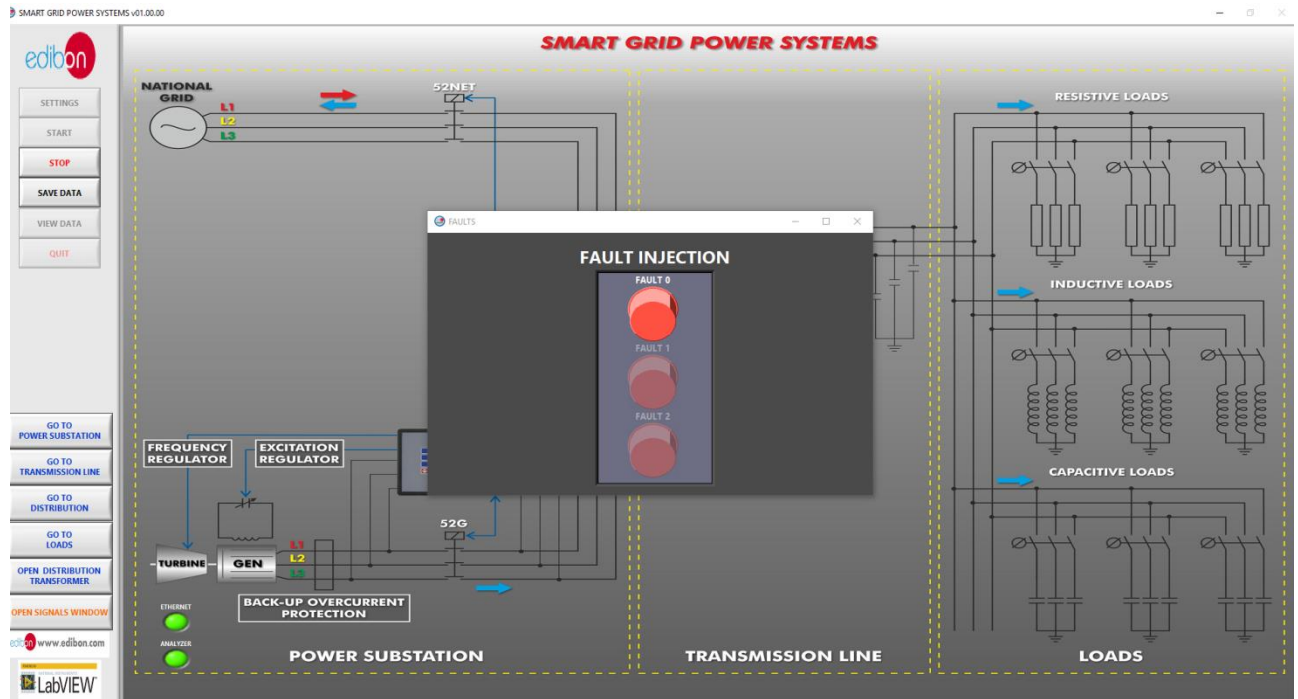


Figure 80: Faults screen.

7.3.9.7 Distribution screen.

This screen shows a three-phase diagram of the two distribution busbars with the corresponding circuit breakers (52) and disconnectors (89) of each distribution and coupling module and the corresponding controls for setting the desired configurations.

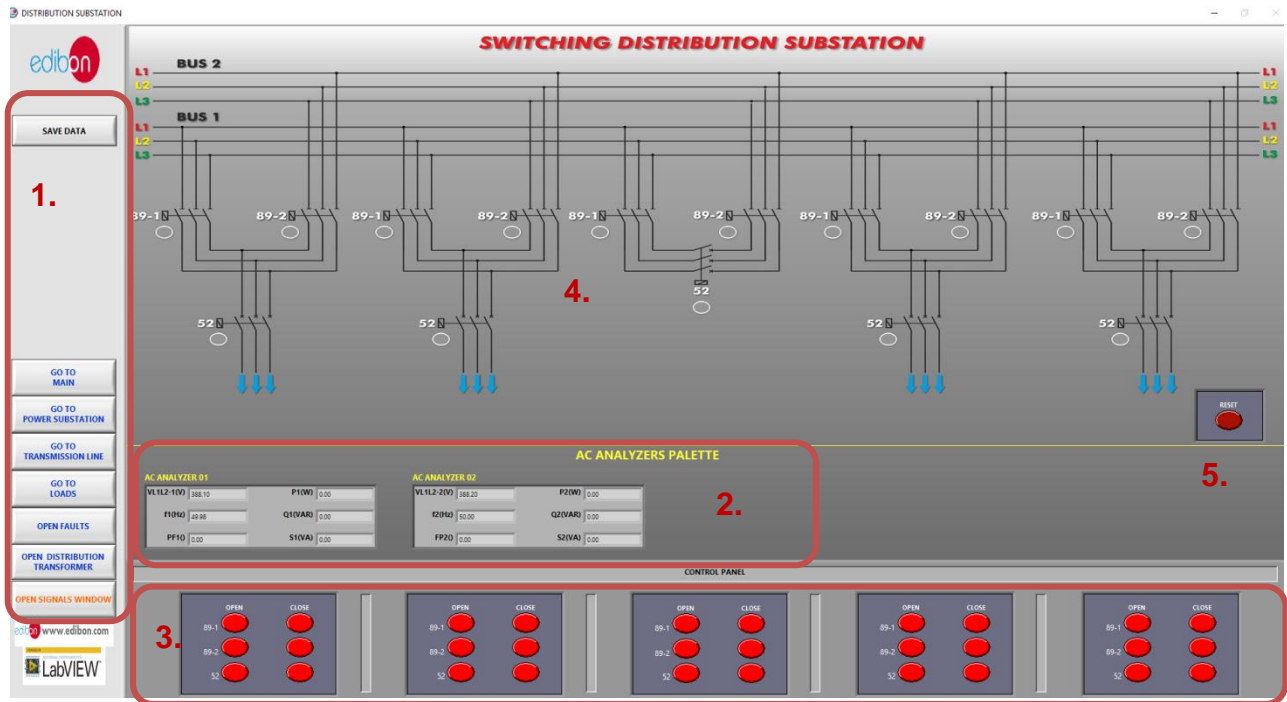


Figure 81: Switching distribution screen.

The figure 72 shows the main parts of this screen:

1. Navigation menu and save data button. To know more about them, go to the main screen description.
2. AC analyzers palette and calculations. These tables show the measures taken by the analyzers and the different between them with the aim of obtain the line losses. The analyzers can be moved to the positions named as AC-ANA in the three-phase diagram. Note that these movements do not change the real position of the analyzers (the measures will be the same).
3. Remote switches for circuit breakers and disconnectors. Through these remote switches the distribution and coupling modules receive the OPEN and CLOSE signals for the 52 and 89 elements.

4. Three-Phase diagram of the two busbars along with the distribution and coupling modules.
5. Reset switch. Through this remote switch all disconnectors and circuit breakers return to OPEN state.

7.3.10 Starting up the application

Follow the steps below to assembly the AEL-TI- modules, activate the protections and turn on the unit:

1. Connect the modules as it is shown in paragraph “Cable assembly of the AEL-TI- modules”.
2. Verify the position of the magneto-thermal circuit breaker placed at the N-ALI01. It must be activated.
3. Turn the removable key to select the ON position in the N-ALI01 module.
4. Adjust the manual control potentiometers to the minimum values allowed and turn on the ON/OFF switch in the N-PSUB module.
5. Turn the selector switches of the N-REFT/3C, N-INDT/3C and N-CAR19T/3C modules to disconnect all loads.

7.3.11 Shutting down the application

Follow the steps below to turn off the unit:

1. Stop the turbine selecting this option in the N-PSUB module (local control mode) or in the SCADA software (remote control mode).
2. Wait until the turbine is turned off and, if the unit has been controlled in remote mode, stop the SCADA system and close it.
3. Switch off the N-PSUB module.
4. Turn off the N-ALI01 module.

7.4 MAIN INSTRUCTIONS, WARNINGS AND PRECAUTIONS

7.4.1 Previous considerations and precautions

Before changing the configuration of any assembly, it will be necessary to switch off the main supply by pressing the module's emergency mushroom (**N-ALI01**). You can also cut the current off by turning the key of the module for the main power supply (**N-ALI01**) until reaching the position OFF. This method will be only used by the instructor, and he or she will keep the mentioned key when the unit is not being used in order to avoid an irresponsible use of it. Check that the automatic magneto-thermal differential switch placed on the main power supply (**N-ALI01**) module is ON for the power supply of the module to be active.

If, for the development of a practical exercise, it is necessary to use modules assembled in different racks, it will be also necessary to connect the grounds of the racks. This way, all the modules will be connected to ground.

You must always have in mind the voltage level of the assembly, taking into account that small terminals will be used for low voltages (24V or 12V) and big terminals for high voltages (230 or 400VAC).

Respect the polarity of the voltages when assembling modules that require a polarized power supply.

Before carrying out practical exercises with motors, it is advisable to check that, according to the metal sheet of the motor features, units can resist the intensities according to the assembly carried out.

Do not forget that you must not exceed the nominal current of the motors. Please, pay special attention to this warning because there are current peaks with fast changes of some electrical parameters.

When injecting faults into the system, to test the back-up protections of the generator motor controller, connect the fault simulator to the primary winding of the distribution transformer and the neutral wire from this winding to the generation line neutral terminal. The step-up transformer must be also included when simulating faults and resistive loads connected and turned on. Do not inject faults when operating in synchronization in the grid due to safety reasons . Back – up protections potentiometers must not be changed. In order to learn more about more about the power generation and distribution protections against faults you should acquire the following additional protection relays:

- N-ERP-PDF01. Differential Protection Relay Module: Protection for transformers, generators or busbars.
- N-ERP-PD01. Distance Protection Relay Module: Protection and control of transmission lines.
- N-ERP-SFT01. Overcurrent and Earth Fault Protection Relay Module: Protection and monitoring of transformers, transmission lines and distribution schemes against overcurrents and earth faults.
- N-ERP-MA01: Feeders Management Relay Module: Protection and monitoring of feeders and overhead lines.

NOTE: For all practical exercises, you must connect the GND's of all modules as it is shown in the wiring models.

7.4.2 Drivers installation and Communication ports configuration

- PCI-1612 installation

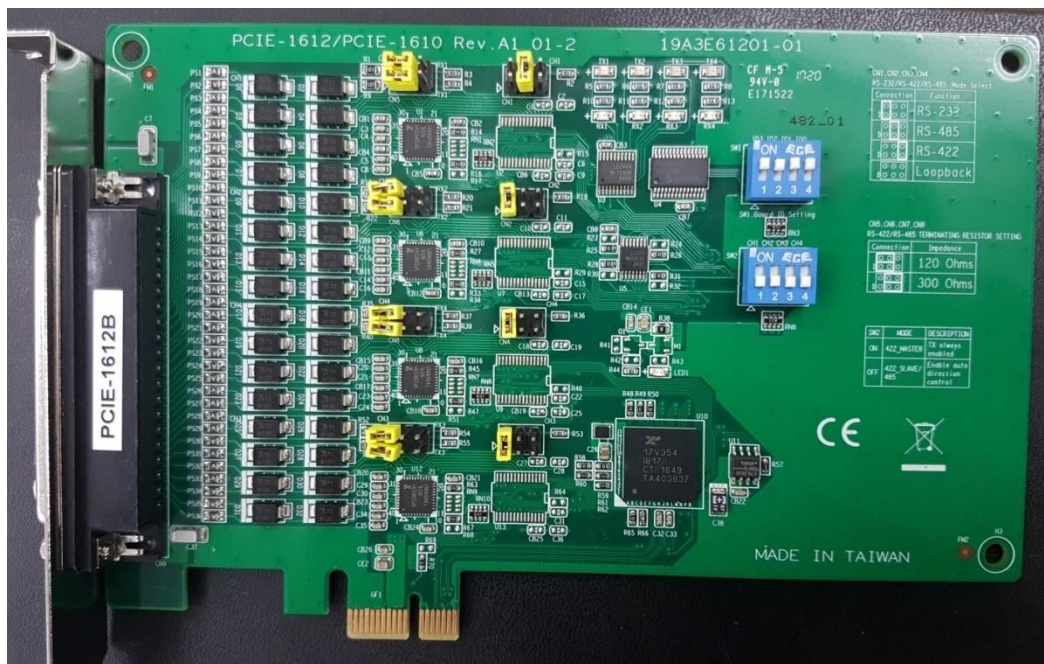


Figure 82: PCI-EXPRESS card

The picture shows the slot where the PCI card must be connected:



Figure 83: PIC-EXPRESS card connection

Tighten the screw:

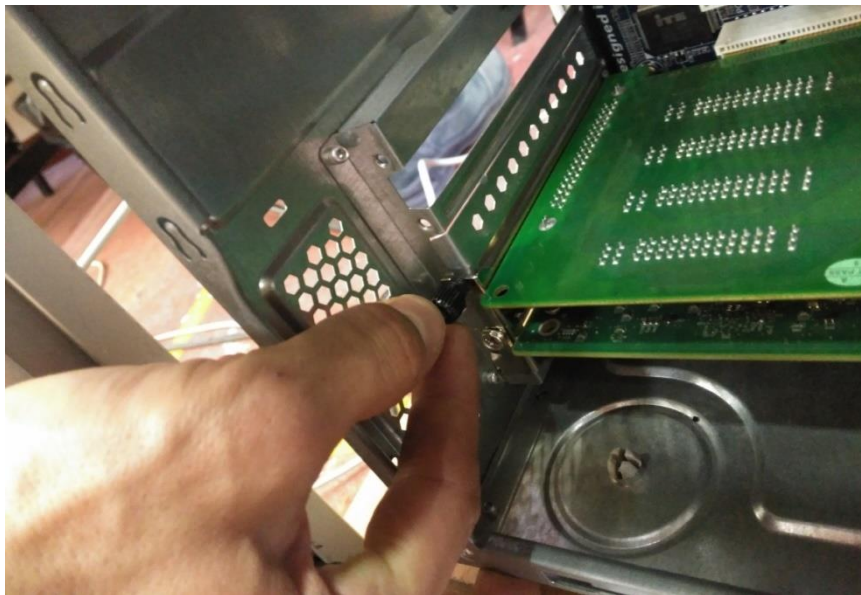


Figure 84: PCI-EXPRESS card fixing

Connect the RS-485 connectors to the network analyzers:



Figure 85: Connection between the PC and the network analyzers t

- Operating systems supported:
 - Windows XP.
 - Windows 7.
 - Windows 8.
 - Windows 8.1.
 - Windows Server 2008 R2.
 - Windows 10.
- Drivers installation steps:
 1. Introduce the drivers CD and the autorun application will appear in a few seconds. Click on Continue.



Figure 86: Welcome screen of the drivers CD

2. Click on "Installation" to access a new screen with the ICOM AND CAN drivers. Select the ICOM Windows drivers.

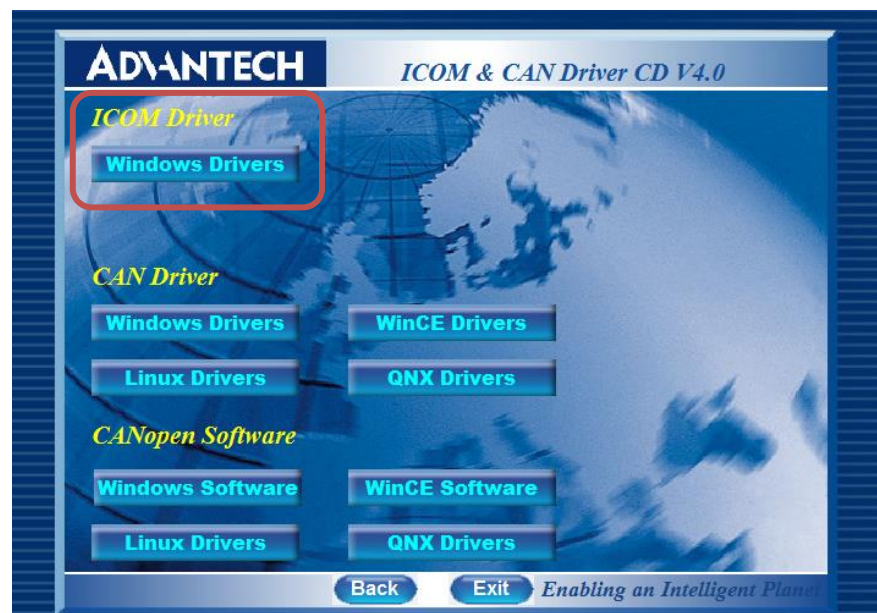


Figure 87: ICOM and CAN drivers

3. Select the PCIE-1612 series and follow the next instruction selecting the destination location and the start menu folder.

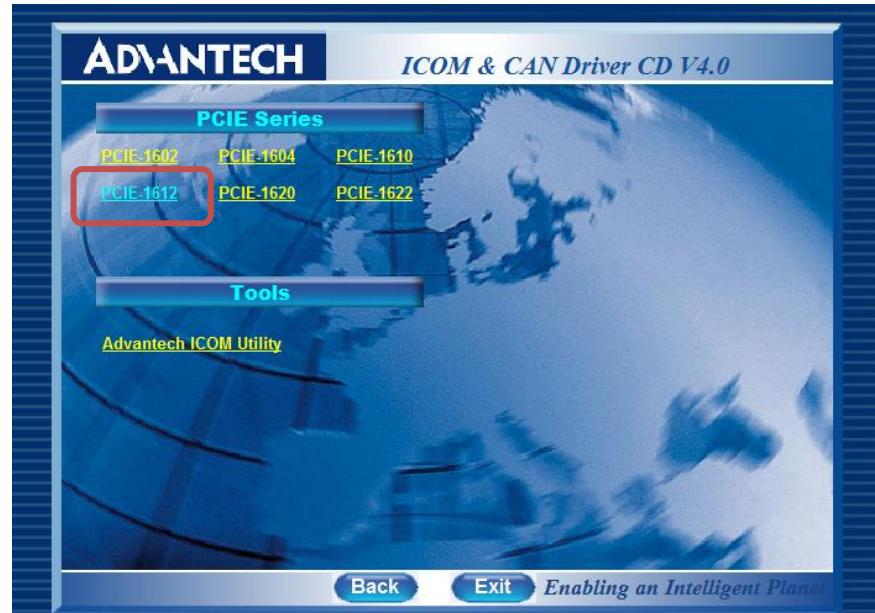


Figure 88: PCIE Series

4. Click on “Install” and wait until the installation finishes.

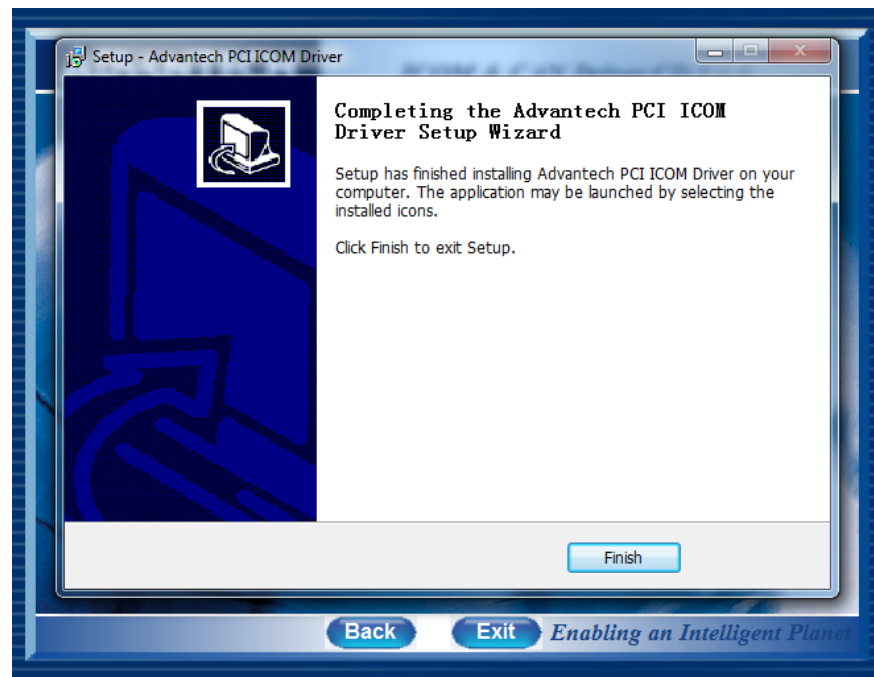


Figure 89: ICOM drivers installation completed

- To know the ports mapped by the Advantech ICOM card, open the “Control panel” and go to “Hardware and sound”. Click on “devices manager”.

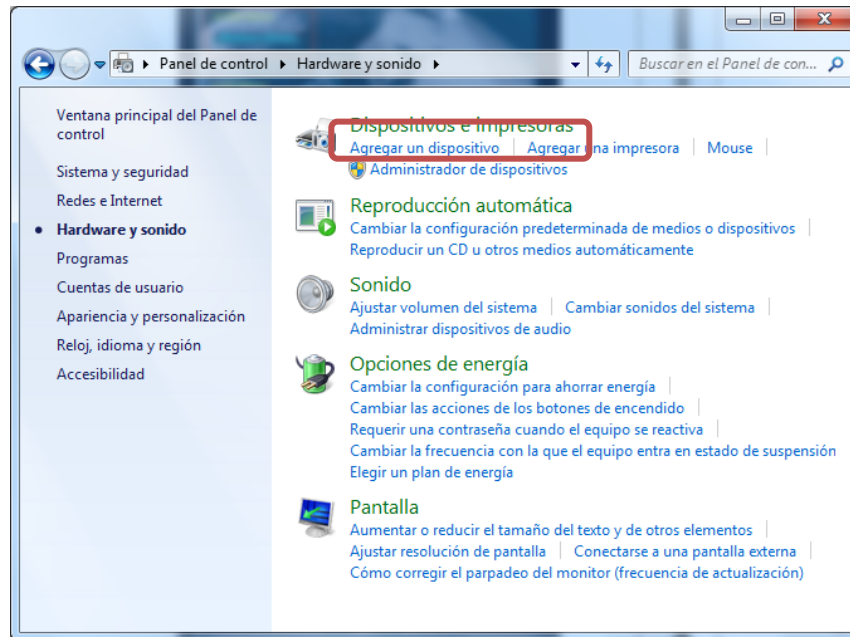


Figure 90: Hardware and sound

- In the “Multi-port serial adapters” folder, you will see “Advantech’s x-Port UART PCI-Express Card”. All serial ports of ICOM cards are under the “Ports (COM & LPT)” folder, you will see “Advantech’s Communications Port (COMxxx)”. These are the serial ports your ICOM cards have been mapped to.

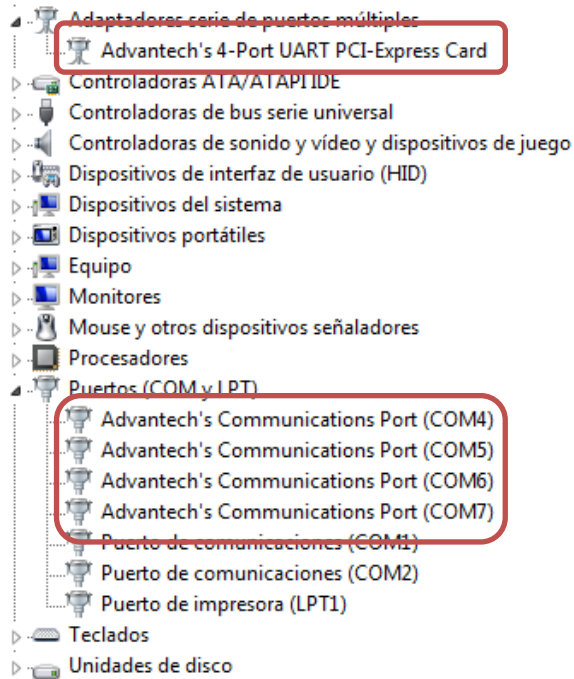


Figure 91: Devices manager

7. The port used to communicate with the AEL-TI- unit is the first installed by the PCI-Express card (COM4). Click on it to verify the speed. It must be equal to 9600 bits per seconds.

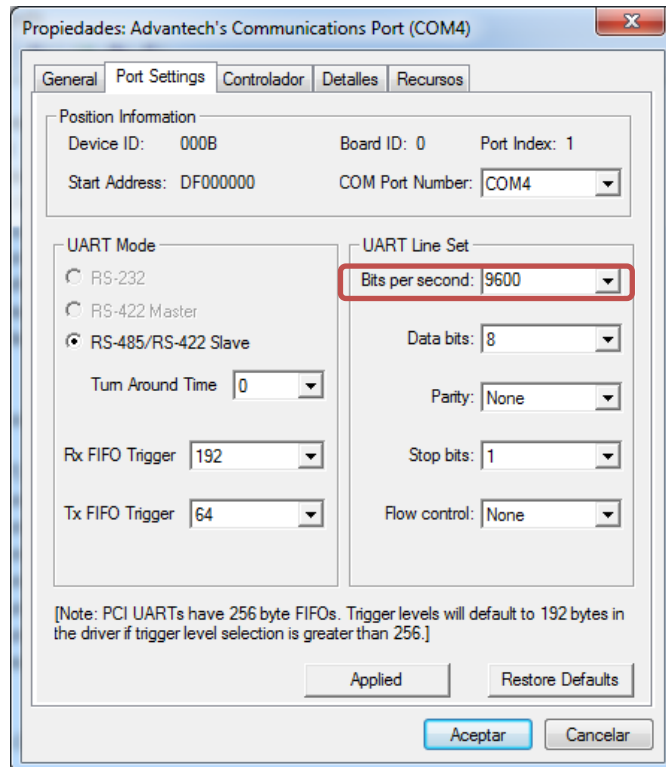


Figure 92: Advantech's Communications Port (COM4) properties

7.4.3 IP address configuration

The communication between the PC and the unit has been made through an Ethernet network. To establish this network it is necessary to set a fixed IP direction to the computer. In the following steps it will be explained the procedure.

1. Go to "Control Panel" in the Windows SO and click on "View network status and tasks".

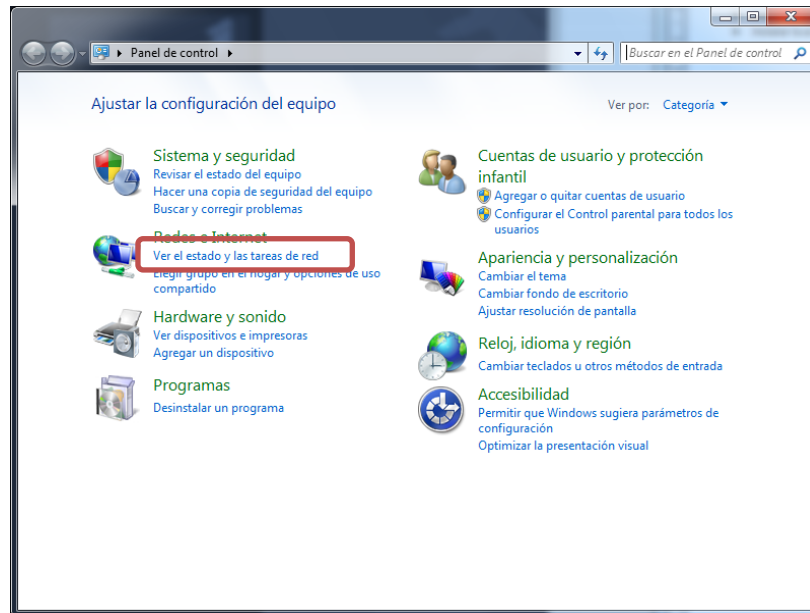


Figure 93: Windows control panel

2. On the left side of the screen, select “Change adapter settings”.

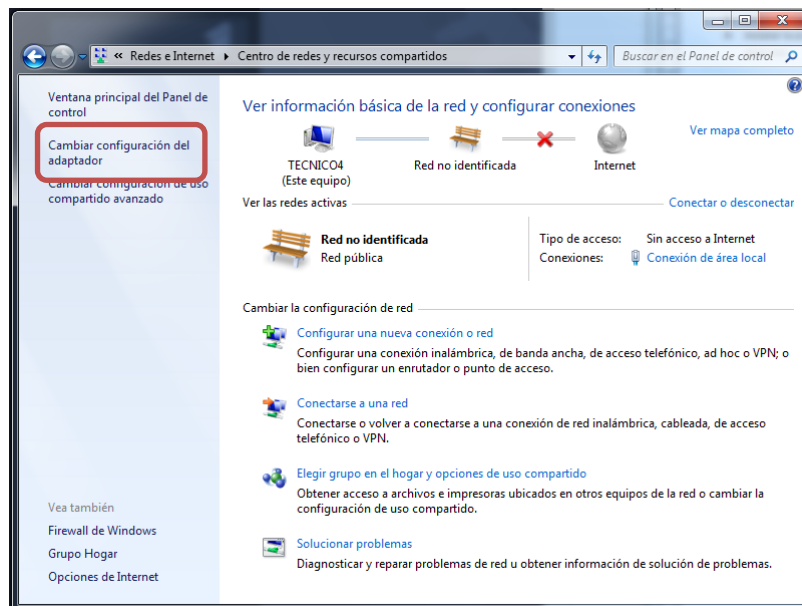


Figure 94: Network and sharing center

3. Click with the right button over the “Local area connection” and select “Properties”.

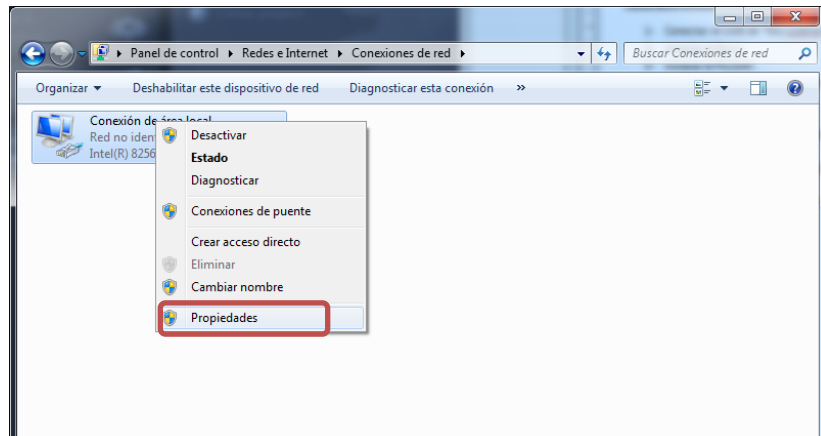


Figure 95: Network connections

4. Select the “Internet protocol version 4 (TCP/IPv4)” and enter in its “Properties”.

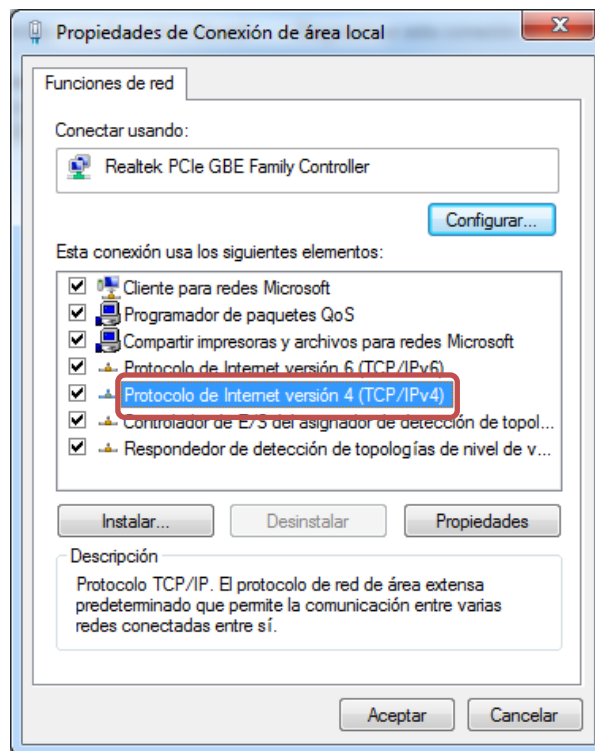


Figure 96: Local area connection properties

5. Select the “Use the following IP address”.
6. Set as “IP address”: 192.168.1.20

7. Set as “Subnet mask”: 255.255.255.0.

8. Push “Ok”.

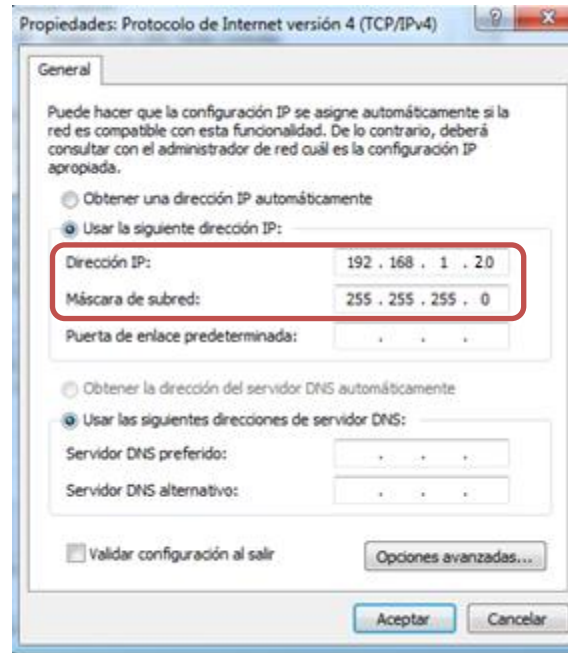


Figure 97: Internet protocol version 4 (TCP/IPv4) properties

9. The IP direction of the computer is configured and the computer is ready to establish an Ethernet network with the AEL-TI- unit.

7.5 LABORATORY PRACTICAL EXERCISES

7.5.1 Practical exercise 1: Stand-alone manual control of voltage and frequency of the generator

7.5.1.1 Objective

The objective of this practice is learning how to control manually the voltage and frequency of the motor-generator group, acting on the motor speed and the excitation current of the generator.

The user will understand the effect of different loads and how to compensate it modifying the speed and excitation current.

7.5.1.2 Required elements

- Industrial Power Supply (N-ALI01)
- Instrumentation Module 1 (N-PPIM2)
- Control and Protection of Turbine-Generator Group Module 1 (N-PPCM1)
- Network Analyzer Unit with Computer Data Acquisition (N-EALD) (1 units).
- Power Generation Substation Module 3 (N-PSUB3)
- Three-Phase Digital Bank of Commutable Resistors (N-CAR35T3D)
- Three-Phase Digital Bank of Commutable Inductances Module (N-CAR36T3D)

- Three-Phase Digital Bank of Commutable Capacitances Module (N-CAR19T3D)
- GMG4.5K2PH. 4,5 kW Generator-Motor Group.

7.5.1.3 Procedure

1. Carry out the steps described in the paragraph “[Starting up the application](#)”.
2. Carry out the wiring shown in the cable assembly section, “[Stand-alone configuration wiring](#)”.
3. The table below shows the final position of the switches placed in the N-PSUB module and the sequence needed to control manually the motor-generator group:

SWITCHES	POSITION
Local/SCADA Control Mode	UP (Local Control Mode)
Manual/Automatic Speed Control	UP (Manual Speed Control)
Manual/Automatic Excitation Control	UP (Manual Excitation Control)
Enable/Disable 52NET	Right (Disable 52NET)
Start/Stop Turbine	Left (Start Turbine)
52G Synchronization Permission	UP

4. Modify slowly the manual excitation control potentiometer to obtain approximately 1A of excitation current (see this current in the N-PPIM2 module).
5. A Network Analyzer is connected after the controller to measure the power and other parameters delivered to the isolated loads.
6. Increase the frequency turning the manual speed control potentiometer and, if it is needed, adjust the voltage generated modifying the excitation current. The aim is to obtain the pre-established conditions in the controller: 380-400V and 50Hz.

Note that the controller has a defined time to reach these conditions and it will activate an alarm if it does not happen (underfrequency alarm). In this case, press the alarms reset button twice. The alarm will be deactivated and it will be possible to try the process again, starting from the last potentiometers positions.

7. When the pre-established conditions (380-400V and 50Hz) are reached, the automatic speed and voltage controller will closed the circuit breaker and the 52G indicator will be turned on.
8. Now, add some resistive loads and display in the instrumentation module (N-PPIM2) and in the analyzer how the parameters change. If the load is too high, an intern alarm in the controller can be activated (undervoltage alarm) but it will not stop the generator.
9. Using the manual control switches, readjust frequency and voltage to obtain again the desired values (380-400V and 50Hz). It is recommended to use a hand for each potentiometer.

10. You can also add inductive or capacitive loads and see the effects in the generator parameters. Note that, if the load is too high, the overload and overcurrent alarm can be activated and the generator will be turned off. In this case, reset the alarms with the alarms reset button and wait until the motor-generator group returns to the operation point.
11. Other interesting protection is activated when the voltage is too high (overvoltage alarm). You can see it connecting different loads, readjusting the generator parameters and disconnecting these loads without readjust the parameters. The amount of load disconnected to produce overvoltage may depend on the line configuration.
12. It is possible to change from manual control to automatic control. To do so, ensure that the voltage is 380V and the frequency is 50 Hz and change the position of the corresponding switches (manual/automatic speed control and manual automatic excitation control). During the transfer of control the turbine and generator may become unstable and any alarm of the controller trips.
13. Do not forget to carry out the step described in the paragraph ‘[Shutting down the application](#)’ to turn off the unit.

7.5.2 Practical exercise 2: Stand-alone automatic control of voltage and frequency of the generator

7.5.2.1 Objective

The objective of this practice is learning how to control automatically the voltage and frequency of the motor-generator group, using the speed and voltage controllers.

The user will understand the effect of different loads and how the controller compensates it.

7.5.2.2 Required elements

- Industrial Power Supply (N-ALI01)
- Instrumentation Module 1 (N-PPIM2)
- Control and Protection of Turbine-Generator Group Module 1 (N-PPCM1)
- Network Analyzer Unit with Computer Data Acquisition (N-EALD) (1 units)
- Power Generation Substation Module 1 (N-PSUB3)
- 3 x 300 W Three-Phase Configurable resistors Module (N-REFT/3C)
- 3 x 300 VAr Three-Phase Configurable Inductances Module (N-INDT/3C)
- 3 x 300 VAr Three-Phase Configurable Capacitors Module (N-CAR19T/3C)
- GMG4.5K2PH. 4,5 kW Generator-Motor Group

7.5.2.3 Procedure

14. Carry out the steps described in the paragraph “[Starting up the application](#)”.

1. Carry out the wiring shown in the cable assembly section, “[Stand-alone configuration wiring](#)”.

2. The table below shows the final position of the switches placed in the N-PSUB module and the sequence needed to control automatically the motor-generator group:

SWITCHES	POSITION
Local/SCADA Control Mode	UP (Local Control Mode)
Manual/Automatic Speed Control	DOWN (Automatic Speed Control)
Manual/Automatic Excitation Control	DOWN (Automatic Excitation Control)
Enable/Disable 52NET	Right (Disable 52NET)
Start/Stop Turbine	Left (Start Turbine)
52G Synchronization Permission	UP

3. A Network Analyzer is connected after the controller to measure the powers and other parameters delivered to the isolated loads

4. When the pre-established conditions (380-400V and 50Hz) are

automatically reached, the automatic speed and voltage controller will closed the circuit breaker and the 52G indicator will be turned on.

5. Add some resistive, capacitive and inductive loads to see how it affects to the generator parameters and how the controller readjusts them.

Note that, if the load is too high, the overload and overcurrent alarm can be activated and the generator will be turned off. In this case, reset the alarms with the reset alarms button and wait until the motor returns to the operation point.

6. It is possible to change from automatic control to manual control. Change the position of the corresponding switches (manual/automatic speed control and manual automatic excitation control) and control the motor-generator group manually. But it is very important to know the initial position of the potentiometers. These potentiometers must be previously set to 50 Hz and 380 VAC.
7. Do not forget to carry out the step described in the paragraph “[Shutting down the application](#)” to turn off the unit.

7.5.3 Practical exercise 3: Synchronization operations with the synchronous generator and the grid

7.5.3.1 Objective

The objective of this practical exercise is to understand the process to synchronize the motor-generator group with the grid which will receive the generated power. For this it is necessary to include both the grid transformer (providing protection to the grid) and the step-up one.

7.5.3.2 Required elements

- Industrial Power Supply (N-ALI01)
- Instrumentation Module 1 (N-PPIM2)
- Control and Protection of Turbine-Generator Group Module 1 (N-PPCM1)
- Network Analyzer Unit with Computer Data Acquisition (N-EALD) (2 units)
- Power Generation Substation Module 1 (N-PSUB3)
- 5 KW Three-Phase Step-up Transformer (TRANS3/5KSU).
- 5 KW Three-Phase Grid Transformer (TRANS3/5KGR).
- GMG4.5K2PH. 4,5 kW Generator-Motor Group (GMG4.5K3PH)

7.5.3.3 Procedure

1. Carry out the step described in the paragraph “Starting up the ”.

2. Carry out the wiring shown in the cable assembly section, “[Synchronization of the generator with the grid wiring](#)”.

3. It is possible to synchronize manually or automatically with the grid. In this practice, we will see the two ways:

Manual synchronization:

4. The table below shows the final position of the switches placed in the N-PSUB module and the sequence needed to synchronize manually with the grid:

SWITCHES	POSITION
Enable/Disable 52NET	Left (Enable 52NET)
Local/SCADA Control Mode	UP (Local Control Mode)
Manual/Automatic Speed Control	UP (Manual Speed Control)
Manual/Automatic Excitation Control	UP (Manual Excitation Control)
Start/Stop Turbine	Left (Start Turbine)
52G Synchronization Permission	UP

5. Modify slowly the manual excitation control potentiometer to obtain approximately 1A of excitation current (see this current in N-PPIM2 module).

6. Increase the frequency turning the manual speed control potentiometer and, if it is needed, adjust the voltage generated modifying the excitation current. The aim is to obtain the pre-established conditions in the controller: 380-400V and 50Hz. After this the circuit breaker will be closed and the 52G indicator will be turned on.

Note that the controller has a defined time to reach these conditions and it will activate an alarm if it does not happen (underfrequency alarm). In this case, press the reset alarms button until the alarm will be deactivated and try the process again starting from the last potentiometers positions.

7. When the pre-established conditions (380-400V and 50Hz) are approximately reached, go to the synchronoscope window of the controller and adjust the phase angle of the generator to the phase angle of the mains.

8. The generator will synchronize with the grid when the difference between the phase angles is small enough; the frequencies and voltages are almost the same.

9. Once the synchronization with the grid is done, the active and reactive power supplied by the generator to the grid can be modified using the manual control potentiometers. Change these values slowly without exceed the 0.6kW and 0.2kVar in order to protect the motor-generator group.

10. Two Network Analyzers are included. One is connected downstream of the step-up transformer and the other is placed upstream of the grid transformer, to measure both the power generated and delivered to the grid, allowing the user to find out the losses and the reactive energy caused by the transformers itself.

11. Do not forget to carry out the step described in the paragraph ‘‘[Shutting down the application](#)’’ to turn off the unit. Note that for uncoupling the generator in manual mode it is needed to reduce first the active and reactive power to zero. After this, the 52G Sync. Permission switch can be turned off.

Automatic synchronization:

12. The table below shows the final position of the switches placed in the N-PSUB module and the sequence needed to synchronize automatically with the grid:

SWITCHES	POSITION
Enable/Disable 52NET	Left (Enable 52NET)
Local/SCADA Control Mode	UP (Local Control Mode)
Manual/Automatic Speed Control	DOWN (Automatic Speed Control)
Manual/Automatic Excitation Control	DOWN (Automatic Excitation Control)
Start/Stop Turbine	Left (Start Turbine)
52G Synchronization Permission	UP

13. See how the controller make that the generator reaches the mains conditions and synchronize with the grid. Once this happens, the controller modifies the active and reactive powers and establishes them at the pre-defined

values.

14. Two Network Analyzers are included. One is connected downstream of the step-up transformer and the other is placed upstream of the grid transformer, to measure both the power generated and delivered to the grid, allowing the user to find out the losses and the reactive energy caused by the transformers itself.
15. Do not forget to carry out the step described in the paragraph ‘[Shutting down the application](#)’ to turn off the unit. Note that for uncoupling the generator in automatic mode it is needed to turn off the Start/Stop turbine switches and wait up to the generator automatically reduce the active and reactive powers given to the grid. After this, the 52G circuit breaker will be turned off and the turbine stops.

7.5.4 Practical exercise 4: Stand-alone operation with transmission line and loads.

7.5.4.1 Objective

The objective of this practice is learning and understanding the operation of a generation system providing power to isolated loads through a transmission line. A step-up transformer, for the simulation of transport voltage increase, and a distribution transformer controlled through a voltage regulator, for compensating line losses and regulating output voltage to the loads, is included.

The user will understand the effects of different loads and configurations of the transmission line in the generator parameters and how the controller compensates them; he will be able to obtain the line losses and carry the out reactive energy compensation needed in real installations through the variable load banks.

7.5.4.2 Required elements

- Industrial Power Supply (N-ALI01)
- Instrumentation Module 1 (N-PPIM2)
- Control and Protection of Turbine-Generator Group Module 1 (N-PPCM1)
- Power Generation Substation Module 1 (N-PSUB3)
- Network Analyzer Unit with Computer Data Acquisition (N-EALD) (2 units)
- Transmission Lines Simulation module (N-AEC1D)

- 3 x 300 W Three-Phase Configurable resistors Module (N-REFT/3C)
- 3 x 300 VAr Three-Phase Configurable Inductances Module (N-INDT/3C)
- 3 x 300 VAr Three-Phase Configurable Capacitors Module (N-CAR19T/3C)
- 5 KW Three-Phase Step-up Transformer (TRANS3/5KSU).
- 5 KW Three-Phase Autotransformer with Motor Voltage Regulator (TRANS3/5KRM).
- GMG4.5K2PH. 4,5 kW Generator-Motor Group (GMG4.5K3PH)

7.5.4.3 Procedure

9. Carry out the step described in the paragraph “[Starting up the application](#)”.
10. Carry out the wiring shown in the cable assembly section “[Stand-alone configuration with transmission line and loads wiring](#)”.
11. The table below shows the final position of the switches placed in the N-PSUB module and the sequence needed to control automatically the motor-generator group:

SWITCHES	POSITION
Local/SCADA Control Mode	UP (Local Control Mode)
Manual/Automatic Speed Control	DOWN (Automatic Speed Control)

Manual/Automatic Excitation Control	DOWN (Automatic Excitation Control)
Enable/Disable 52NET	Right (Disable 52NET)
Start/Stop Turbine	Left (Start Turbine)
52G Synchronization Permission	UP

12. When the pre-established conditions in the controller (380-400V and 50Hz) are reached the automatic speed and voltage controller will close the circuit breaker contactor and the 52G indicator will be turned on. Now add some resistive, capacitive and inductive loads to see how it affects to the generator parameters and how the controller readjusts them.

Note that, if the load is too high, the overload and overcurrent alarm can be activated and the generator will be turned off. In this case, reset the alarms with the reset alarms button and wait until the motor returns to the operation point.

13. Two network analyzers are connected upstream and downstream of the transmission line with the aim of measure the line losses and the final power delivered to the loads. Modify the position of the jumpers placed in the transmission line impedances and see how it affects to the losses.

14. Adjust the voltage regulator commutator (UP or DOWN positions) and check how the voltage and power delivered to the loads change. Adjust it so the delivered voltage is the pre-established one or the closest possible.

15. After measuring the transmission line output parameters carry out the

corresponding calculus to find out the load banks that have to be placed to achieve the measured power factors desired correction (close to the unity). Play also with the impedances of the transmission line being aware of the positions where each power factor is measured.

16. The unbalanced load alarm is activated when the difference between the loads placed in the lines is significant. Try to activate this alarm modifying the jumpers of the lines (phase loss 1, 2 and 3).

17. It is possible to change from automatic control to manual control. Change the position of the corresponding switches (manual/automatic speed control and manual automatic excitation control) and control the motor-generator group manually. But it is very important to know the initial position of the potentiometers. These potentiometers must be previously set to 50 Hz and 380 VAC.

18. Do not forget to carry out the step described in the paragraph “[Shutting down the application](#)” to turn off the unit.

7.5.5 Practical exercise 5: Automatic synchronization with the grid along with transmission line and distributed loads.

7.5.5.1 Objective

The objective of this practice is learning and understanding how to control a generation system synchronized with the grid and at the same time delivering power to isolated loads which are distributed through distribution and coupling busbars to simulate real power switching substations.

The user will understand the effects of different loads and configurations of the transmission line in the generator parameters, the power consumption and the power delivered to the grid.

7.5.5.2 Required elements

- Industrial Power Supply (N-ALI01).
- Instrumentation Module 1 (N-PPIM2).
- Control and Protection of Turbine-Generator Group Module 1 (N-PPCM1).
- Power Generation Substation Module 1 (N-PSUB3).
- Network Analyzer Unit with Computer Data Acquisition (N-EALD) (2 units).
- Transmission Lines Simulation module (N-AE1CD).
- 3 x 300 W Three-Phase Configurable resistors Module (N-REFT/3C).
- 3 x 300 VAr Three-Phase Configurable Inductances Module (N-INDT/3C).

- 3 x 300 VAr Three-Phase Configurable Capacitors Module (N-CAR19T/3C).
- 5 KW Three-Phase Step-up Transformer (TRANS3/5KSU).
- 5 KW Three-Phase Autotransformer with Motor Voltage Regulator (TRANS3/5KRM).
- 5 KW Three-phase Grid Transformer (TRANS3/5KGR).
- Distribution Busbar Module (N-BUS08).
- Coupling Busbar (NBUS09).
- GMG4.5K2PH. 4,5 kW Generator-Motor Group (GMG4.5K3PH).

7.5.5.3 Procedure

1. Carry out the step described in the paragraph “[Starting up the application](#)”.
2. Carry out the wiring shown in the cable assembly section, “[Synchronization with the grid along with transmission line and distributed loads wiring](#)”.
3. It is possible to synchronize manually or automatically with the grid. In this practice, we will use the automatical way.
4. The table below shows the final position of the switches placed in the N-PSUB module and the sequence needed to synchronize automatically with the grid:

SWITCHES	POSITION
----------	----------

Enable/Disable 52NET	Left (Enable 52NET)
Local/SCADA Control Mode	UP (Local Control Mode)
Manual/Automatic Speed Control	DOWN (Automatic Speed Control)
Manual/Automatic Excitation Control	DOWN (Automatic Excitation Control)
Start/Stop Turbine	Left (Start Turbine)
52G Synchronization Permission	UP

5. See how the controller makes the generator reach the mains conditions, then the 52G circuit breaker closes and the green synchronization conditions indicator turns on, finally synchronizing with the grid. Once this happens, the controller modifies the active and reactive powers and established them at the pre-defined values.

6. Add some resistive, capacitive and inductive loads to see how it affects to the generator parameters (check how the controller readjust them) and consequently the power consumption and the power delivered to the grid.

Note that, if the load is too high, the overload and overcurrent alarm can be activated and the generator will be turned off. In this case, reset the alarms with the reset alarms button and wait until the motor returns to the operation point.

7. One network analyzer is connected before the grid transformer to measure the power delivered to the grid while the other one is placed after the distribution transformer to measure the total power consumed by the

distributed loads. These strategic locations enable the user to find out other parameters such as the energy losses through the transmission line or the required loads to carry out the power factor correction if desired just by performing corresponding calculus.

8. Adjust the voltage regulator commutator (UP or DOWN positions) and check how the voltage delivered to the loads change. Adjust it so the delivered voltage is the pre-established one or the closest possible one.
9. Add some resistive, capacitive and inductive loads to see how it affects to the generator parameters (check how the controller readjust them) and consequently the power consumption and the power delivered to the grid.

Note that, if the load is too high, the overload and overcurrent alarm can be activated and the generator will be turned off. In this case, reset the alarms with the reset alarms button and wait until the motor returns to the operation point.

10. Change the arrangement of the loads through distribution and coupling busbar modules, simulating power switching substations. For this modify in the state of the disconnectors (82) and circuit breakers (52) of both modules by pushing "OPEN" and "CLOSE" buttons or through 24 VDC input signals and perform the desired load distribution.

Take into account that only circuit breakers can work under load so carry out the appropriate sequences or the module will not let you do so. It is important to notice that the yellow lights indicate the presence of voltage in each bus.

11. It is possible to change from automatic control to manual control. Change

the position of the corresponding switches (manual/automatic speed control and manual automatic excitation control) and control the motor-generator group manually. But it is very important to know the initial position of the potentiometers. These potentiometers must be previously set to 50 Hz and 380 VAC.

12. Do not forget to carry out the step described in the paragraph ‘[Shutting down the application](#)’ to turn off the unit.

7.5.6 Practical exercise 6: Digital faults simulation in stand-alone mode.

7.5.6.1 Objective

The objective of this practice is learning how to test the motor-generator controller back-up protection relays against overcurrents and the signalling alarms located in this module. For this, a digital fault simulator is included to inject one, two or three pole faults always in stand-alone operation so the grid cannot be damaged.

The user will learn different type of faults, the effects of its injection and how the protections are set for a safe operation of the application.

7.5.6.2 Required elements

- Industrial Power Supply (N-ALI01).
- Instrumentation Module 1 (N-PPIM2).
- Control and Protection of Turbine-Generator Group Module 1 (N-PPCM1).
- Power Generation Substation Module 1 (N-PSUB3).
- Transmission Lines Simulation module (N-AE1CD).
- 3 x 300 W Three-Phase Configurable resistors Module (N-REFT/3C).
- 3 x 300 VAr Three-Phase Configurable Inductances Module (N-INDT/3C).
- 3 x 300 VAr Three-Phase Configurable Capacitors Module (N-CAR19T/3C).
- 5 KW Three-Phase Step-up Transformer (TRANS3/5KSU).

- 5 KW Three-Phase Autortransformer with Motor Voltage Regulator (TRANS3/5KRM).
- Distribution Busbar Module (N-BUS08).
- Coupling Busbar (NBUS09).
- GMG4.5K2PH. 4,5 kW Generator-Motor Group (GMG4.5K3PH).
- Digital Fault Simulator Module (N-ERP-MF01).

7.5.6.3 Procedure

1. Carry out the step described in the paragraph “[Starting up the application](#)”.
2. Carry out the wiring shown in the cable assembly section, “[Stand –alone configuration with transmission line and loads wiring](#)”.
3. Back-up protections parameters are already set so the students must not vary its potentiometers:

<i>Back-up protections</i>	Level	Hysteresis	Delay
Overcurrent protection	115%	10%	3s
Inverse power protection	20%	1%	2s

4. The table below shows the final position of the switches placed in the N-PSUB module and the sequence needed to control automatically the motor-generator group:

SWITCHES	POSITION
Enable/Disable 52NET	Right (Disable 52NET)
Local/SCADA Control Mode	UP (Local Control Mode)
Manual/Automatic Speed Control	DOWN (Automatic Speed Control)
Manual/Automatic Excitation Control	DOWN (Automatic Excitation Control)
Start/Stop Turbine	Left (Start Turbine)
52G Synchronization Permission	UP

5. The digital fault simulation module is injected in the primary winding of the distribution transformer.
6. The three resistive loads must be turned on and consuming power.
7. Set the type of fault to be injected through the module configuration as explained in the'' [Operation](#)'' section for the N-ERP-MF01. Play also with the impedances of the fault line and check its effects.
8. Push the button ''fault injection'' to start the fault simulation.
9. Check the effect of the fault injection.
10. If any alarm sets off the application will stop. To restart it push twice the ''Reset alarms'' button in the N-PSUB module.
11. Do not forget to carry out the step described in the paragraph ''[Shutting down the application](#)'' to turn off the unit.

7.5.7 Practical exercise 7: Stand-alone manual control of voltage and frequency of the generator with SCADA system

7.5.7.1 Objective

The objective of this practice is learning how to control manually the voltage and frequency of the motor-generator group, using a SCADA system.

The user will understand the effect of different loads in the generator parameters and how to compensate it modifying the speed and excitation current from the SCADA.

7.5.7.2 Required elements

- Industrial Power Supply (N-ALI01).
- Instrumentation Module 1 (N-PPIM2).
- Control and Protection of Turbine-Generator Group Module 1 (N-PPCM1).
- Network Analyzer Unit with Computer Data Acquisition (N-EALD) (1 units).
- Power Generation Substation Module 3 (N-PSUB3).
- Three-Phase Digital Bank of Commutable Resistors (N-CAR35T3D).
- Three-Phase Digital Bank of Commutable Inductances Module (N-CAR36T3D).
- Three-Phase Digital Bank of Commutable Capacitances Module (N-CAR19T3D).

- GMG4.5K2PH. 4,5 kW Generator-Motor Group (GMG4.5K3PH).

7.5.7.3 Procedure

1. Carry out the step described in the paragraph “Starting up the ”.
2. Carry out the wiring shown in the cable assembly section, “ [Stand-alone configuration wiring](#)”.
3. In the N-PSUB module, select the SCADA control mode.
4. Open the SCADA software and press the Start button, you will see the following screen.

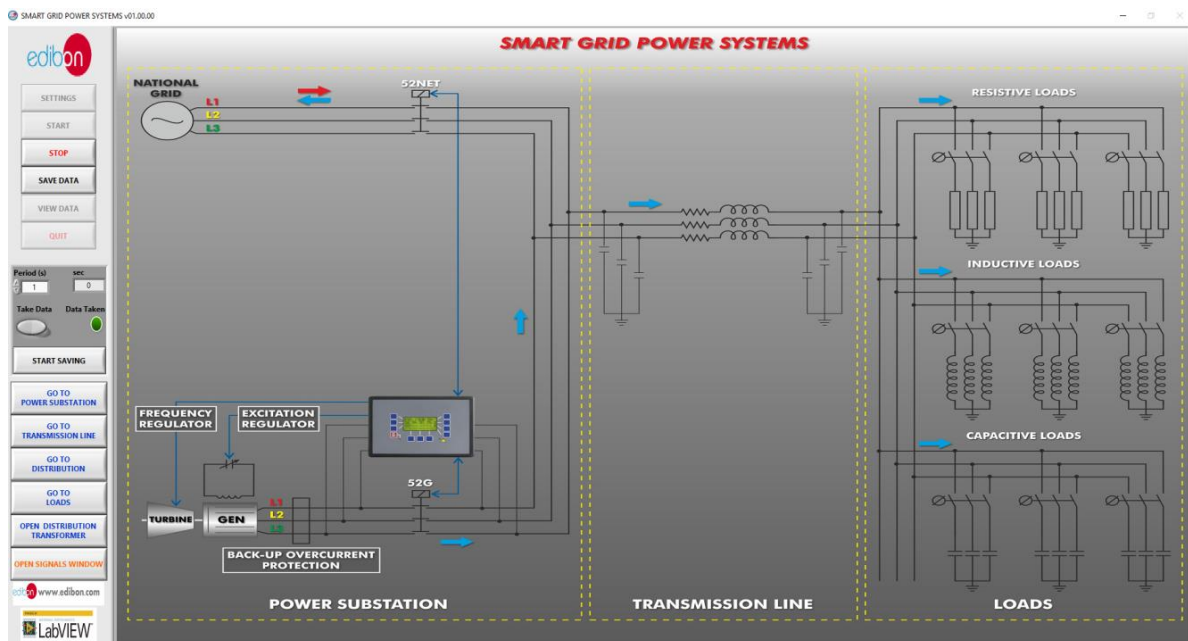


Figure 98: SCADA main screen

5. To record automatically all the data of the processes to be carried out push the button “SAVE DATA”, set the desired time period and select “START SAVING” to create the saving file.
6. Go to the “GO TO POWER SUBSTATION” and follow the sequence

shown in this table to control manually the motor-generator group with the SCADA software:

SWITCHES	POSITION
Manual/Automatic Speed Control	UP (Manual Speed Control)
Manual/Automatic Excitation Control	UP (Manual Excitation Control)
Enable/Disable 52NET	DOWN (Disable 52NET)
Start/Stop Turbine	UP (Start Turbine)
52G Synchronization Permission	UP

7. A Network Analyzer is connected after the controller to measure the power and other parameters delivered to the isolated loads.
8. When the manual controls are activated, two gaps appear to regulate the speed and excitation current. Modify the default values to obtain the pre-established conditions in the controller: 380-400V and 50Hz.
9. When the pre-established conditions (380-400V and 50Hz) are reached, the automatic speed and voltage controller will closed the circuit breaker contactor and the 52G indicator will be turned on.

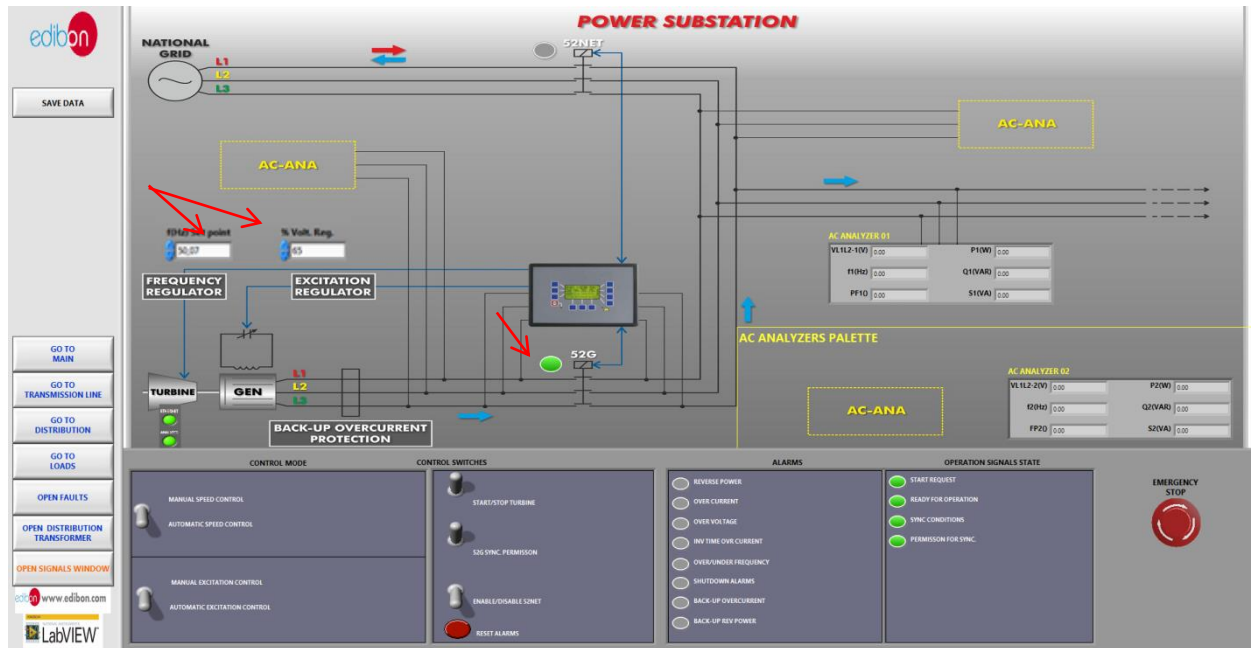


Figure 99: Power substation screen

10. Now, add some resistive loads and display in the AC analyzers palette how the parameters change. If the load is too high, an internal alarm in the controller can be activated (undervoltage alarm) but it will not stop the generator.

For example carry out the three steps implementation of the resistive load banks regarding power and generation voltage. For this go to "GO TO LOADS" option and push progressively the corresponding buttons for each bank.

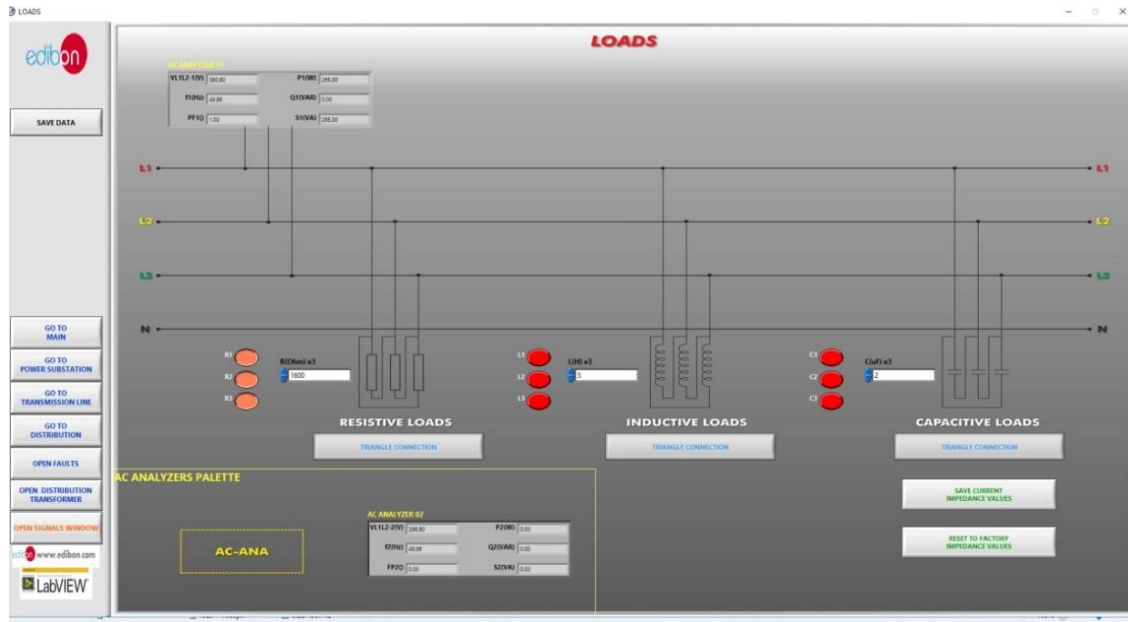


Figure 100: Loads screen

11. To see the measurements graph in real time go to ‘OPEN SIGNAL WINDOW’ and select the desired parameters. Check how the measured power increases with the loads and has transient changes due to the voltage which is not corrected in manual control mode.

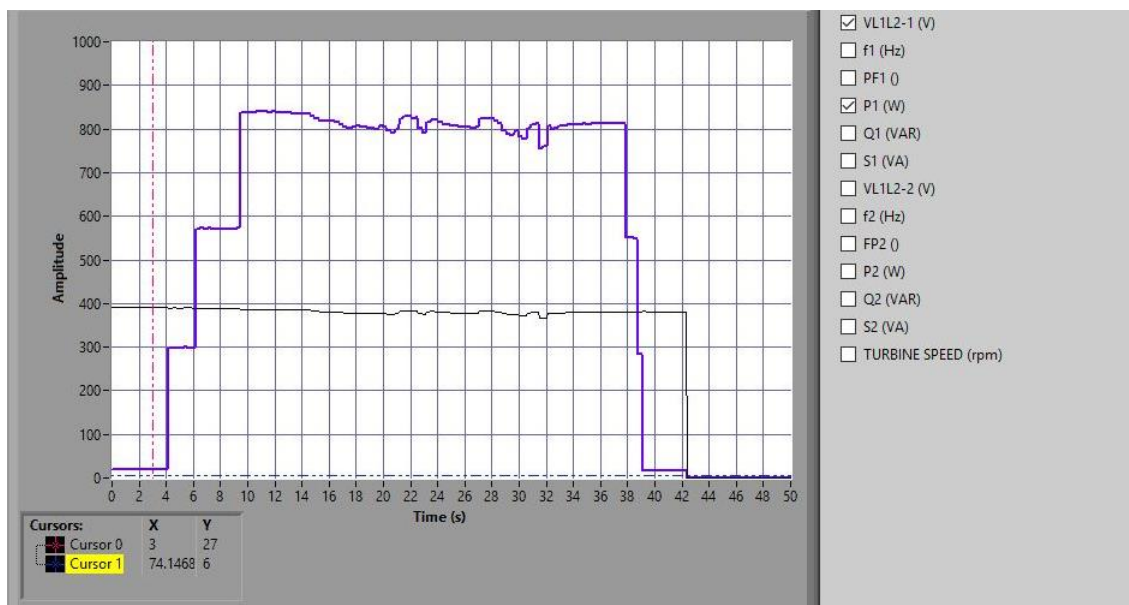


Figure 101: Three steps implementation of resistive loads with manual control

12. Using the manual controls, readjust frequency and voltage to obtain again the desired values (380-400V and 50Hz).
13. You can also add inductive or capacitive loads and see the effects in the generator parameters. Note that, if the load is too high, the overload and overcurrent alarm can be activated and the generator will be turned off. In this case, reset the alarms with the alarms reset button and wait until the motor returns to the operation point.
14. Other interesting protection is activated when the voltage is too high (overvoltage alarm). You can see it connecting different loads, readjusting the generator parameters and disconnecting these loads without readjust the parameters. The amount of load disconnected to produce overvoltage depends on the line configuration and the current excitation.
15. It is possible to change from manual control to automatic control. To do this, ensure that the voltage is 380V and the frequency is 50 Hz and change the position of the corresponding switches (manual/automatic speed control and manual automatic excitation control).
16. Do not forget to carry out the step described in the paragraph “[Shutting down the application](#)” to turn off the unit.

7.5.8 Practical exercise 8: Stand-alone automatic control of voltage and frequency of the generator with SCADA system

7.5.8.1 Objective

The objective of this practice is learning how to control automatically the voltage and frequency of the motor-generator group, using a speed and voltage controller.

The user will understand the effect of different loads in the generator parameters and how the controller compensates it by modifying the speed and excitation current in remote mode.

7.5.8.2 Required elements

- Industrial Power Supply (N-ALI01).
- Instrumentation Module 1 (N-PPIM2).
- Control and Protection of Turbine-Generator Group Module 1 (N-PPCM1).
- Network Analyzer Unit with Computer Data Acquisition (N-EALD) (1 units)
- Power Generation Substation Module 3 (N-PSUB3).
- Three-Phase Digital Bank of Commutable Resistors (N-CAR35T3D).
- Three-Phase Digital Bank of Commutable Inductances Module (N-CAR36T3D).
- Three-Phase Digital Bank of Commutable Capacitances Module (N-CAR19T3D).

- GMG4.5K2PH. 4,5 Kw Generator-Motor Group (GMG4.5K3PH).

7.5.8.3 Procedure

1. Carry out the step described in the paragraph “[Starting up the application](#)”.
2. Carry out the wiring described in the cable assembly section,” [Stand-alone configuration wiring](#)”.
3. In the N-PSUB module, select the SCADA control mode.
4. Open the SCADA software and press the Start button, you will see the following screen.

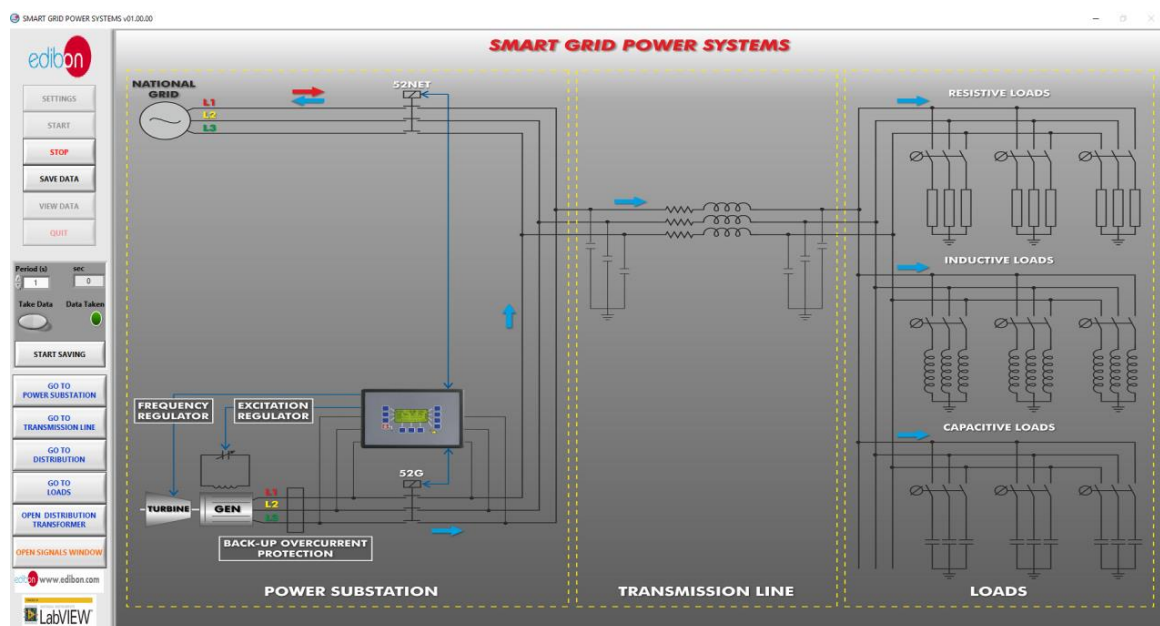


Figure 102: SCADA main screen

5. Go to “ GO TO POWER SUBSTATION’ ‘and follow the sequence shows in this table to control automatically the motor-generator group with the SCADA software:

SWITCHES	POSITION
Manual/Automatic Speed Control	DOWN (Automatic Speed Control)
Manual/Automatic Excitation Control	DOWN (Automatic Excitation Control)
Enable/Disable 52NET	DOWN (Disable 52NET)
Start/Stop Turbine	UP (Start Turbine)
52G Synchronization Permission	UP

- A network analyzer is connected after the controller to measure the powers and other parameters delivered to the isolated loads.
- When the pre-established conditions (380-400V and 50Hz) are reached, the automatic speed and voltage controller will close the circuit breaker contactor and the 52G indicator will be turned on.

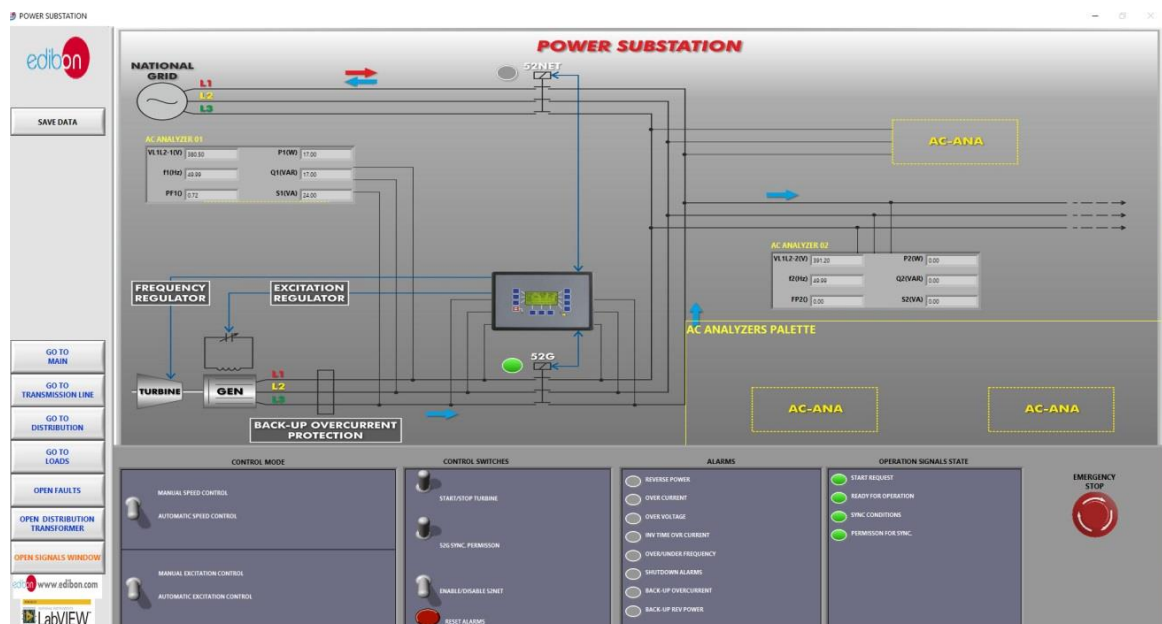


Figure 103: Power substation screen

8. To see the real time measurements graph go to "OPEN SIGNAL WINDOW" and select the desired parameters. Check how the voltage and frequency change with time until reaching the operating conditions.

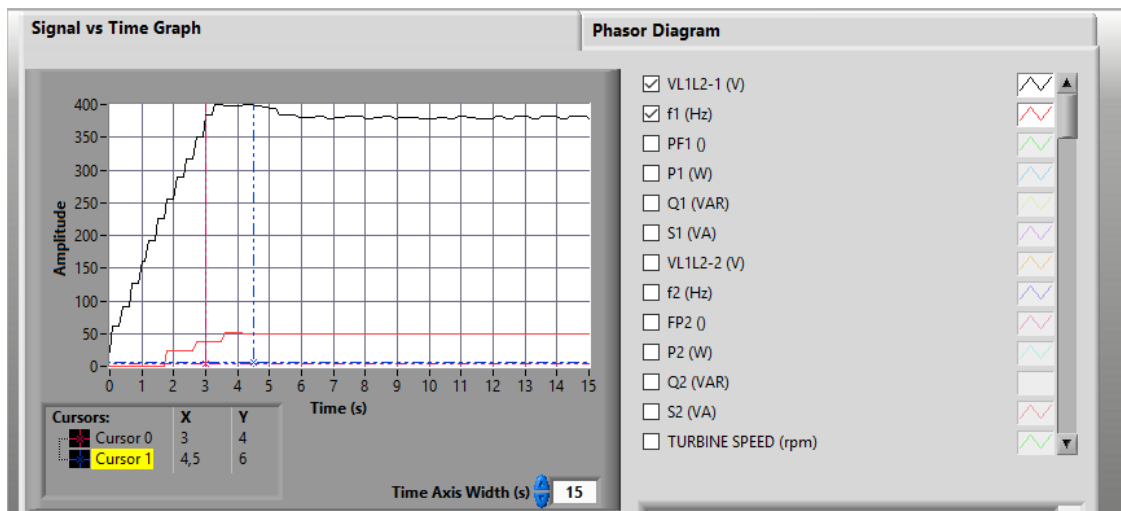


Figure 104: Voltage and frequency parameters during automatic control of the generator

9. Add some resistive, capacitive or inductive loads to see how it affects to the generator parameters and how the controller readjusts them.

For example carry out a three step implementation of the resistive loads. Check how the controller continuously corrects voltage and frequency providing a smoother power until loads are disconnected again.

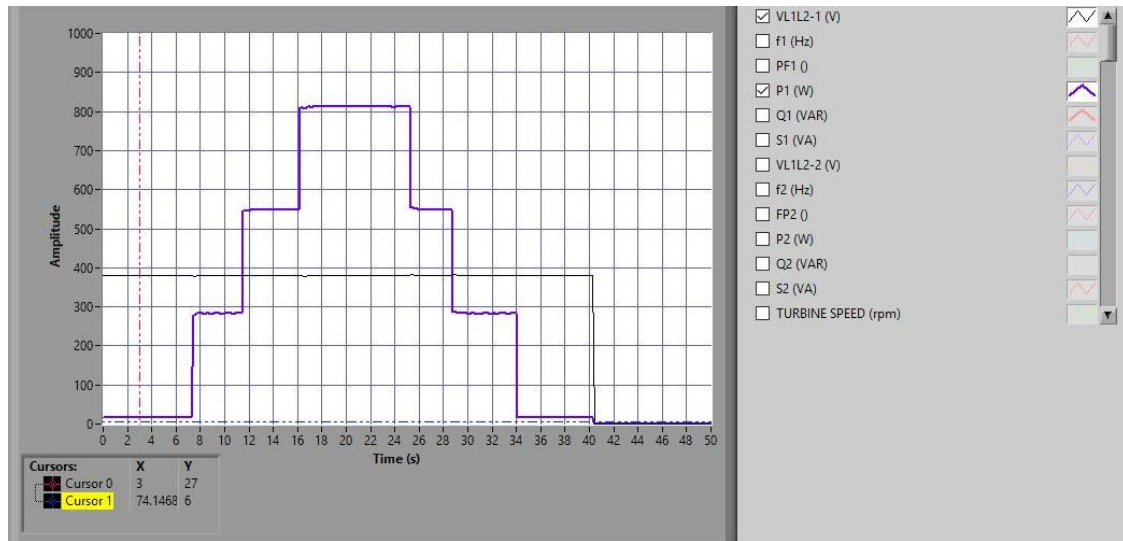


Figure 105: Three steps implementation of resistive loads with automatic control

10. Include one or more bank of inductances to see the effects in the generator parameters. For this go to ‘‘ GO TO LOADS ‘‘ and push the buttons for the desired inductances. Check how reactive power shows up, lowering the power factor, which can also be seen selecting the phasor diagram option in the ‘‘OPEN SIGNALS WINDOW’.

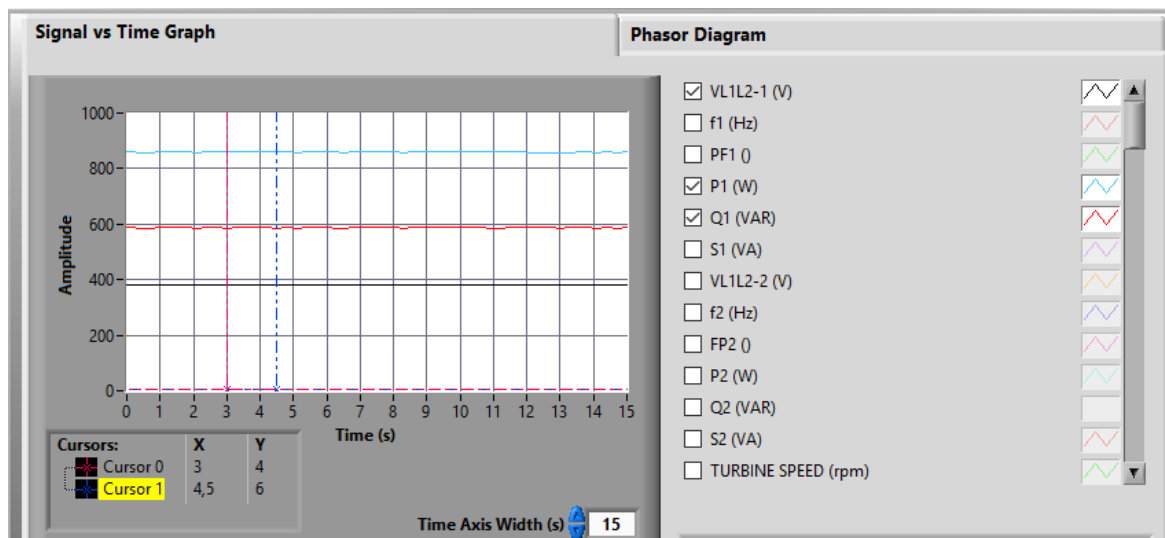


Figure 106: Effect of inductances in active and reactive powers.

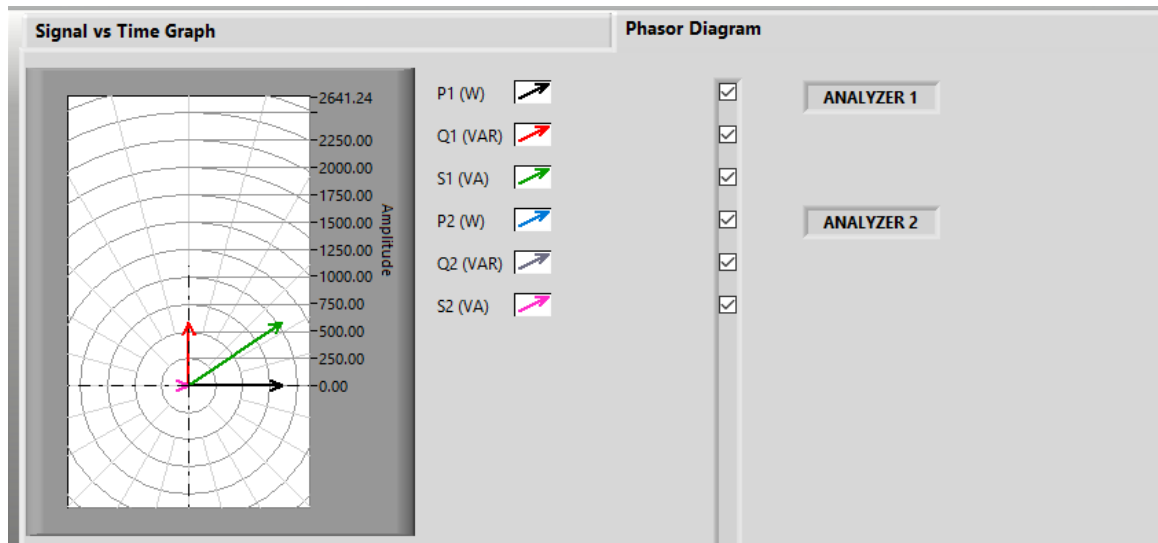


Figure 107: Phasor diagram of powers

11. Note that, if the load is too high, the overload and overcurrent alarm can be activated and the generator will be turned off. In this case, reset the alarms with the alarms reset button and wait until the motor returns to the operation point.
12. It is possible to change from automatic control to manual control. Change the position of the corresponding switches (manual/automatic speed control and manual automatic excitation control) and control the motor-generator group manually.
13. Do not forget to carry out the step described in the paragraph ‘[Shutting down the application](#)’ to turn off the unit.

7.5.9 Practical exercise 9: Automatic synchronization operations with the synchronous generator and the grid with SCADA system.

7.5.9.1 Objective

The objective of this practical exercise is to understand the process to synchronize the motor-generator group with the grid by means of the SCADA system.

7.5.9.2 Required elements

- Industrial Power Supply (N-ALI01)
- Instrumentation Module 1 (N-PPIM2)
- Control and Protection of Turbine-Generator Group Module 1 (N-PPCM1)
- Network Analyzer Unit with Computer Data Acquisition (N-EALD) (2 units)
- Power Generation Substation Module 1 (N-PSUB3)
- 5 KW Three-Phase Step-up Transformer (TRANS3/5KSU).
- 5 KW Three-Phase Grid Transformer (TRANS3/5KGR).
- GMG4.5K2PH. 4,5 kW Generator-Motor Group (GMG4.5K3PH)

7.5.9.3 Procedure

1. Carry out the step described in the paragraph “Starting up the ”.
2. Carry out the wiring shown in the cable assembly section, “

Synchronization of the generator with the grid wiring''.

3. In the N-PSUB module, select the SCADA control mode.
4. Open the SCADA software and press the Start button, you will see the following screen.

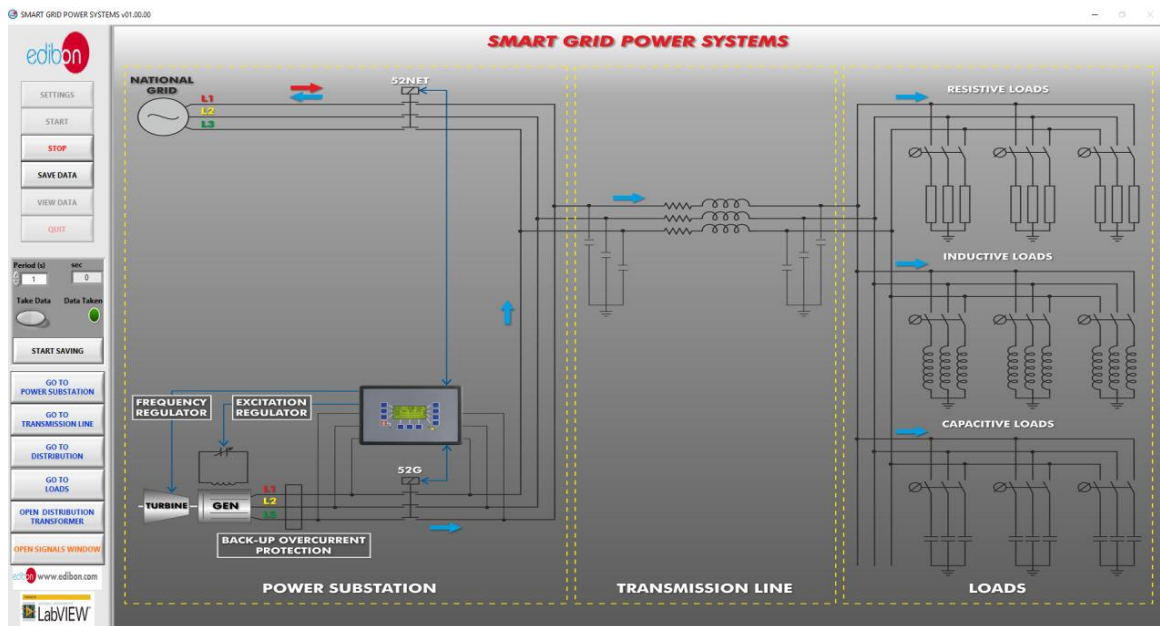


Figure 108: SCADA main screen

5. Go to ‘ GO TO POWER SUBSTATION’ and follow the sequence shown in this table to synchronize automatically the motor-generator group using the SCADA software:

SWITCHES	POSITION
Enable/Disable 52NET	UP (Enable 52NET)
Manual/Automatic Speed Control	DOWN (Automatic Speed Control)
Manual/Automatic Excitation Control	DOWN (Automatic Excitation Control)

Start/Stop Turbine	UP (Start Turbine)
52G Synchronization Permission	UP

6. See how the controller makes the generator reach the mains conditions, then the 52G circuit breaker closes and the green synchronization conditions indicator turns on, finally synchronizing with the grid. Once this happens, the controller modifies the active and reactive powers and established them at the pre-defined values. To see the transient status of the 52G circuit breaker select it in the ‘Signal vs Time Graph’ and multiply the signal factor by 1000 so it is visible together with the other parameters.

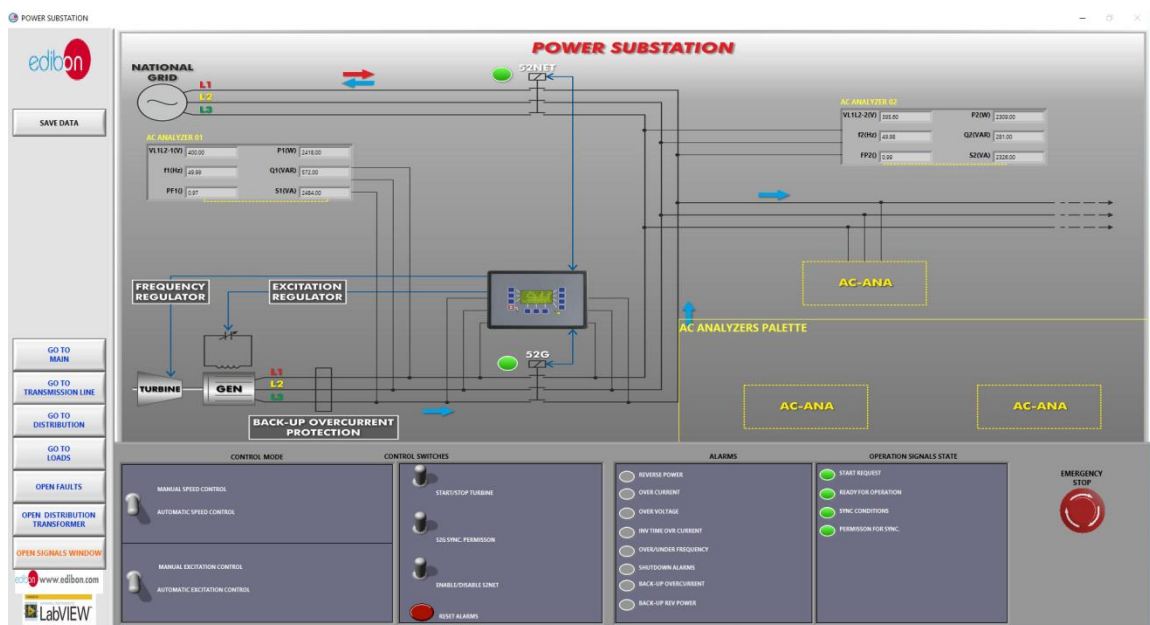


Figure 109: Power substation screen

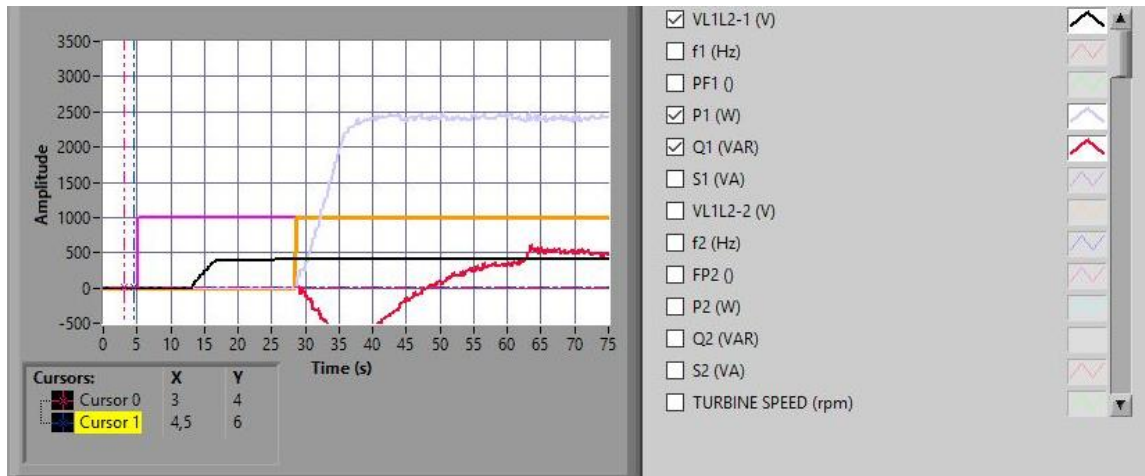


Figure 110: Synchronization process with 52G status in orange.

7. Two Network Analyzers are included. One is connected downstream of the step-up transformer and the other is placed upstream of the grid transformer, to measure both the generated and delivered power to the grid, being noticeable the losses and the reactive energy caused by the transformers itself. Go to “OPEN SIGNAL WINDOWS” and select the real time parameters you want to check.

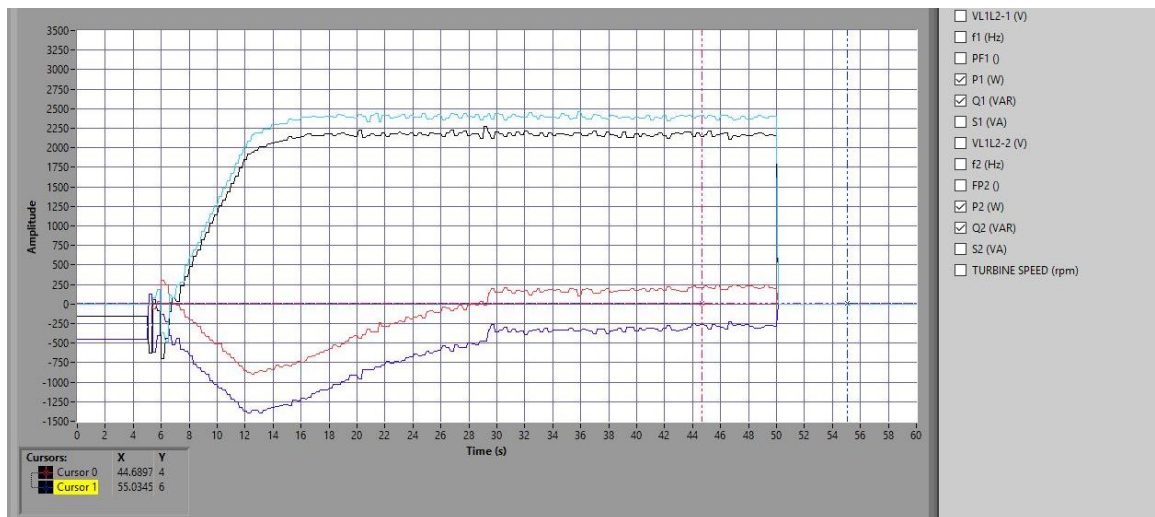


Figure 111: Measurement of both active and reactive power by both analyzers.

8. To see the measurements of the losses between analyzers go to “GO TO TRANSMISSION LINE”. In the lower box it is shown the difference among measured powers and among measured voltages. Remind that the position of the analyzers only depends of the real wiring.

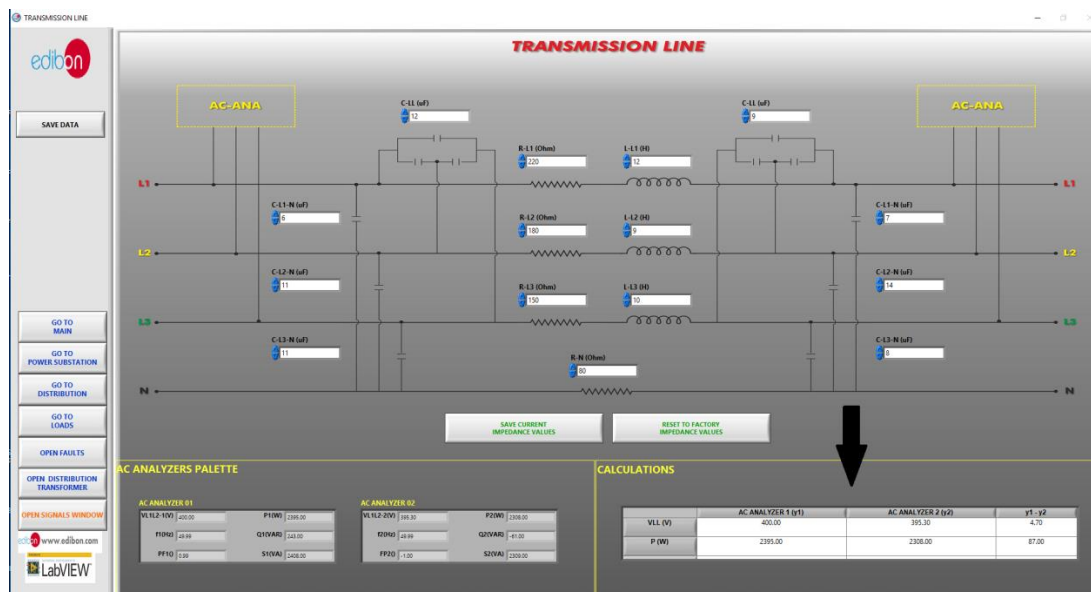


Figure 112: Transmission line screen

9. Do not forget to carry out the step described in the paragraph “[Shutting down the application](#)” to turn off the unit. Note that for uncoupling the generator in automatic mode it is needed to turn off the Start/Stop turbine switches and wait up to the generator automatically reduce the active and reactive powers given to the grid. After this, the 52G circuit breaker will be turned off and the turbine stops.
10. The synchronization with the grid can be also done through manual control. For this the user must select “MANUAL SPEED CONTROL” and “MANUAL EXCITATION CONTROL” in the power substation screen. Modify the values of the gaps until reaching the pre-established conditions

(3800-400V, 50Hz), the 52G indicator will turn on, and go to the synchroscope window of the controller and adjust the phase angle of the generator to the phase angle of the mains. The generator will synchronize with the grid when the difference between the phase angles is small enough.

7.5.10 Practical exercise 10: Stand-alone operation with transmission line and loads with SCADA system.

7.5.10.1 Objective

The objective of this practice is learning and understanding the operation controlled from the SCADA of a generation system providing power to isolated loads through a transmission line through. A step-up transformer, for the simulation of transport voltage increase, and a distribution transformer controlled through a voltage regulator, for compensating line losses and regulating output voltage to the loads, is included.

The user will understand the effects of different loads and configurations of the transmission line in the generator parameters and how the controller compensates them; he will be able to obtain the line losses and carry the out reactive energy compensation needed in real installations through the variable load banks.

7.5.10.2 Required elements

- Industrial Power Supply (N-ALI01)
- Instrumentation Module 1 (N-PPIM2)
- Control and Protection of Turbine-Generator Group Module 1 (N-PPCM1)
- Power Generation Substation Module 1 (N-PSUB3)
- Network Analyzer Unit with Computer Data Acquisition (N-EALD) (2 units)
- Transmission Lines Simulation module (N-AEC1D)

- 3 x 300 W Three-Phase Configurable resistors Module (N-REFT/3C)
- 3 x 300 VAr Three-Phase Configurable Inductances Module (N-INDT/3C)
- 3 x 300 VAr Three-Phase Configurable Capacitors Module (N-CAR19T/3C)
- 5 KW Three-Phase Step-up Transformer (TRANS3/5KSU).
- 5 KW Three-Phase Autotransformer with Motor Voltage Regulator (TRANS3/5KRM).
- GMG4.5K2PH. 4,5 kW Generator-Motor Group (GMG4.5K3PH)

7.5.10.3 Procedure

15. Carry out the step described in the paragraph “Starting up the ”.
16. Carry out the wiring shown in the cable assembly section, “ [Stand-alone configuration with transmission line and loads wiring](#)”.
17. In the N-PSUB module, select the SCADA control mode.
18. Open the SCADA software and press the Start button, you will see the following screen.

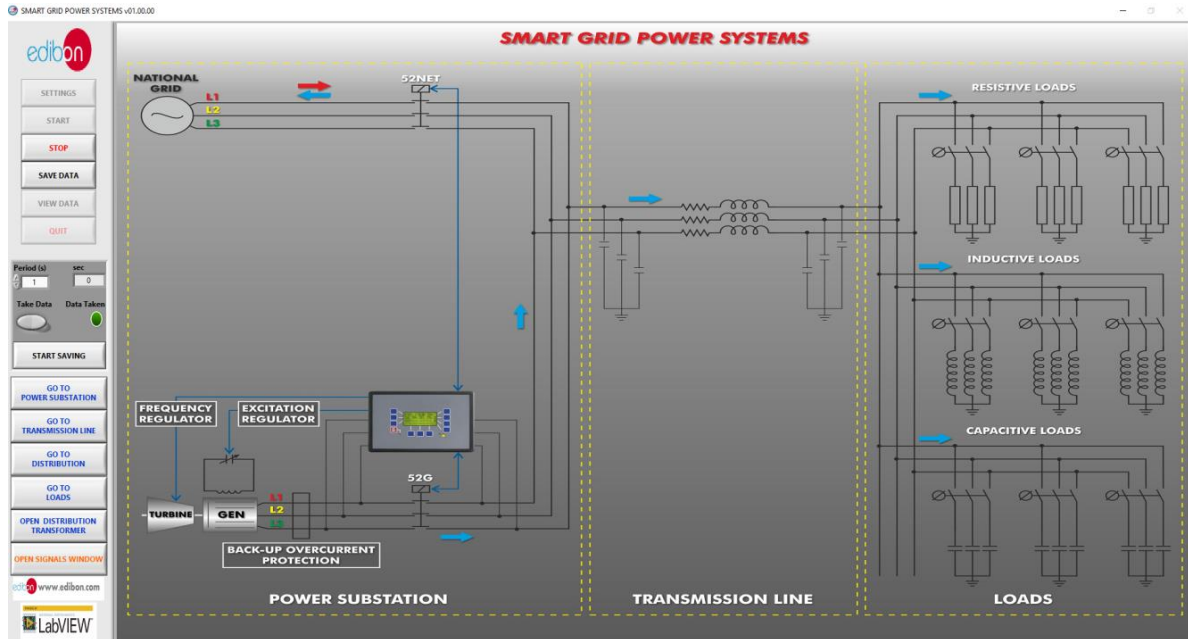


Figure 113: SCADA main screen

1. Go to ‘GO TO POWER SUBSTATION’ and follow the sequence shown in this table:

SWITCHES	POSITION
Enable/Disable 52NET	DOWN (Disable 52NET)
Manual/Automatic Speed Control	DOWN (Automatic Speed Control)
Manual/Automatic Excitation Control	DOWN (Automatic Excitation Control)
Start/Stop Turbine	UP (Start Turbine)
52G Synchronization Permission	UP

19. When the pre-established conditions in the controller (380-400V and 50Hz) are reached the automatic speed and voltage controller will close the circuit breaker contactor and the 52G indicator will be turned on. Now add some resistive, capacitive and inductive loads to see how it affects to the generator parameters and how the controller readjusts them.

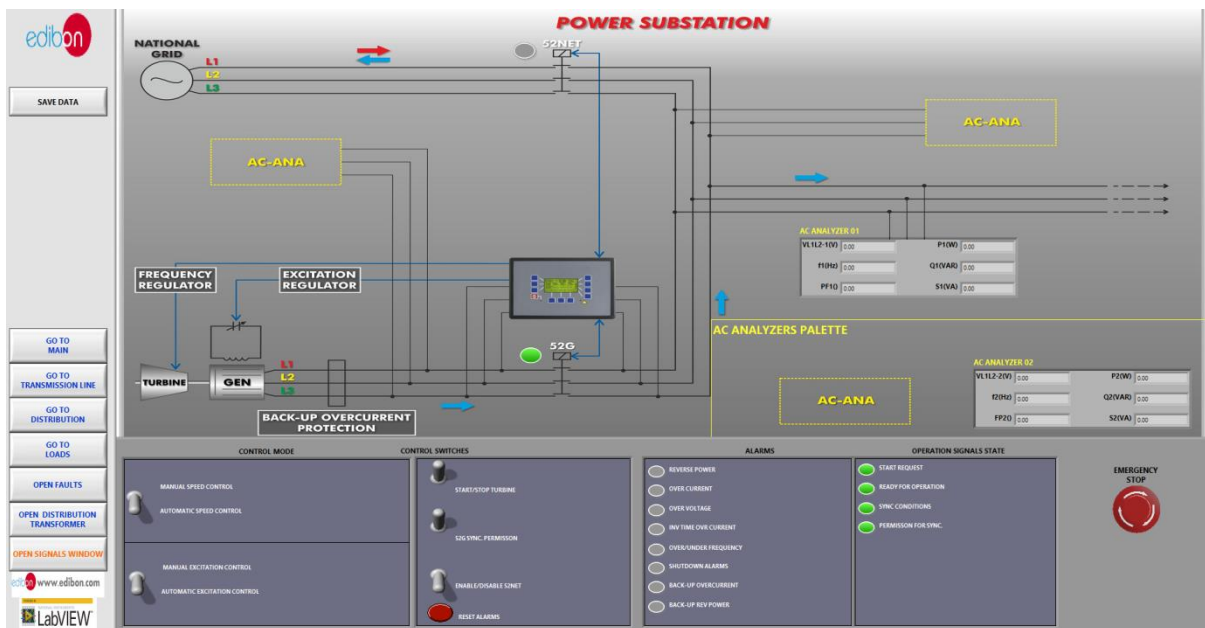


Figure 114: Power substation screen

Note that, if the load is too high, the overload and overcurrent alarm can be activated and the generator will be turned off. In this case, reset the alarms with the reset alarms button and wait until the motor returns to the operation point.

20. Two network analyzers are connected upstream and downstream of the transmission line with the aim of measure the line losses and the final power delivered to the loads.

21. Modify the position of the jumpers placed in the transmission line impedances and see how it affects to the power and voltage losses. For this

go to “GO TO TRANSMISSION LINE” and check the analyzers palette where the difference between both of them is shown.

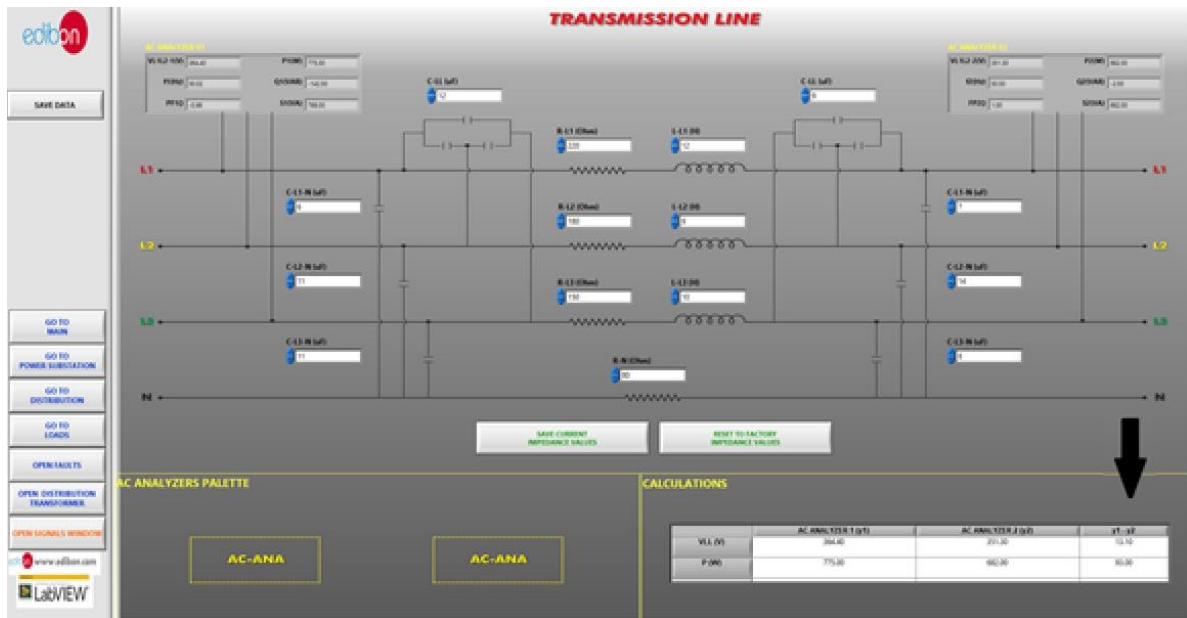


Figure 115: Transmission line screen

22. Adjust the voltage regulator commutator and check how the voltage and power delivered to the loads change. Adjust it so the delivered voltage is the pre-established one or the closest possible. For this go to “OPEN DISTRIBUTION TRANSFORMER” and press “UP ” or “DOWN” to increase or decrease the delivered voltage.



Figure 116: Voltage regulator screen for the regulating transformer control

23. The unbalanced load alarm is activated when the difference between the loads placed in the lines is significant. Try to activate this alarm modifying the jumpers of the lines (phase loss 1, 2 and 3).
24. After measuring the transmission line output parameters add some more inductive loads and carry out the corresponding calculus to find out the load banks that have to be placed to achieve the desired power factors correction (close to the unity). Play also with the impedances of the transmission line being aware of the positions where each power factor is measured. Check the real time power factor correction through "OPEN SIGNALS WINDOW" screen.

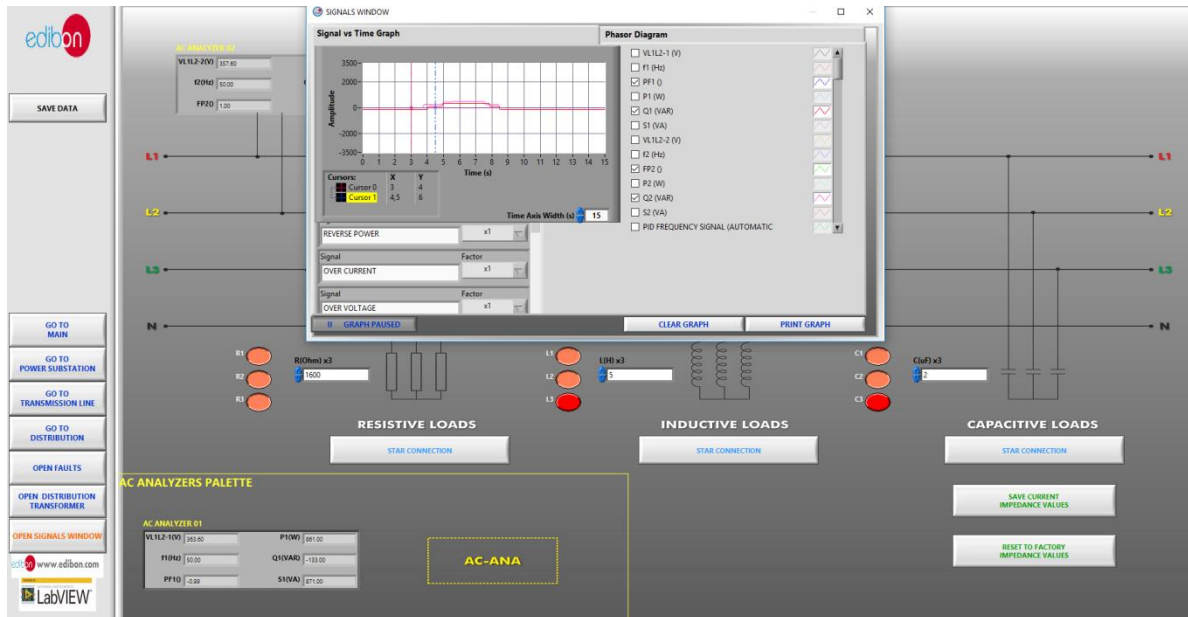


Figure 114: Power factor correction

25. It is possible to change from automatic control to manual control. Change the position of the corresponding switches (manual/automatic speed control and manual automatic excitation control) and control the motor-generator group manually. But it is very important to know the initial position of the potentiometers. These potentiometers must be previously set to 50 Hz and 380 VAC.

26. Do not forget to carry out the step described in the paragraph ‘Shutting down the application’ to turn off the unit.

7.5.11 Practical exercise 11: Automatic synchronization with the grid along with transmission line and distributed loads with SCADA system.

7.5.11.1 Objective

The objective of this practice is learning and understanding how to control a generation system synchronized with the grid and at the same time delivering power to isolated loads which are distributed through distribution and coupling busbars to simulate real power switching substations, all this through the SCADA system.

The user will understand the effects of different loads and configurations of the transmission line in the generator parameters, the power consumption and the power delivered to the grid.

7.5.11.2 Required elements

- Industrial Power Supply (N-ALI01).
- Instrumentation Module 1 (N-PPIM2).
- Control and Protection of Turbine-Generator Group Module 1 (N-PPCM1).
- Power Generation Substation Module 1 (N-PSUB3).
- Network Analyzer Unit with Computer Data Acquisition (N-EALD) (2 units).
- Transmission Lines Simulation module (N-AE1CD).
- 3 x 300 W Three-Phase Configurable resistors Module (N-REFT/3C).
- 3 x 300 VAr Three-Phase Configurable Inductances Module (N-INDT/3C).

- 3 x 300 VAr Three-Phase Configurable Capacitors Module (N-CAR19T/3C).
- 5 KW Three-Phase Step-up Transformer (TRANS3/5KSU).
- 5 KW Three-Phase Autotransformer with Motor Voltage Regulator (TRANS3/5KRM).
- 5 KW Three-phase Grid Transformer (TRANS3/5KGR).
- Distribution Busbar Module (N-BUS08).
- Coupling Busbar (NBUS09).
- GMG4.5K2PH. 4,5 kW Generator-Motor Group (GMG4.5K3PH).

7.5.11.3 Procedure

19. Carry out the step described in the paragraph “Starting up the ”.

20. Carry out the wiring shown in the cable assembly section, “[Synchronization with the grid along with transmission line and distributed loads wiring](#)”

21. In the N-PSUB module, select the SCADA control mode.

22. Open the SCADA software and press the Start button, you will see the following screen.

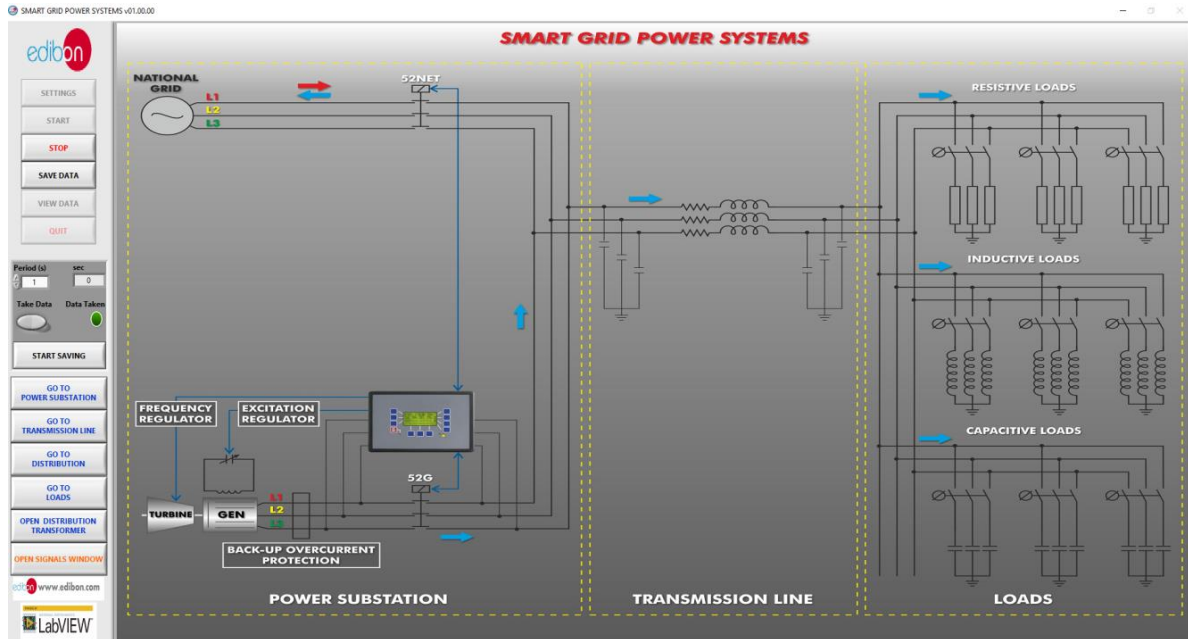


Figure 115: SCADA main screen

2. Go to ‘ GO TO POWER SUBSTATION’ and follow the sequence shown in this table:

SWITCHES	POSITION
Enable/Disable 52NET	UP (Enable 52NET)
Manual/Automatic Speed Control	DOWN (Automatic Speed Control)
Manual/Automatic Excitation Control	DOWN (Automatic Excitation Control)
Start/Stop Turbine	UP (Start Turbine)
52G Synchronization Permission	UP

1. See how the controller makes the generator reach the mains conditions, then

the 52G circuit breaker closes and the green synchronization conditions indicator turns on, finally synchronizing with the grid. Once this happens, the controller modifies the active and reactive powers and established them at the pre-defined values.

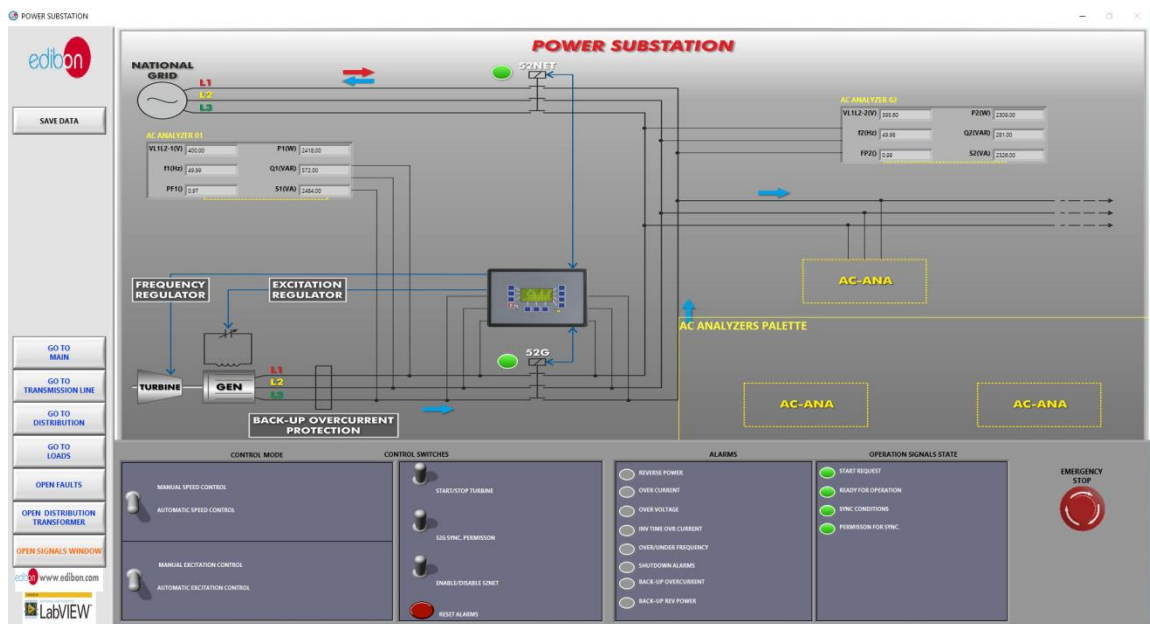


Figure 116: Power substation screen

2. One network analyzer is connected before the grid transformer to measure the power delivered to the grid while the other one is placed after the distribution transformer to measure the total power consumed by the distributed loads.
23. Add some resistive, capacitive and inductive loads for power consumption to see how it affects to the generator parameters (check how the controller readjusts them) and consequently to the power consumption and the power delivered to the grid.

Note that, if the load is too high, the overload and overcurrent alarm can be activated and the generator will be turned off. In this case, reset the alarms

with the reset alarms button and wait until the motor returns to the operation point.

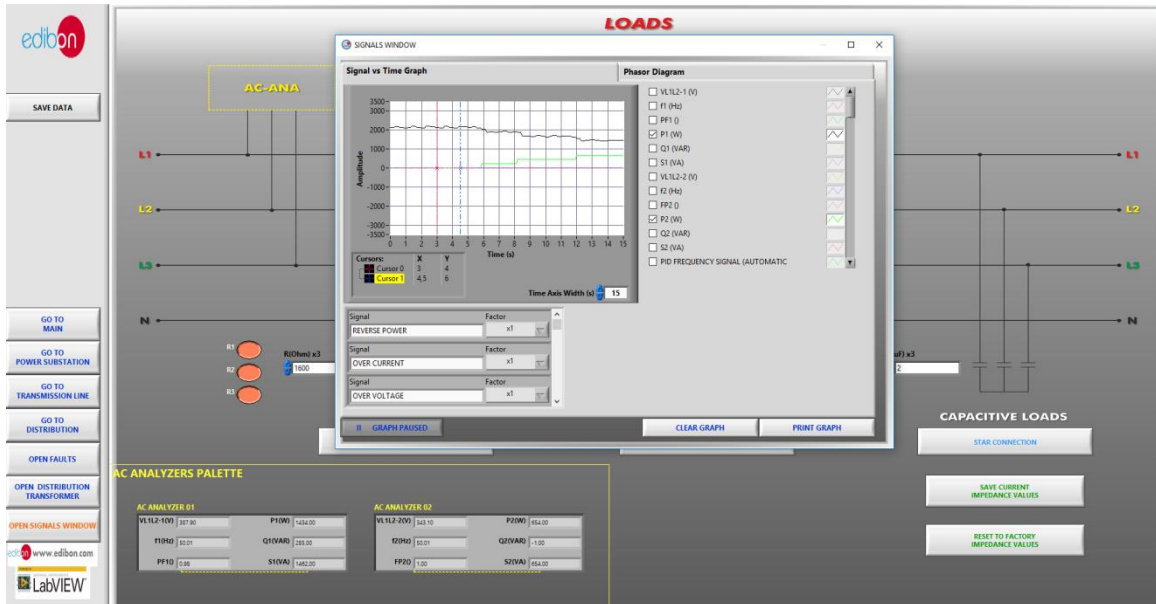


Figure 117: Effects of adding loads to delivered to grid and generated powers

24.. These strategic locations of the analyzers enable the user to find out other parameters such as the energy losses or voltage drop through the transmission line or the required loads to carry out the power factor correction if desired just by performing corresponding calculus. Go to “GO TO TRANSMISSION LINE” to check the differences between the analyzers measurements in the analyzers palette.

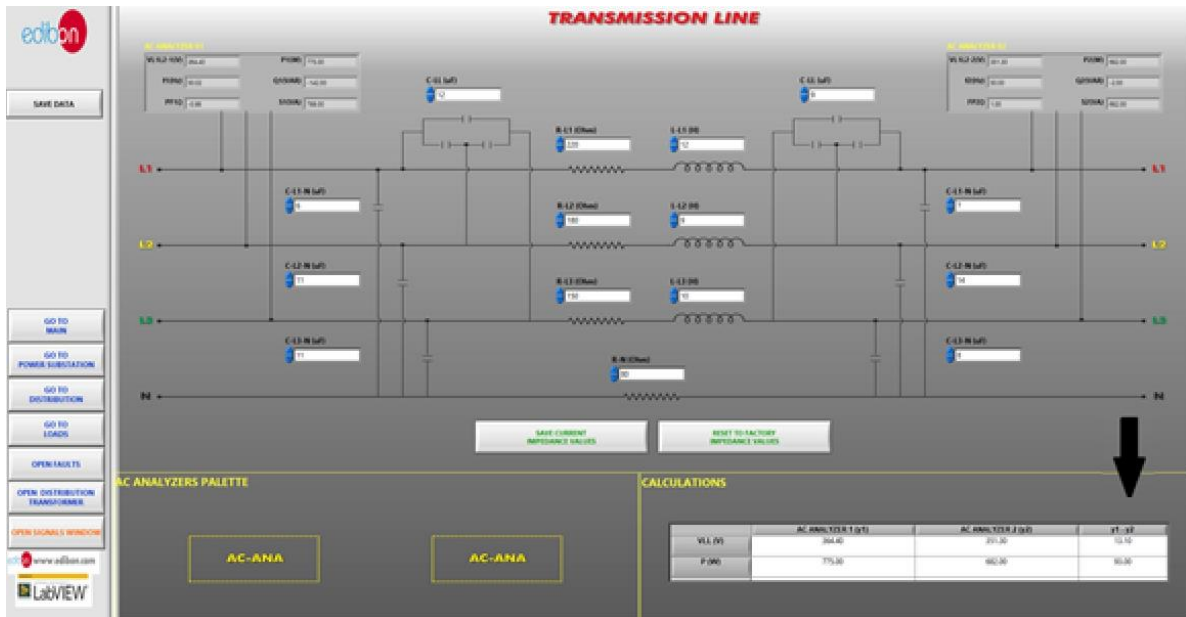


Figure 118: Transmission line screen

25. Adjust the voltage regulator commutator (UP or DOWN positions) and check how the voltage delivered to the loads change. Adjust it so the delivered voltage is the pre-established one or the closest possible one.

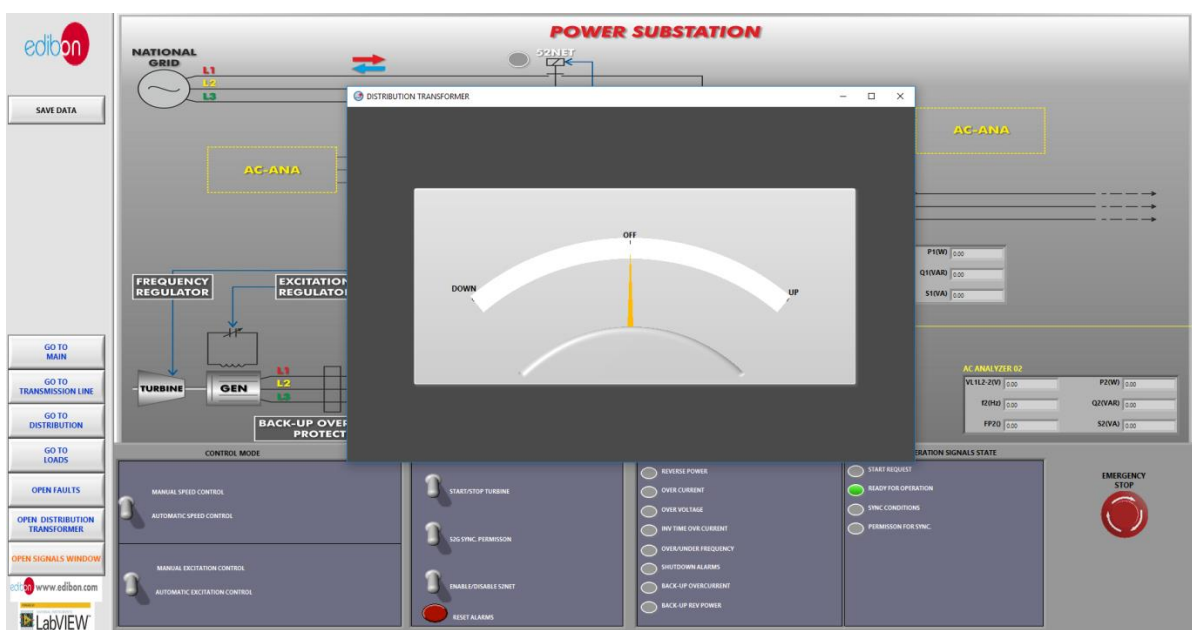


Figure 119: Voltage regulator screen for regulating transformer control

26. Change the arrangement of the loads through distribution and coupling busbar modules, simulating power switching substations. For this modify in the state of the disconnectors (82) and circuit breakers (52) of both modules by pushing “OPEN” and “CLOSE” buttons or through 24 VDC input signals and perform the desired load distribution.

Take into account that only circuit breakers can work under load so carry out the appropriate sequences or the module will not let you do so. It is important to note that the yellow lights indicate the presence of voltage in each bus.

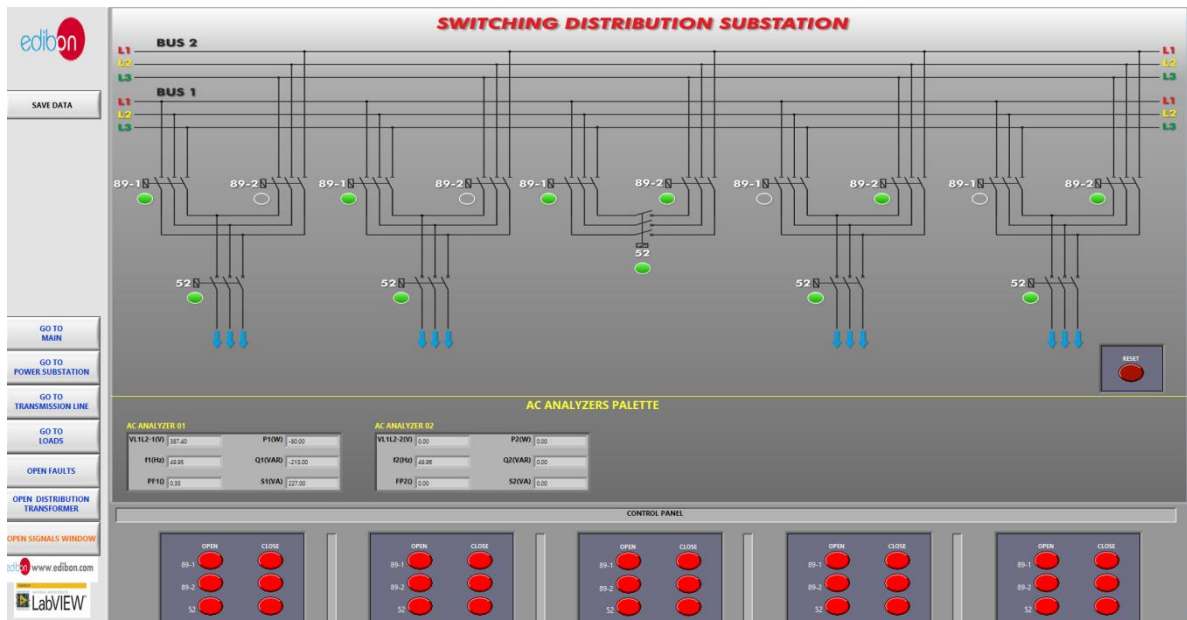


Figure 120: Example of load distribution in the distribution screen

27. It is possible to change from automatic control to manual control. Change the position of the corresponding switches (manual/automatic speed control

and manual automatic excitation control) and control the motor-generator group manually. But it is very important to know the initial position of the potentiometers. These potentiometers must be previously set to 50 Hz and 380 VAC.

28. Do not forget to carry out the step described in the paragraph ‘[Shutting down the application](#)’ to turn off the unit.

7.5.12 Practical exercise 12: Digital faults simulation in stand-alone mode with SCADA system.

7.5.12.1 Objective

The objective of this practice is learning how to test the motor-generator controller back-up protection relays against overcurrents and the signalling alarms located in this module through the SCADA system. For this, a digital fault simulator is included to inject one, two or three pole faults always in stand-alone operation so the grid cannot be damaged.

The user will learn different type of faults, the effects of its injection and how the protections are set for a safe operation of the application.

7.5.12.2 Required elements

- Industrial Power Supply (N-ALI01).
- Instrumentation Module 1 (N-PPIM2).
- Control and Protection of Turbine-Generator Group Module 1 (N-PPCM1).
- Power Generation Substation Module 1 (N-PSUB3).
- Transmission Lines Simulation module (N-AE1CD).
- 3 x 300 W Three-Phase Configurable resistors Module (N-REFT/3C).
- 3 x 300 VAr Three-Phase Configurable Inductances Module (N-INDT/3C).
- 3 x 300 VAr Three-Phase Configurable Capacitors Module (N-CAR19T/3C).

- 5 KW Three-Phase Step-up Transformer (TRANS3/5KSU).
- 5 KW Three-Phase Autotransformer with Motor Voltage Regulator (TRANS3/5KRM).
- Distribution Busbar Module (N-BUS08).
- Coupling Busbar (NBUS09).
- GMG4.5K2PH. 4,5 kW Generator-Motor Group (GMG4.5K3PH).
- Digital Fault Simulator Module (N-ERP-MF01).

7.5.12.3 Procedure

29. Carry out the step described in the paragraph “Starting up the”.

30. Carry out the wiring shown in the cable assembly section, “ [Stand –alone configuration with transmission line and loads wiring](#)”.

31. In the N-PSUB module, select the SCADA control mode.

32. Open the SCADA software and press the Start button, you will see the following screen.

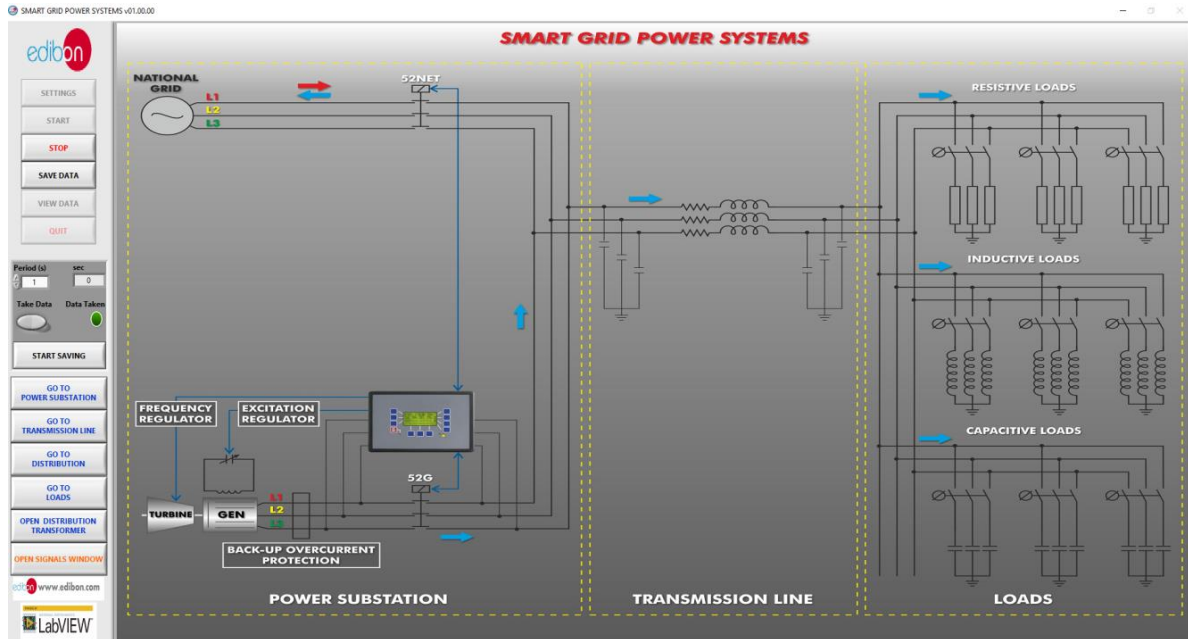


Figure 121: SCADA main screen

3. Go to ‘ GO TO POWER SUBSTATION’ and follow the sequence shown in this table:

SWITCHES	POSITION
Enable/Disable 52NET	DOWN (Disable 52NET)
Manual/Automatic Speed Control	DOWN (Automatic Speed Control)
Manual/Automatic Excitation Control	DOWN (Automatic Excitation Control)
Start/Stop Turbine	UP (Start Turbine)
52G Synchronization Permission	UP

33.Back-up protections parameters are already set so the students must not vary

its potentiometers:

<i>Back-up protections</i>	Level	Hysteresis	Delay
Overcurrent protection	115%	10%	3s
Inverse power protection	20%	1%	2s

34.The location of the fault injection is assumed to be in the primary winding of the distribution transformer.

35.Turn on the resistive loads for power consumption. For this go to ‘ GO TO LOADS’ and press the switches for resistive loads.

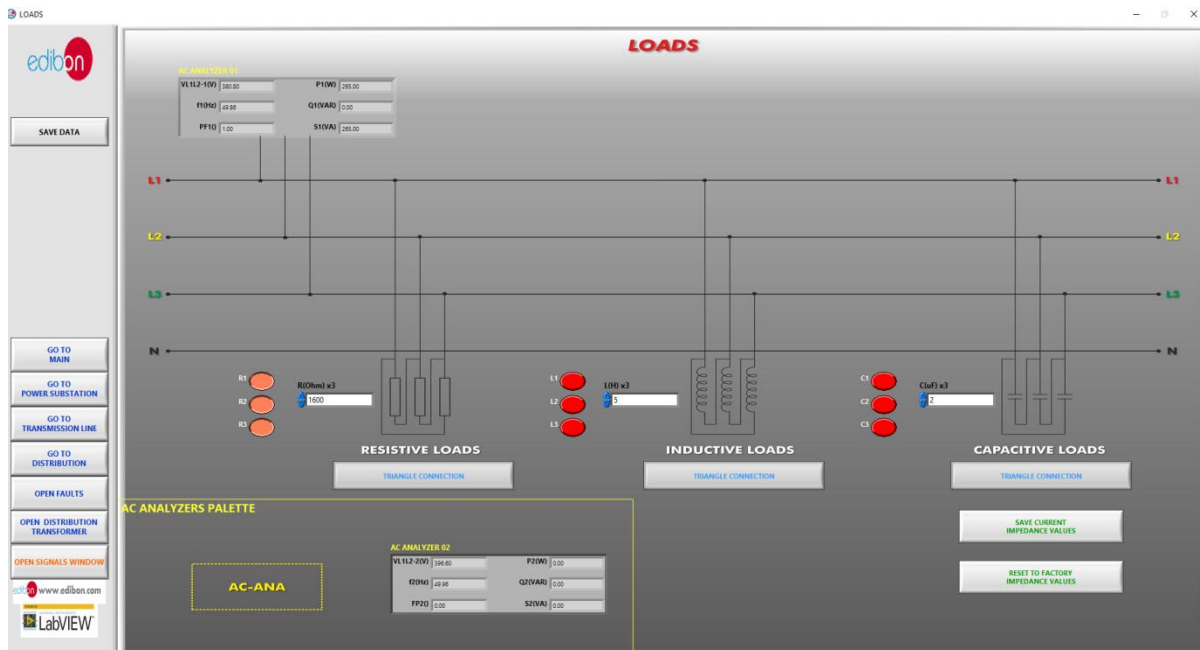


Figure 122: Loads screen

36.Set the type of fault to be injected through the module configuration as explained in the ‘ Operation’ section for the N-ERP-MF01.It has to be set

in the hardware (real wiring), not possible through the SCADA system.
 Play also with the impedances of the fault lines to check its effects afterwards.

37.To inject the fault go to ‘‘OPEN FAULTS’’ and select‘‘FAULT INJECTION’’’.

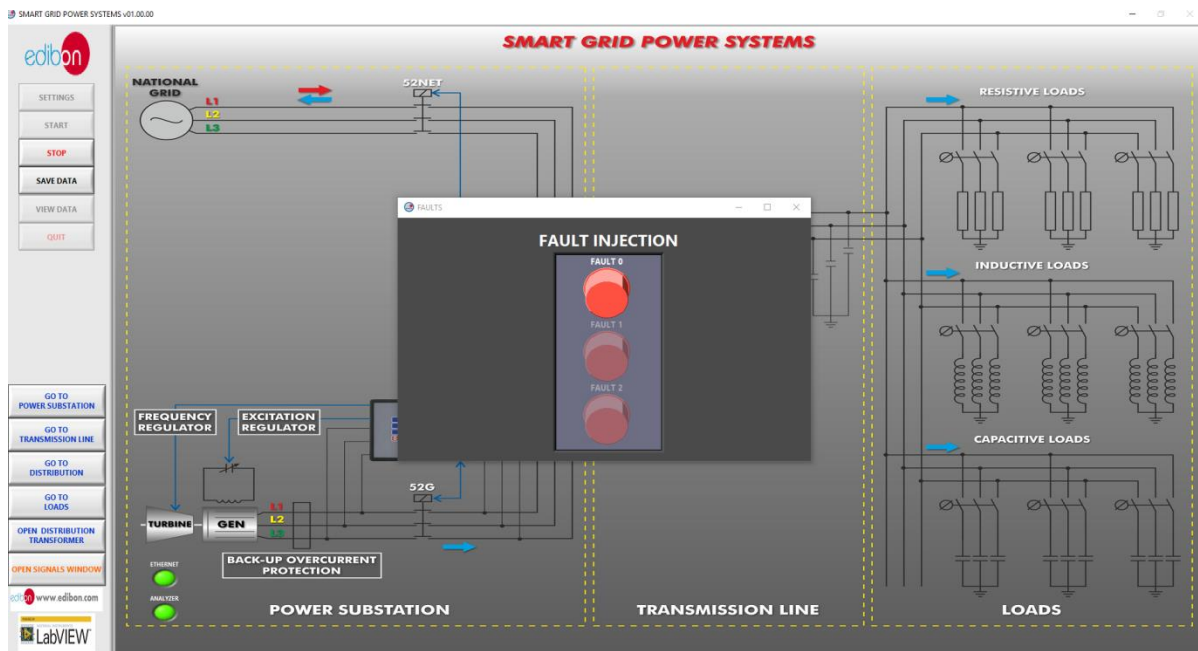


Figure 123: Faults screen

38.Check the effect of the fault injection.

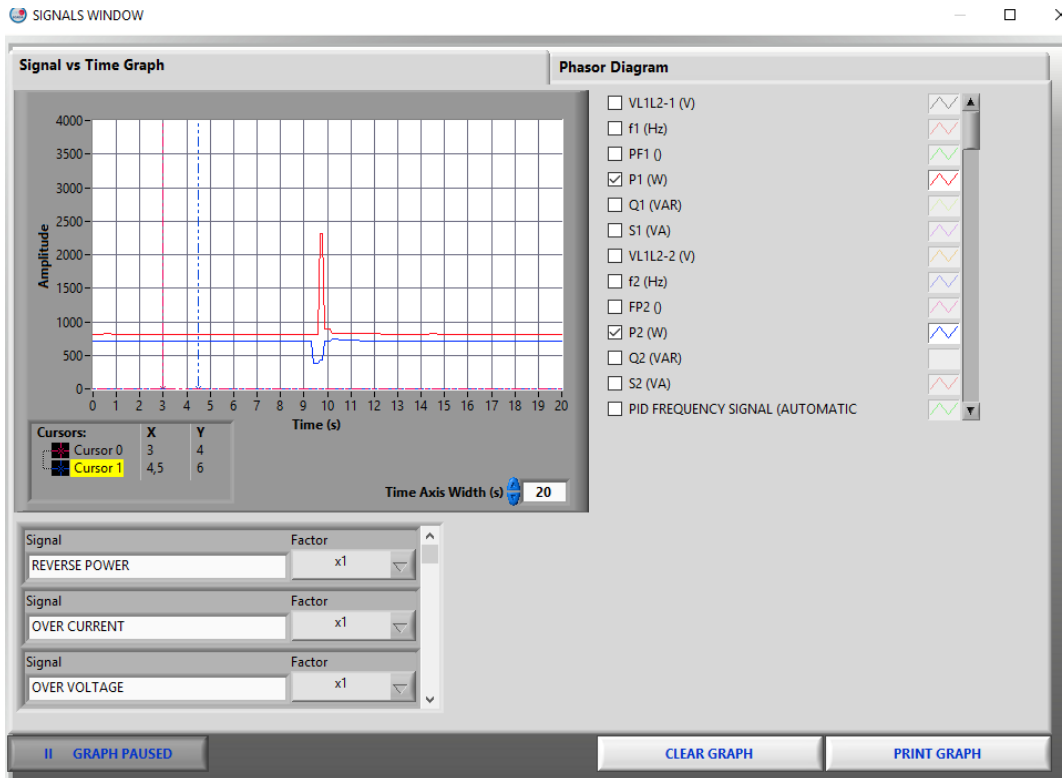


Figure 124: One pole fault with no impedance

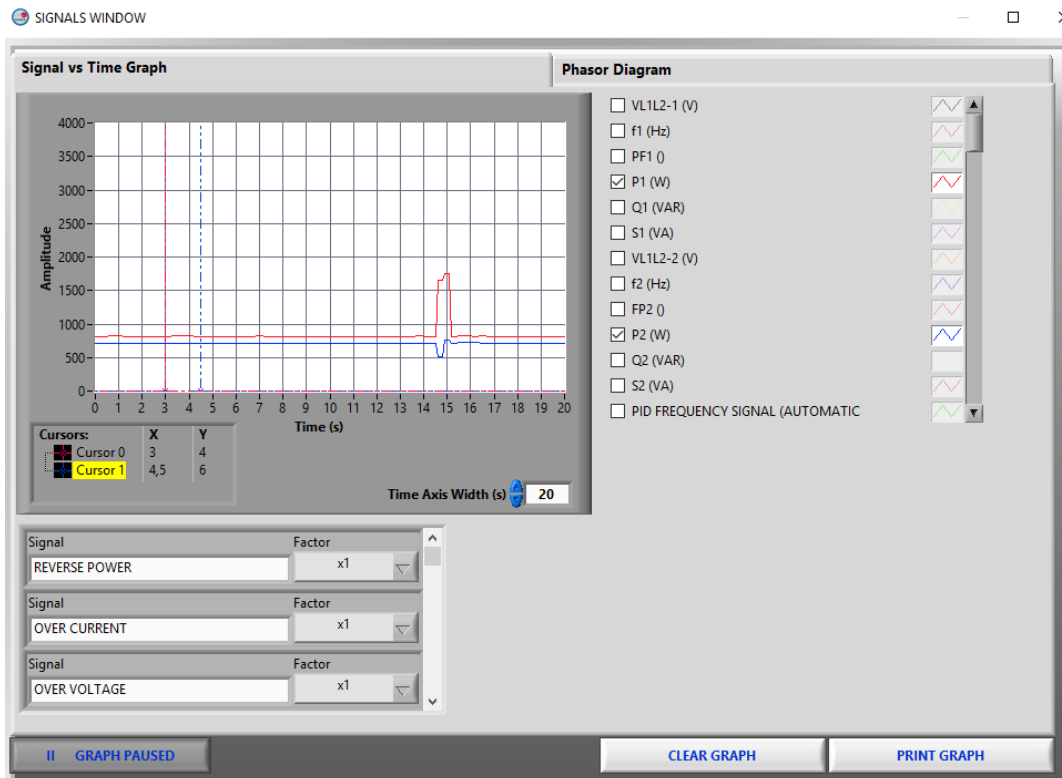


Figure 125: One pole fault with impedance

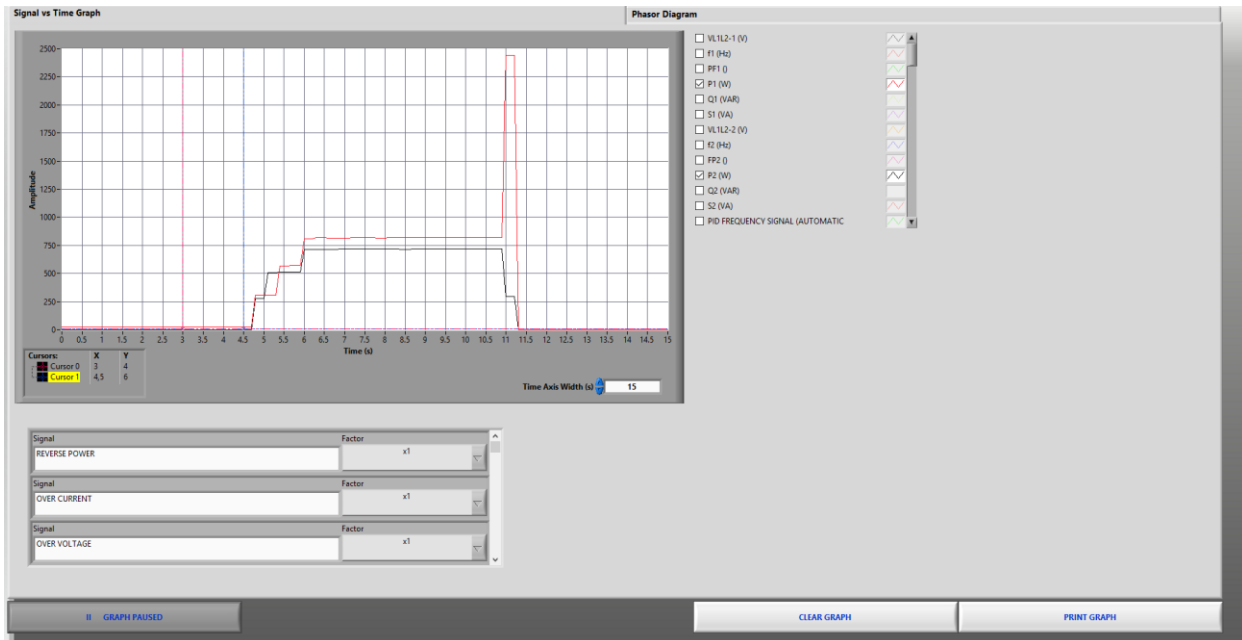


Figure 126: Two pole fault with half impedance

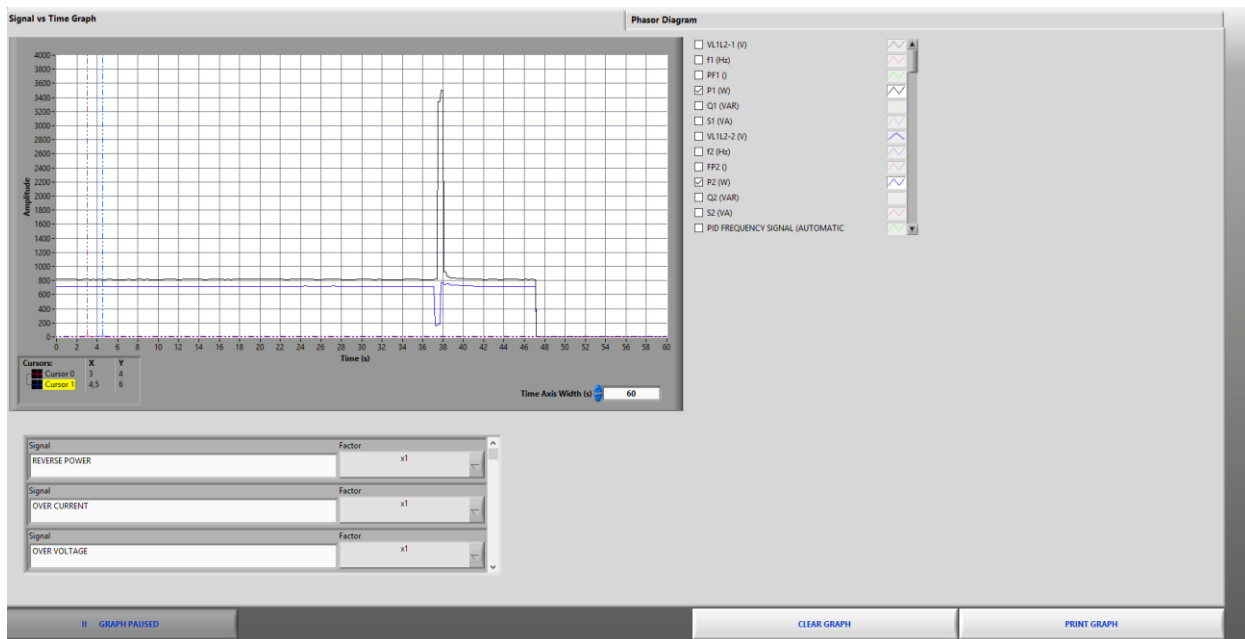


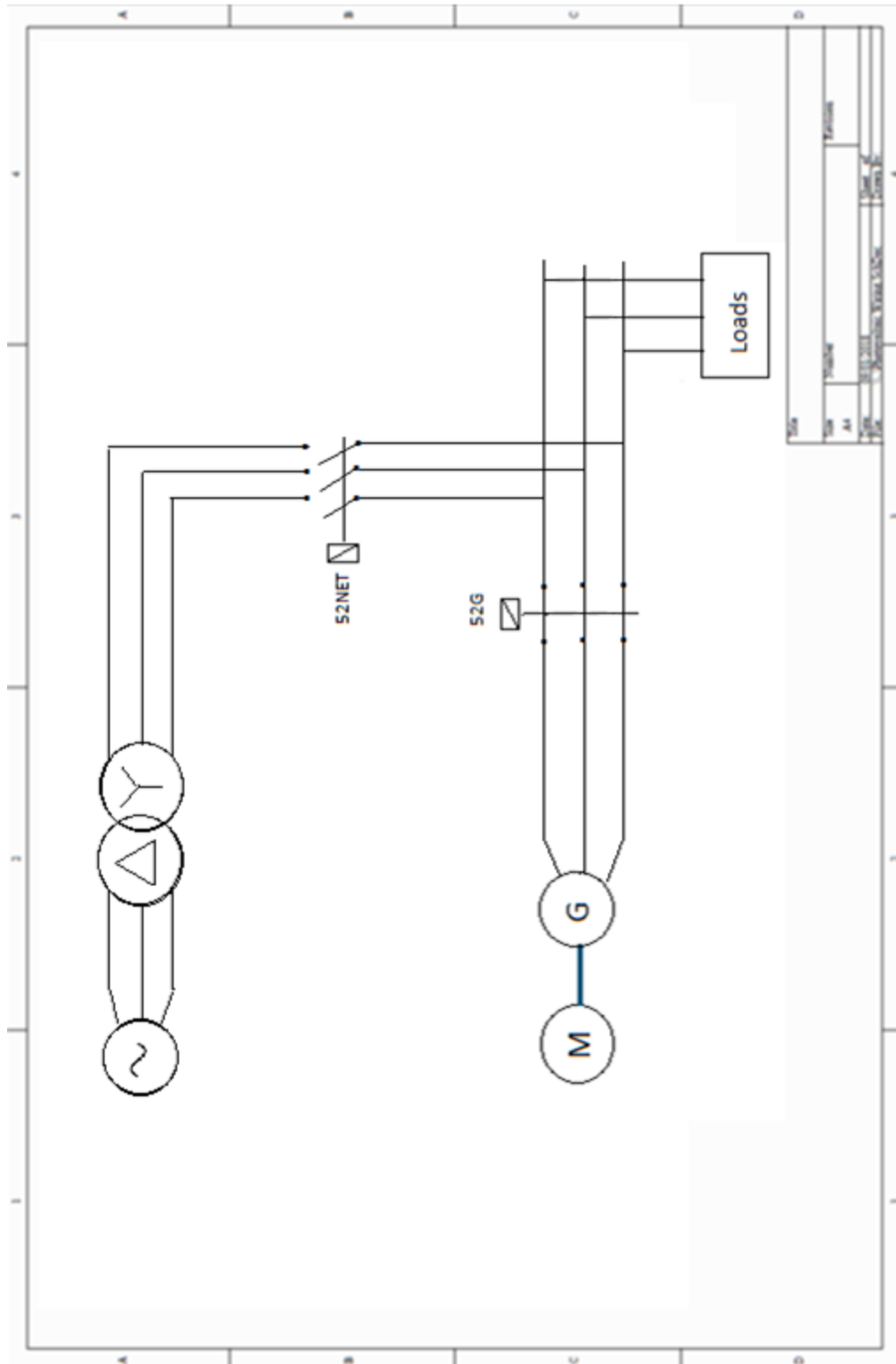
Figure 127: Three pole fault with impedance

39. When overcurrent or any other alarm sets off the application will stop. To restart it push twice the "Reset alarms" button in the N-PSUB module.

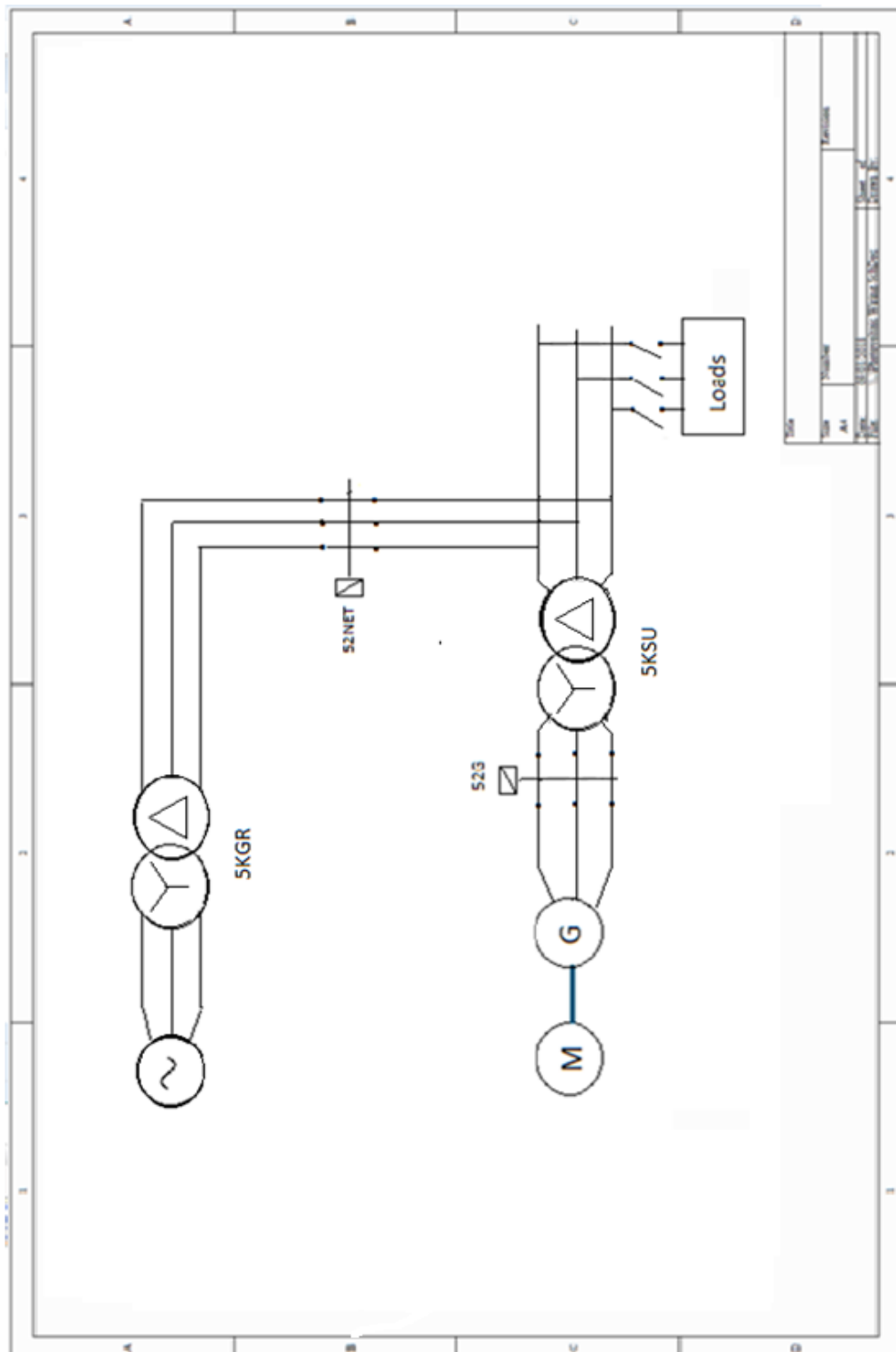
40. Do not forget to carry out the step described in the paragraph ‘[Shutting down the application](#)’ to turn off the unit.

7.6 APPENDICES

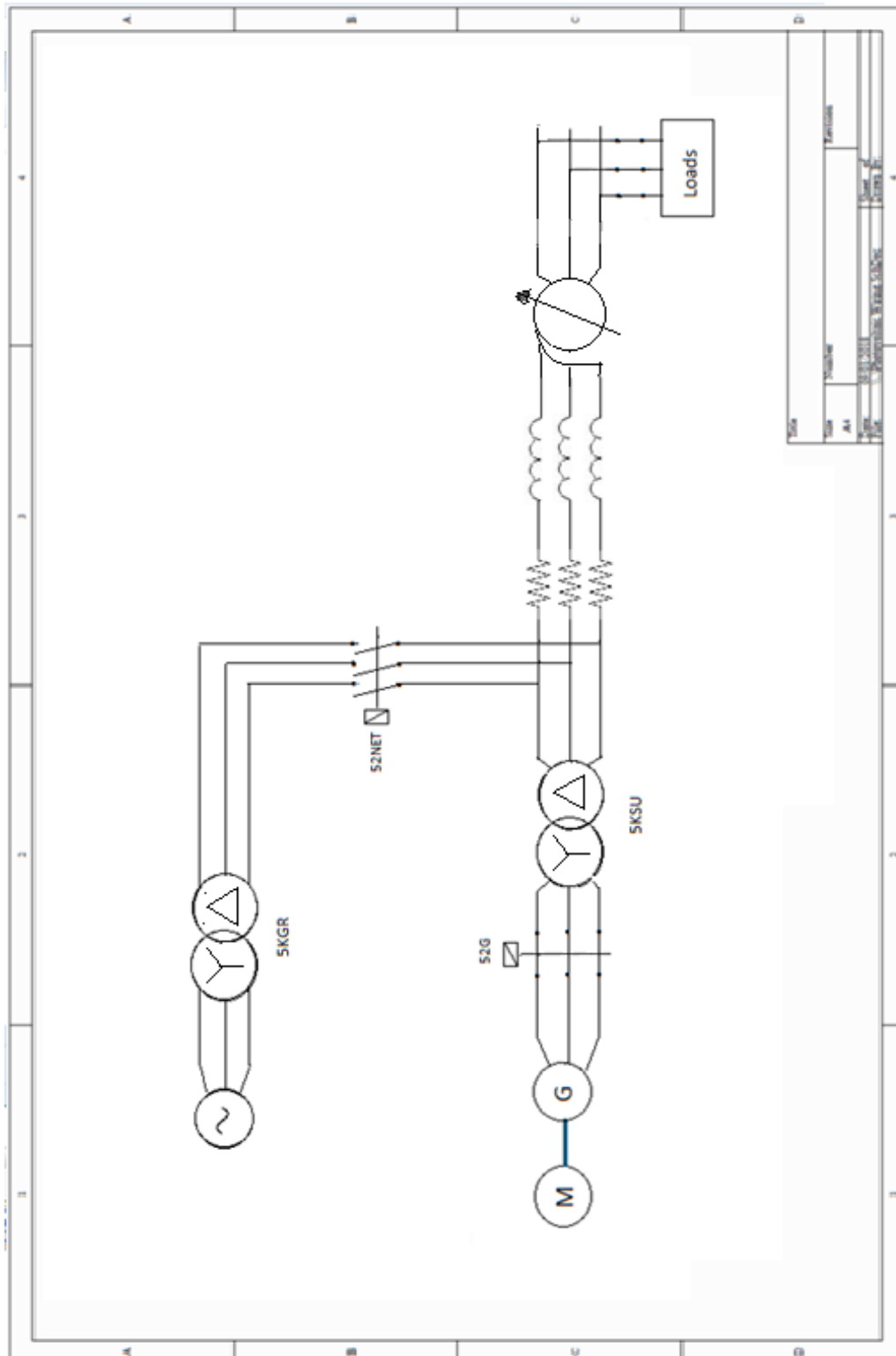
7.6.1 Appendix 1: Stand-alone configuration



7.6.2 Appendix 2: Synchronization of the generator with the grid



7.6.3 Appendix 3: Stand-alone configuration along with transmission line and loads



7.6.4 Appendix 4: Synchronization with the grid along with transmission line and distributed loads.

