جامعة فلسطين التقنية
خضوري
Palestine Technical University
Kadoorei

Faculty of Engineering and Technology

Department of Electrical Engineering

Electrical Power Systems Lab Manual (12110512)

First Edition

Student Manual

Prepared by:

Eng. TareQ FoQha

2020

Abstract

The electrical power systems laboratory at the Palestine Technical University Kadoorie designed to directly apply theory learned in lectures to devices that will be studied in the laboratory. The Lab focuses on all aspects of electrical power systems: power generation, transmission and distribution lines, protection systems, electric power management systems and a wide range of electrical measurement systems. Research projects carried out in this laboratory include generation, transmission and distribution of electrical energy and all facilities that guarantee the safe supply of electrical energy. In addition to the monitoring, control and supervision systems that are studied and followed in this laboratory.

Objectives

The laboratory course is intended to provide practical understanding of power system operation, control and protection. The main goal is to enable students to apply and test theoretical knowledge they mastered in previous years of studies. The laboratory course enables them to develop practical skills in various fields of power engineering in a controlled environment.

The Laboratory covers all phases for the:

- electrical power ***generation***;
- electrical power ***distribution***, transformers and high voltage lines (with simulator);
- ***use*** of the power (Load);
- ***power factor correction,*** with synchronous phase advancer (typical of the power factor correction performed in power plants or distribution power plants), power factor correction with batteries of manual or automatic insertion batteries (typical of power factor correction carried out in the final user);
- ***Measurement instruments*** typical of this field;
- ***Protection devices*** specific of this field.

  All protection and control devices of the electrical machines are exactly equal to those installed in the industrial units. So, the sequences of control maneuvers in the control stations are exactly equal to those necessary in the industrial units.

SAFETY RULES

1. Please don't touch any live parts.
2. Never use an electrical tool in a damp place.
3. Don't carry unnecessary belongings during performance of practicals (like water bottle, bags etc).
4. Before connecting any leads/wires, make sure power is switched off.
5. In case of an emergency, push the nearby red color emergency switch of the panel or immediately call for help.
6. In case of electric fire, never put water on it as it will further worsen the condition; use the class C fire extinguisher.

Fire is a chemical reaction involving rapid oxidation (combustion) of fuel. Three basic conditions when met, fire takes place. These are fuel, oxygen & heat, absence of any one of the component will extinguish the fire.

Figure: Fire Triangle

A(think ashes): paper, wood etc

B(think barrels): flammable liquids

C(think circuits): electrical fires

If there is a small electrical fire, be sure to use only a Class C or multipurpose (ABC) fire extinguisher, otherwise you might make the problem worsen.

The letters and symbols are explained in left figure. Easy to remember words are also shown.

***Don't** play with electricity, Treat electricity with respect, it deserve*

List of Experiments

Chapter 1

Three-Phase Synchronous Generator Experiments

Contents

Experiment (1)	Synchronous Generator Operating Alone

Objectives:

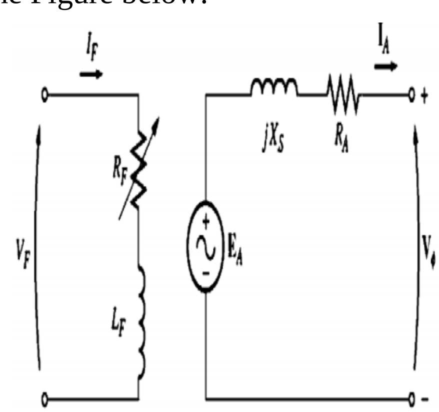
1. Mastering the exact procedures required for generator's starting and stop and their exact sequence.
2. To understand how terminal voltage varies with load in a synchronous generator operating alone.
3. To measure the voltage regulation of a synchronous generator under different loads.
4. To understand the regulation characteristic required to compensate voltage of the synchronous generator loaded with various loads.
5. Use the Automatic Voltage Regulator (AVR) to keep the voltage across the terminals of the synchronous generator constant at the load variation.

Theory and concepts:

The **Alternator** (Three-Phase Synchronous Generator) is mainly a machine absorbing mechanical power from a ***prime mover*** and transforming it into electrical power. An **Alternator** is an electrical machine that has two differentiated parts in its construction: the **stator** and the **rotor**.

The stator (fixed windings in the machine casing) includes three-phase windings, shifted of 120 electrical degrees, star or delta connected. From the stator terminal you can take the outgoing three phase power. The rotor, moved by the prime mover, at fixed speed, contains the d.c. excitation winding. The excitation can be provided by a variable independent source or by a d.c. (exciter) generator, coaxial to the rotor and so moved by the prime mover. The per-phase equivalent circuit of this machine is shown in the Figure below:

- **V_F:** Excitation Voltage;
- **E_A:** Internal generated voltage;
- **V_Φ:** Output phase voltage;
- **R_F:** Field resistance;
- **I_F:** field current**;**
- **I_A:** Output current;
- **X_S:** Synchronous reactance (consisting of the sum of the armature reactance and the coil 's self-inductance);
- **R_A:** Stator resistance.



The rate of rotation of the magnetic fields in the machine is related to the stator electrical frequency by the following Equation:

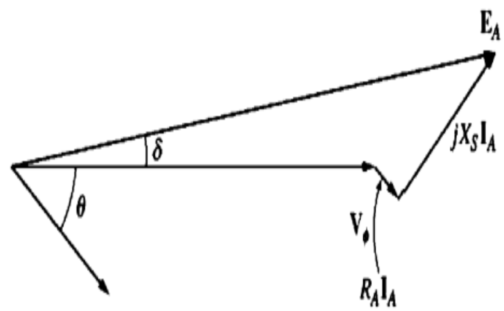
$$f_e = \frac{n_m P}{120}$$

The voltage induced in a given stator phase depends on the flux Φ in the machine, the frequency or speed of rotation, and the machine's construction by the following Equation:

$$E_A = K\,\Phi\,\omega$$

An understanding of how load variations effect the operation of the generator can be obtained by considering the phasor diagram.

- **E_A:** Internal generated voltage;
- **V_Φ:** Output phase voltage;
- **X_S:** Synchronous reactance;
- **I_A:** Output current;
- **θ:** Power factor angle;
- **δ:** Torque/power angle.

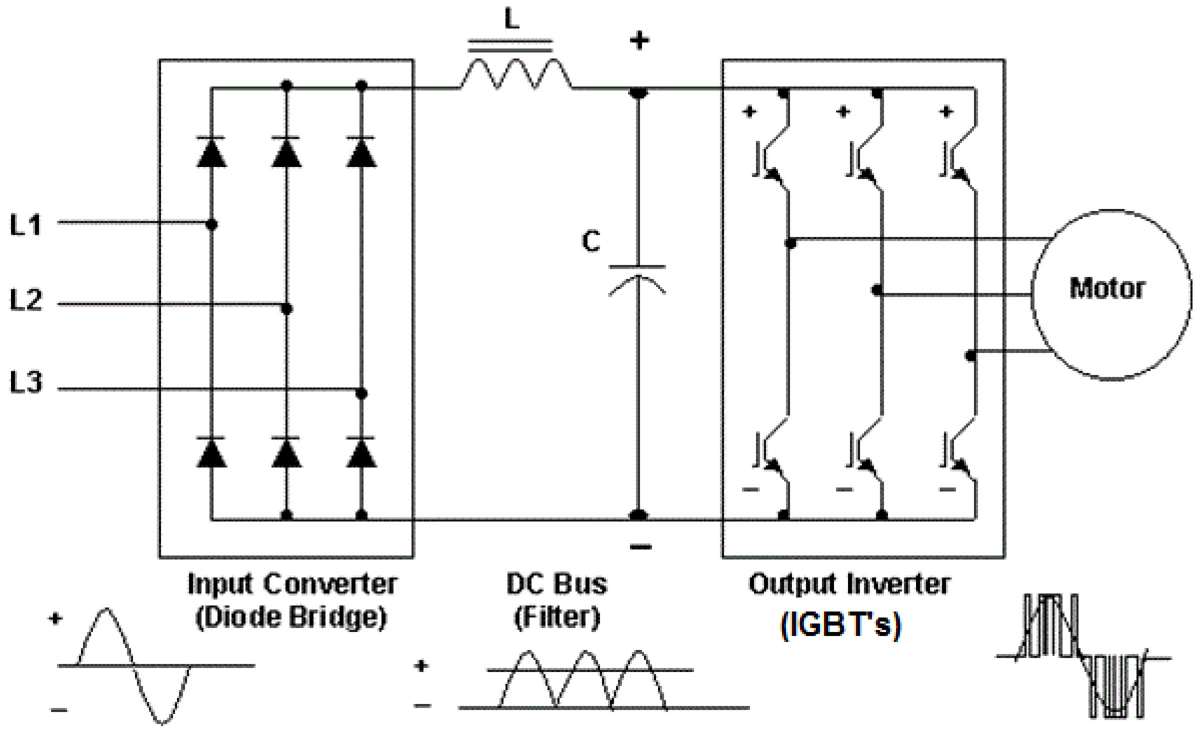


Variable Frequency Drive (VFD) (AC-Drive):

A variable frequency drive (VFD) is an electronic device that controls the speed of AC induction motors. Both three phase and single phase VFDs can convert input power to adjustable frequency and voltage source for controlling speed of AC induction motors. The frequency of the power applied to an AC motor determines the motor speed, based on the equation:

$$n_m = \frac{120 f}{P}$$

AC supply comes from the facility power network while the rectifier converts network AC power to DC power. The filter and DC bus work together to smooth the rectified DC power and to provide clean, low-ripple DC power to the inverter.



Automatic Voltage Regulator (AVR):

The automatic voltage regulator (AVR) is used to regulate the voltage. It takes the fluctuate voltage and changes them into a constant voltage. The fluctuation in the voltage mainly occurs due to the variation in load on the supply system. The variation in voltage damages the equipment of the power system.

Necessary Material:

1. **GCB-3/EV:** Control board for the generating set mod.
2. **MSG-3/EV:** Synchronous generator-motor unit mod.
3. **RL-2/EV:** Variable resistive load mod.
4. **IL-2/EV:** Variable inductive load mod.
5. **CL-2/EV:** Variable capacitive load mod.
6. **AVR-E/EV:** Automatic Voltage Regulator mod.

Experimental Procedures:

Part I: Connection of the Motor-Generator set and the control board GCB-3/EV.

1. Connect between the machines of set MSG-3/EV and the control board GCB-3/EV as shown in Figure 1.

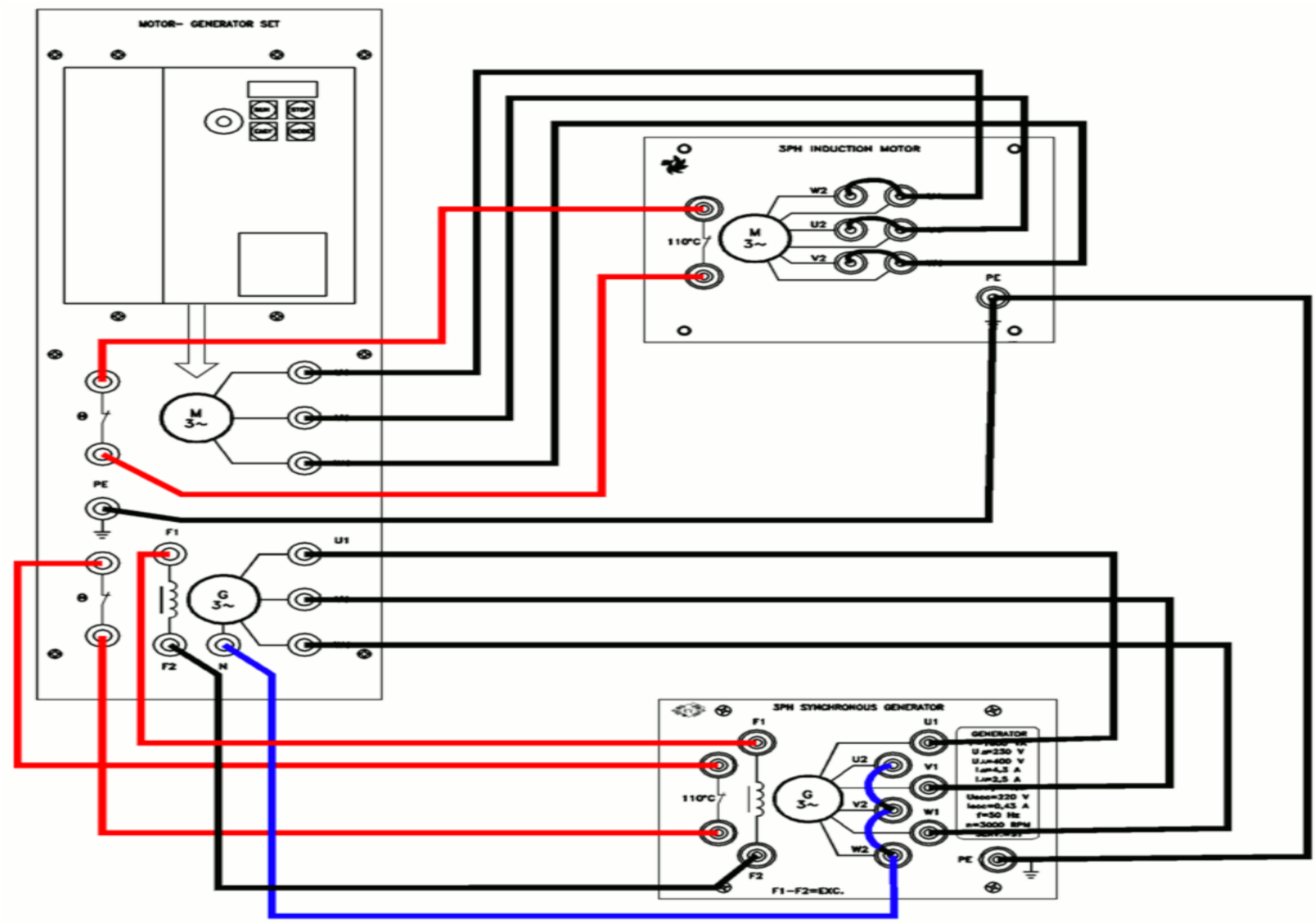


Figure (1)

2. Complete the wiring including the load as shown in figure 2. Be sure that all step switches of each load are in position of excluded load (OFF).
3. Set the rotary switch to the position 1 (ON) and the RUN / STAND-BY switch to RUN.
4. Adjust the speed to obtain 50.0 Hz in the AC motor drive.
5. Adjust the excitation of the synchronous generator to obtain a voltage equal to 400 V.

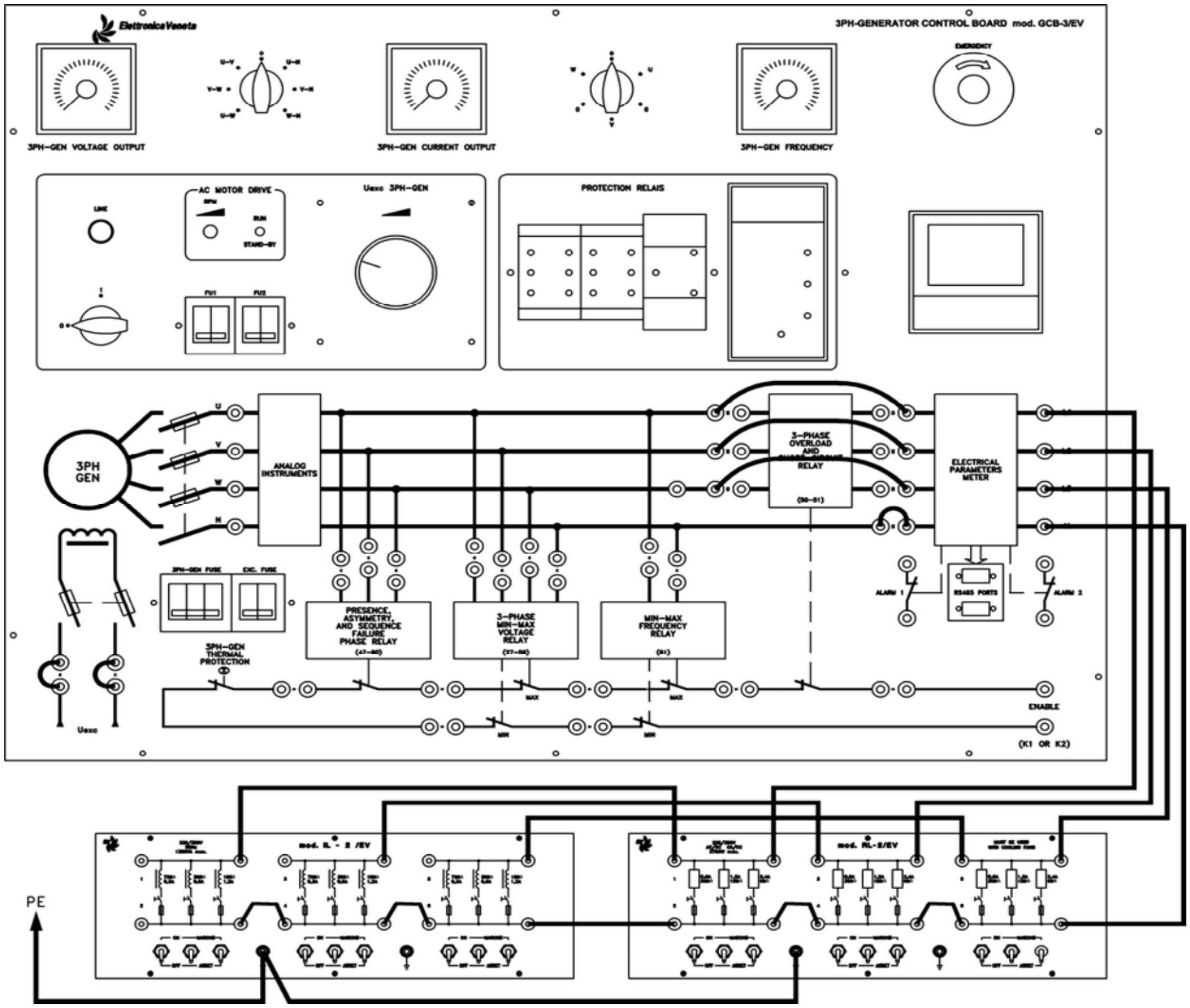


Figure (2)

Part II: Study the behavior of the synchronous generator under resistive load.

1. Set the synchronous generator under load with the insertion of the resistive load (with different values of the resistive load) and measure the following using the power analyzer:
   (a) Current drawn by the load (**I_{load}**) in **mA.**
   (b) Terminal voltage of the synchronous generator (**V_T**) in **V.**
   (c) Power consumed by the load **(P)** in **W**.

2. Calculate the voltage regulation in each case.
   To calculate the voltage regulation of a synchronous generator you will use the following relation:

$$\frac{V_{nl} - V_{fl}}{V_{fl}} x\, 100\%$$

Resistive Load in Ω		**I_{load} (mA)**	**V_T (V)**	**P (W)**	**VR%**
No-Load		0	400.0	0	--
A	720				
B	360				
A||B	240				
C	180				
A||C	144				
B||C	120				
A||B||C	103				

3. Switch off all loads and make sure that the no-load voltage is 400V.

Part III: Study the behavior of the synchronous generator under resistive-inductive load.

1. Set the synchronous generator under load with the insertion of the resistive-inductive load (with different values of the inductive load) and measure the following using the power analyzer:
   (a) Current drawn by the load (**I_{load}**) in **mA.**
   (b) Terminal voltage of the synchronous generator (**V_T**) in **V.**
   (c) Power consumed by the load **(P)** in **W**.

2. Calculate the voltage regulation in each case.

Resistive-Inductive Load		**I_{load} (mA)**	**V_T (V)**	**P (W)**	**VR%**
R (Ω)	L (mH)				
No-Load		0	400.0	0	--
A	A				
A	B				
A	A||B				
A	C				
A	A||C				
A	B||C				
A	A||B||C				

3. Switch off all loads and set the no-load voltage at 300V.

Part IV: Study the behavior of the synchronous generator under resistive-capacitive load.
<u>Note:</u> Do not let the terminal voltage exceed 450V.

1. Set the synchronous generator under load with the insertion of the resistive-capacitive load (with different values of the capacitive load) and measure the following using the power analyzer:
   (a) Current drawn by the load (**I_{load}**) in **mA.**
   (b) Terminal voltage of the synchronous generator (**V_T**) in **V.**
   (c) Power consumed by the load **(P)** in **W**.

2. Calculate the voltage regulation in each case.

Resistive-Capacitive Load		**I_{load} (mA)**	**V_T (V)**	**P (W)**	**VR%**
R (Ω)	C (μF)				
No-Load		0	400.0	0	--
A	A				
A	B				

Sketch the terminal characteristic of this generator for different types of loads (R, R-L and R-C) (Terminal voltage versus load current).

Part V: Output voltage regulation of a synchronous generator under resistive load.

1. Set the synchronous generator under load with the insertion of the resistive load (with different values of the resistive load).
2. Increase the excitation current to obtain a voltage equal to 400 V and measure the following using the power analyzer:
   (a) Current drawn by the load (**I_{load}**) in **mA.**
   (b) Excitation current (**I_f**) in **mA** (Use multimeter).
   (c) Power consumed by the load **(P)** in **W**.

<u>Note:</u> Do not let the excitation current exceed 0.43A.

Resistive Load in Ω		**I_{load} (mA)**	**I_f (mA)**	**P (W)**
Open Circuit		0		0
A	720			
B	360			
A||B	240			

Part VI: Output voltage regulation of a synchronous generator under resistive-inductive load.

1. Set the synchronous generator under load with the insertion of the resistive-inductive load (with different values of the inductive load).
2. Increase the excitation current to obtain a voltage equal to 400 V and measure the following using the power analyzer:
   (a) Current drawn by the load (**I_{load}**) in **mA.**
   (b) Excitation current (**I_f**) in **mA** (use multimeter).
   (c) Power consumed by the load **(P)** in **W**.

Note: Do not let the excitation current exceed 0.43A.

Resistive-Inductive Load		I_{load} (mA)	I_f (mA)	P (W)
R (Ω)	L (mH)			
Open Circuit		0		0
A	A			
A	B			

Part VII: Output voltage regulation of a synchronous generator under resistive-capacitive load.

1. Set the terminal no-load voltage at 300V.
2. Set the synchronous generator under load with the insertion of the resistive-capacitive load (with different values of the capacitive load).
3. Decrease the excitation current to obtain a voltage equal to 300 V and measure the following using the power analyzer:
   (a) Current drawn by the load (**I_{load}**) in **mA.**
   (b) Excitation current (**I_f**) in **mA** (use multimeter)**.**
   (c) Power consumed by the load **(P)** in **W**.

Note: Do not let the excitation current exceed 0.43A.

Resistive-Capacitive Load		I_{load} (mA)	I_f (mA)	P (W)
R (Ω)	C (µF)			
Open Circuit		0		0
A	A			
A	B			

Sketch the regulation characteristic of this generator for different types of loads (R,R-L and R-C) (Field current versus load current).

Part VIII: Automatic Voltage Regulator for Synchronous Generator.

1. Connect the device AVR-E/EV to the panel GCB-3/EV.
2. Connect the terminals L1, L2, L3 and N of the AVR-E/EV to the output terminals U, V, W and N of the synchronous three-phase generator and connect the terminals F1 and F2 of the AVR-E/EV to the terminals F1 and F2 of the excitation circuit of the synchronous generator as shown in Figure 3.
3. With the connection of the AVR-E/EV to panel GCB-3/EV, no adjustment of the excitation voltage Uexc is possible anymore, using the proper variator.
4. Set the synchronous generator under load with the insertion of the resistive load and measure the following electrical quantities using the power analyzer:
   (a) Current drawn by the load (**I_{load}**) in **mA.**
   (b) Excitation current (**I_f**) in **mA** (use multimeter).
   (c) Power consumed by the load **(P)** in **W**.
5. Change the load to resistive-Inductive load (with different values of the Inductive load) and measure the above electrical quantities using the power analyzer.
6. Change the load to resistive-capacitive load (with different values of the capacitive load) and measure the above electrical quantities using the power analyzer.

Resistive Load		**I_{load} (mA)**	**I_f (mA)**	**P (W)**
R (Ω)				
No Load		0		0
A				
B				
Resistive-inductive Load		**I_{load} (mA)**	**I_f (mA)**	**P (W)**
R (Ω)	L (mH)			
No Load		0		0
A	A			
A	B			
Resistive-capacitive Load		**I_{load} (mA)**	**I_f (mA)**	**P (W)**
R (Ω)	C (μF)			
No Load		0		0
A	A			

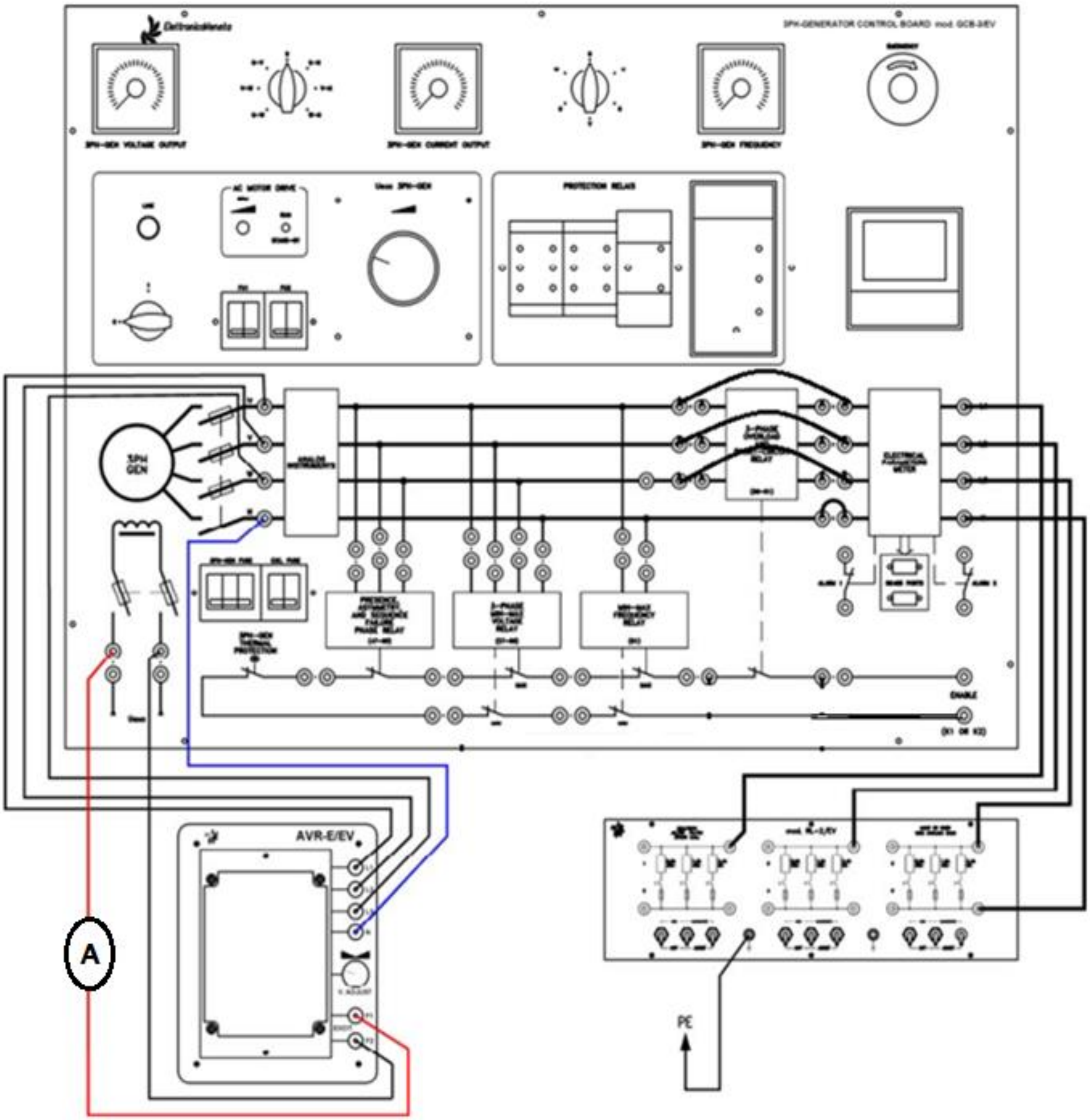


Figure (3)

Questions:

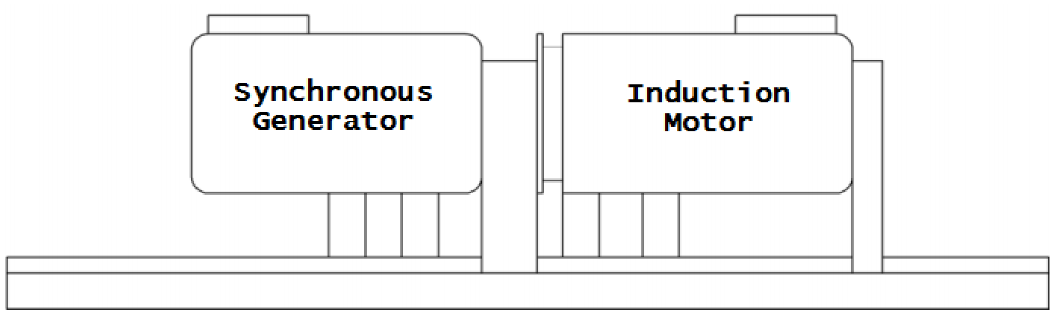
1. Explain the effects of increasing loads on the terminal voltage of the synchronous generator and explain how to reduce these effects?

2. Show by drawing the effect of load changes on the phasor diagram of the synchronous generator with Constant:
   (a) Unity PF;
   (b) Lagging PF;
   (c) Leading PF.

3. Motor-generator set consisting of an induction motor driving a synchronous generator; the ratings of the synchronous generator and Induction motor are as follows:

Synchronous Generator
Capacity = 1000 VA;
Armature Voltage = 400 V, Y-connection;
Poles= 2;
Excitation voltage = 220 V;
Excitation current = 0.43 A;
Power Factor = 0.8.

Induction Motor
Rated Power = 2 hp;
Rated Voltage = 400 V, Y-connection;
Full-load speed = 2860 rpm;
Frequency = 50 Hz.



(a) What mechanical speed in rpm would be required to generate voltage at a frequency of 50-Hz?
(b) Determine the slip of the Induction Motor?
(c) Calculate the rated current of the generator?

Experiment (2)	Synchronous Generator Protection

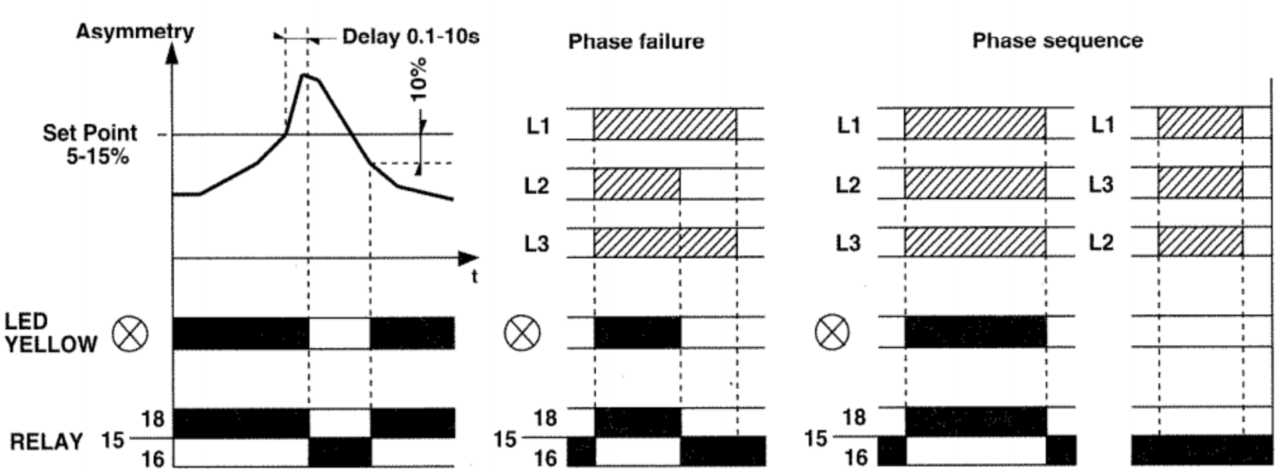
Objectives:

Studying and applying a relay for:

1. Phase sequence, phase failure and voltage asymmetry to a three-phase circuit.
2. Max/min three-phase voltage.
3. Max/min frequency of a power production plant.
4. Maximum current (overcurrent) to a three-phase line.

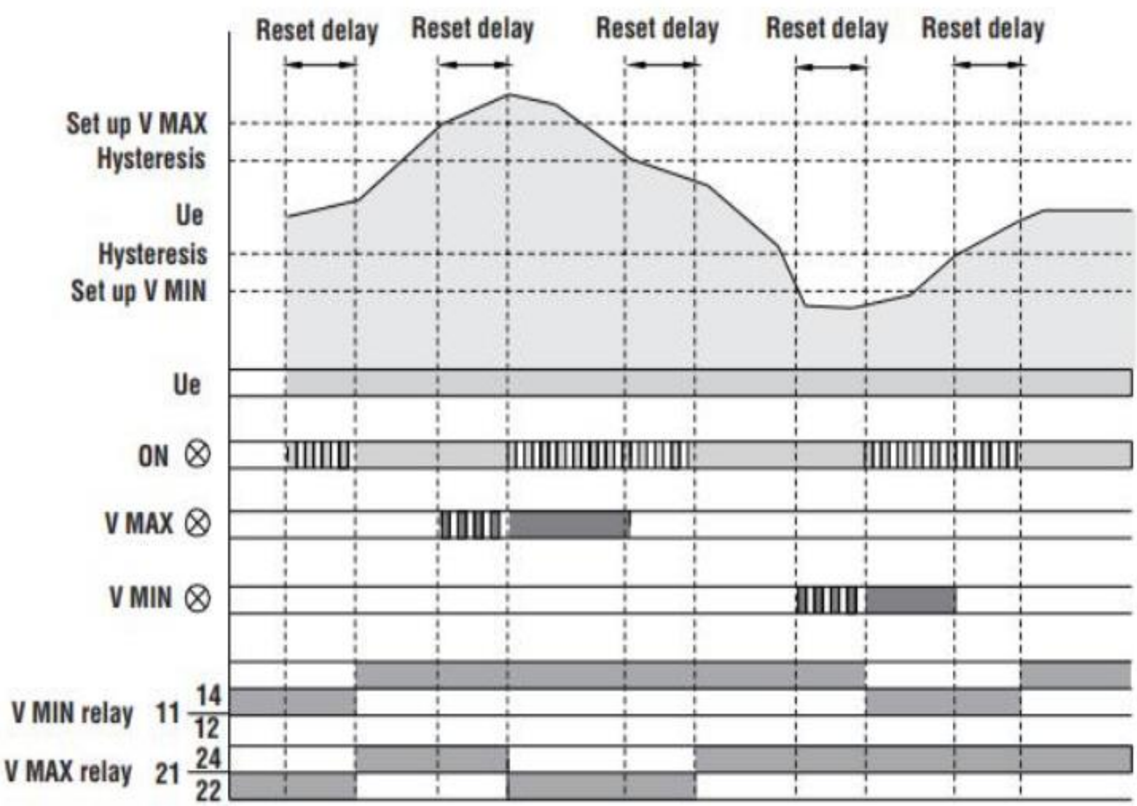
Theory and concepts:

1. **Relay for phase sequence, phase failure and voltage asymmetry.**
   It detects that the triad of voltages is in the set direction and detects the voltage asymmetries, occurring, for instance, for too unbalanced load. Its action prevents dangerous overvoltages to the synchronous generator.
   The operation diagram of this relay is shown in the following figure:



2. **Relay for Max/min three-phase voltage.**

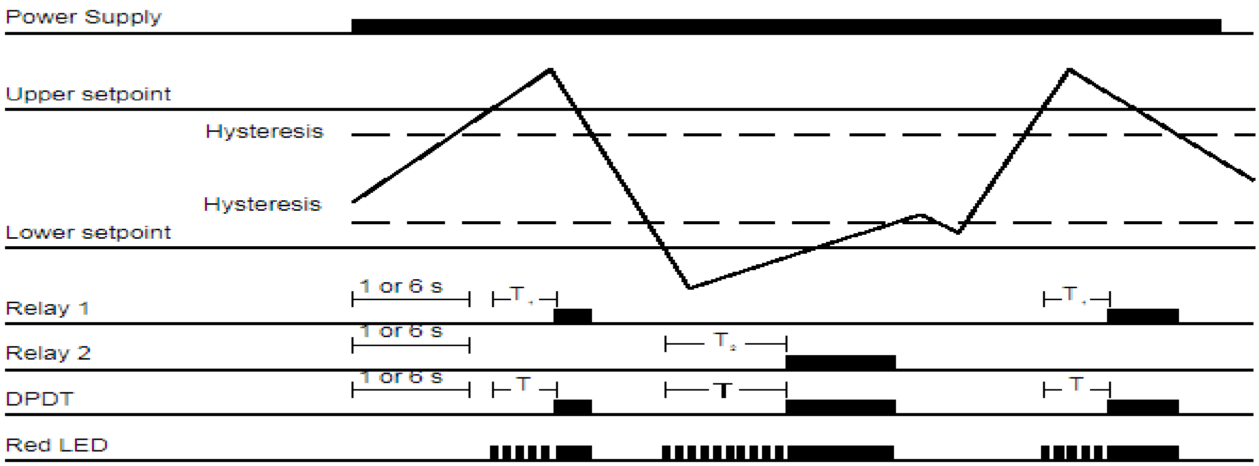
   It detects the limit of the voltage triad produced in normal operation by the synchronous generator, or distributed to the transmission line. Usually, the relay, acts on the main switch to set the controlled object out of service (synchronous generator or user connected with the line) when a voltage rise or drop can cause malfunctions or damages. The operation diagram of this relay is shown in the following figure:



3. **Relay for Max/min frequency of a power production plant.**

   The relay enables the max/min frequency control of the alternating power output by the synchronous generator in normal operation. As protection device, it acts on the main switch of the synchronous generator. It is used to protect the synchronous generator in case of over or under speed of the prime mover.

   The operation diagram of this relay is shown in the following figure:



4. **Relay for Maximum current (overcurrent) to a three-phase line**
   The three-phase ammetric relay operating as maximum current (overload) protection enables to fix the limit of current output by a synchronous generator (its rated power) or the current a power line can usually bear. Usually the relay acts on the main switch to set the controlled object (synchronous generator or line) out of service.
   The overload settings (current and delay time) are shown in the following table:

Overload current		Overload tripping delay-time	
Microswitch	I setting A	Microswitch	t setting s
None	0.5 A	None	1
1	0.6 A	1	2
2	0.7 A	2	3
1 + 2	0.8 A	1 + 2	4
4	0.9 A	4	5
4 + 1	1 A	4 + 1	6
4 + 2	1.1 A	4 + 2	7
4 + 2 + 2	1.2 A	4 + 2 + 2	8
8	1.3 A	8	9
8 + 1	1.4 A	**8 + 1**	10
8 + 2	1.5 A	8 + 2	11
8 + 2 + 1	1.6 A	8 + 2 + 1	12
8 + 4	1.7 A	8 + 4	13
8 + 4 + 1	1.8 A	8 + 4 + 1	14
8 + 4 + 2	1.9 A	8 + 4 + 2	15
8 + 4 + 2 +1	2 A	8 + 4 + 2 +1	16

Necessary Material:

1. **GCB-3/EV:** Control board for the generating set mod.
2. **MSG-3/EV:** Synchronous generator-motor unit mod.
3. **RL-2/EV:** Variable resistive load mod.
4. **IL-2/EV:** Variable inductive load mod.

Experimental Procedures:

Part I: Relay for phase sequence, phase failure and voltage asymmetry.

1. Insert three jumpers into the terminals set to power the relay for phase sequence, phase lacking and voltage asymmetry as indicated in Figure 1.
2. Connect an ohmmeter to check the state of the output relay contact and complete the wiring involving the step resistive load mod. RL-2/EV, be sure that all switches of the steps of each phase are in position of excluded load (OFF) as shown in Figure 1.

Test 1: Disconnect one of the three phases and check the intervention of the output relay.

Test 2: Displace one of the three phases with another one and check the intervention of the output relay.

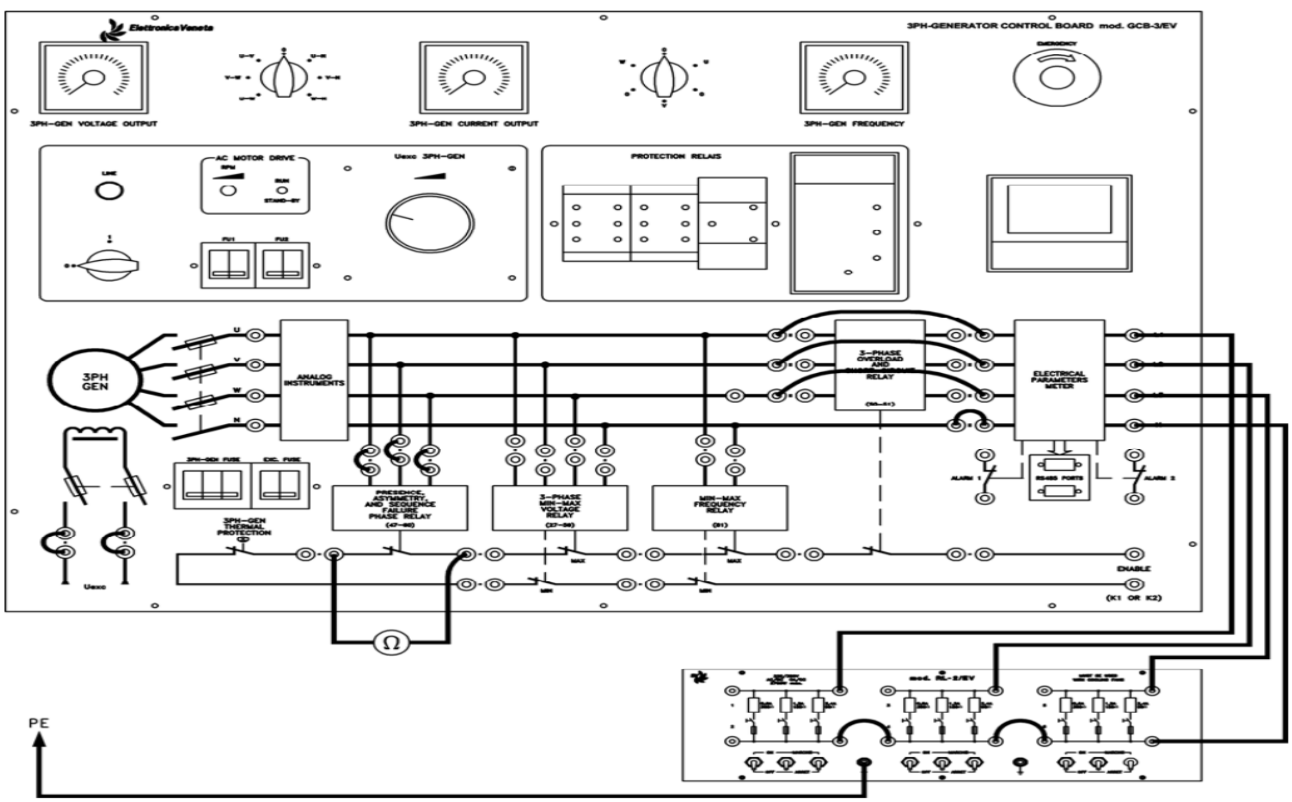


Figure (1)

3. Set the synchronous generator under load with the insertion of the resistive load.

Test 3: Put unbalanced load and record the value of phase voltages and currents (using power analyzer) and delay time (using chronometer), fill the following table.

Asymmetry %	Line voltages (V)			Line currents (mA)			Operation delay in asymmetry	Measured delay (Sec)
	Va	Vb	Vc	Ia	Ib	Ic		
5% (AB,A,A)							10 sec	
7.5% (C,A,A)							10 sec	
10% (AC,A,A)							10 sec	

Part II: Max/min three-phase voltage Relay.

1. Remove jumpers of the symmetry relay and insert four jumpers into the terminals set to power the max/min three-phase voltage relay as indicated in Figure 2.
2. Connect an ohmmeter to check the state of the output relay contact and complete the wiring of the GCB-3/EV panel as shown in Figure 2.

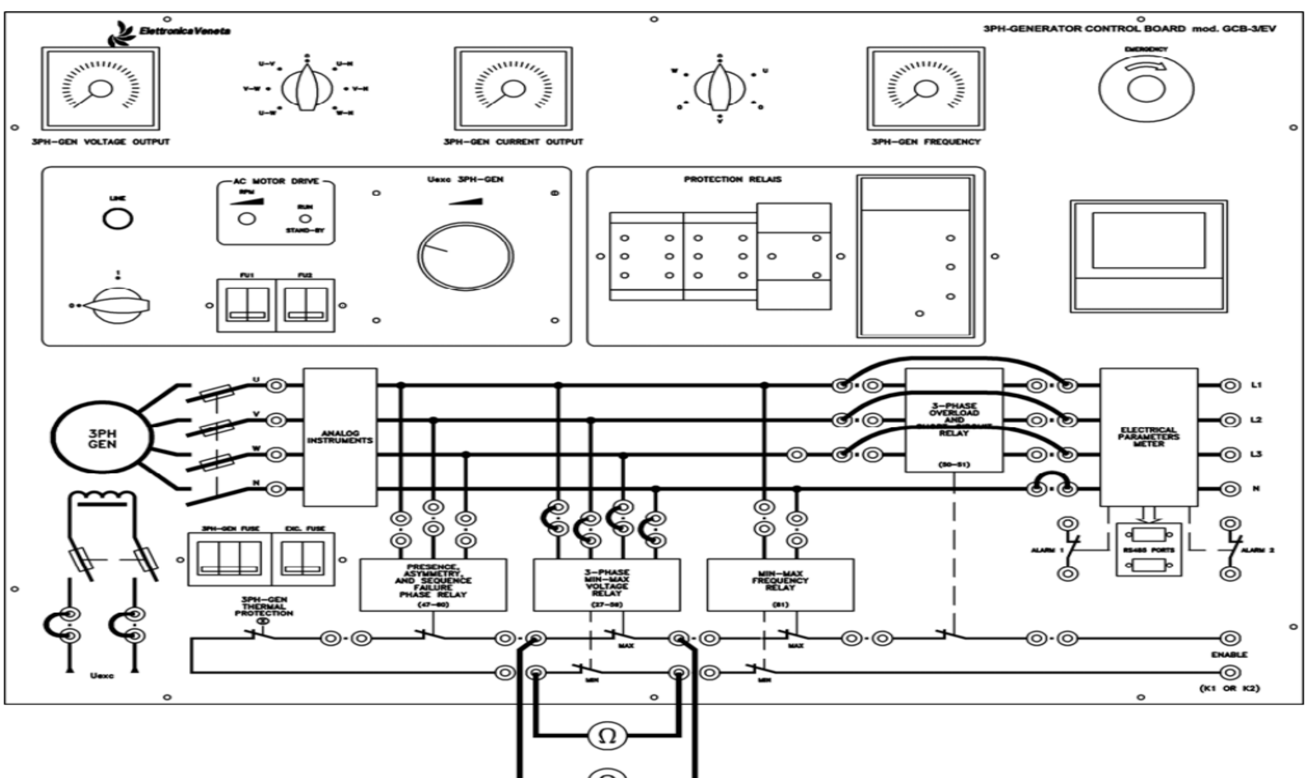


Figure (2)

Test 1: Max voltage relay.

Increase the voltage supplied by the synchronous generator by increasing the excitation current and record the time between the "overvoltage" moment and the same output relay tripping one. Reduce the voltage again to its rated value (400 V) and check the alarm suppression (the maximum voltage output relays is reset). Consider that the relay has an hysteresis of **3%** with respect to the set point. Determine at which value of voltage will the relay reset?

Maximum voltage threshold %	Line voltage (V)	Maximum voltage intervention delay	Measured delay (Sec)	Reset Value (V)
105%		5 sec		
110%		5 sec		

Test 2: Min voltage relay.

Way 1: Decrease the voltage supplied by the synchronous generator by decreasing the excitation current and record the time between the "undervoltage" moment and the same output relay tripping one. Increase the voltage again to its rated value (400 V) and check the alarm suppression (the minimum voltage output relays is reset). Consider that the relay has an hysteresis of **3%** with respect to the set point. Determine at which value of voltage will the relay reset?

Maximum voltage threshold %	Line voltage (V)	Maximum voltage intervention delay	Measured delay (Sec)	Reset Value (V)
95%		5 sec		
90%		5 sec		

Way 2: Complete the wiring including the step resistive load mod. RL-2/EV. Be sure that all step switches of each phase are in position of load excluded (OFF). Set the synchronous generator under load with the insertion of the resistive load (with different values of the resistive load) and measure the following:

Resistive Load in Ω	Minimum voltage threshold %	Line voltage (V)	Minimum voltage intervention delay	Measured delay (Sec)	Reset Value (V)
A	95%		5 sec		
A||B	90%		5 sec		

Part III: Max/min frequency Relay.

1. Remove jumpers of the max/min voltage relay and Insert two jumpers into the terminals set to power the max/min frequency relay as indicated in Figure 3.
2. Connect an ohmmeter to check the state of the output relay contact and complete the wiring of the GCB-3/EV panel as shown in Figure 3.

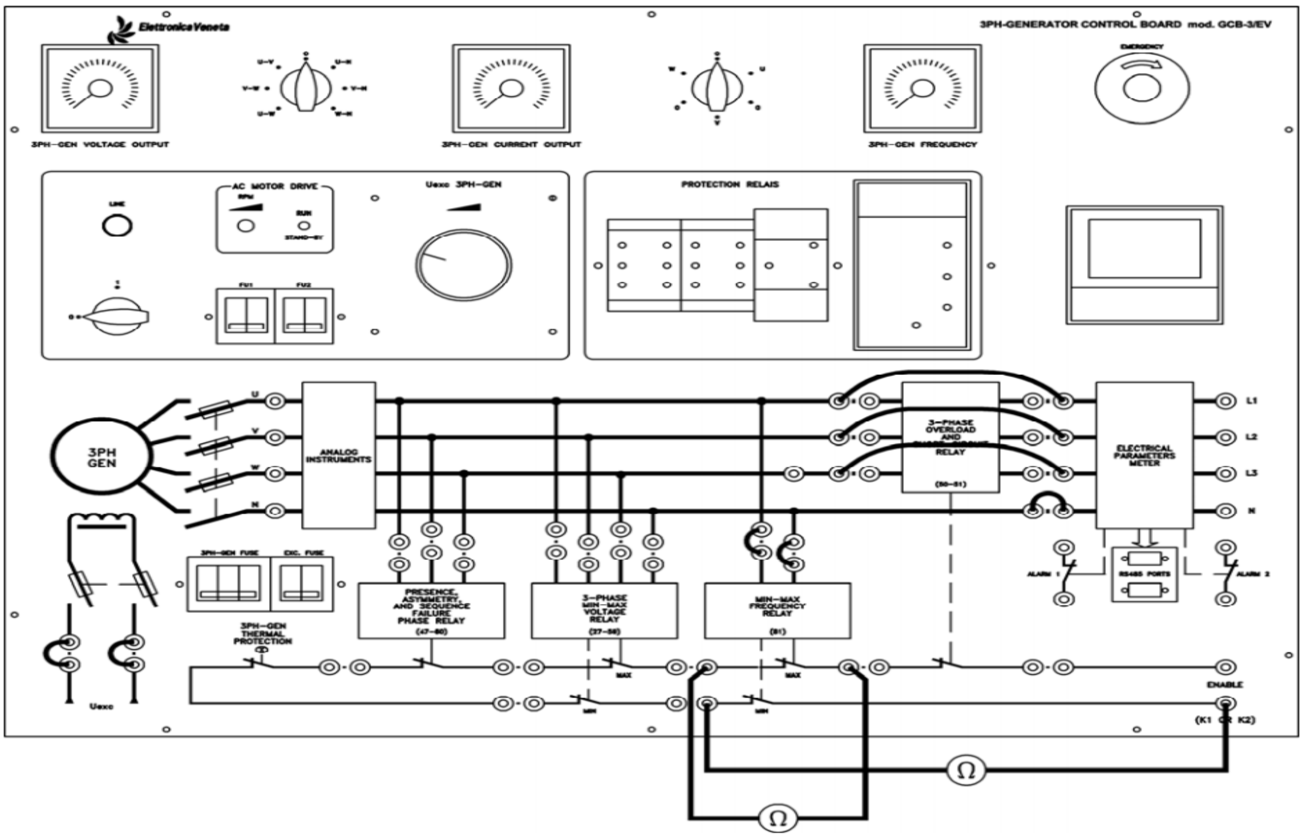


Figure (3)

Test 1: Max frequency relay.

Increase the test frequency using RPM potentiometer and record the time between the overfrequency and the same output relay tripping one.

Maximum frequency threshold	Frequency (Hz)	Maximum frequency intervention delay	Measured delay (Sec)
50.1 Hz (+10%)		3 sec	
50.2 Hz (+20%)		3 sec	

Test 2: Min frequency relay.

Decrease the test frequency using RPM potentiometer and record the time between the under frequency and the same output relay tripping one.

Minimum frequency threshold	Frequency (Hz)	Maximum frequency intervention delay	Measured delay (Sec)
49.9 Hz (-10%)		5 sec	
48.8 Hz (-20%)		5 sec	

Part IV: Overcurrent and Short circuit Relay.

1. Remove jumpers of the max/min frequency relay and connect the 3-Phase Overload and the Short-Circuit relay with the proper terminals via six jumpers as indicated in Figure 4.
2. Connect an ohmmeter to check the state of the output relay contact and complete the wiring of the GCB-3/EV panel and complete the wiring including the step resistive load mod. RL-2/EV to obtain the current regulation in the ammetric relay as shown in Figure 4.

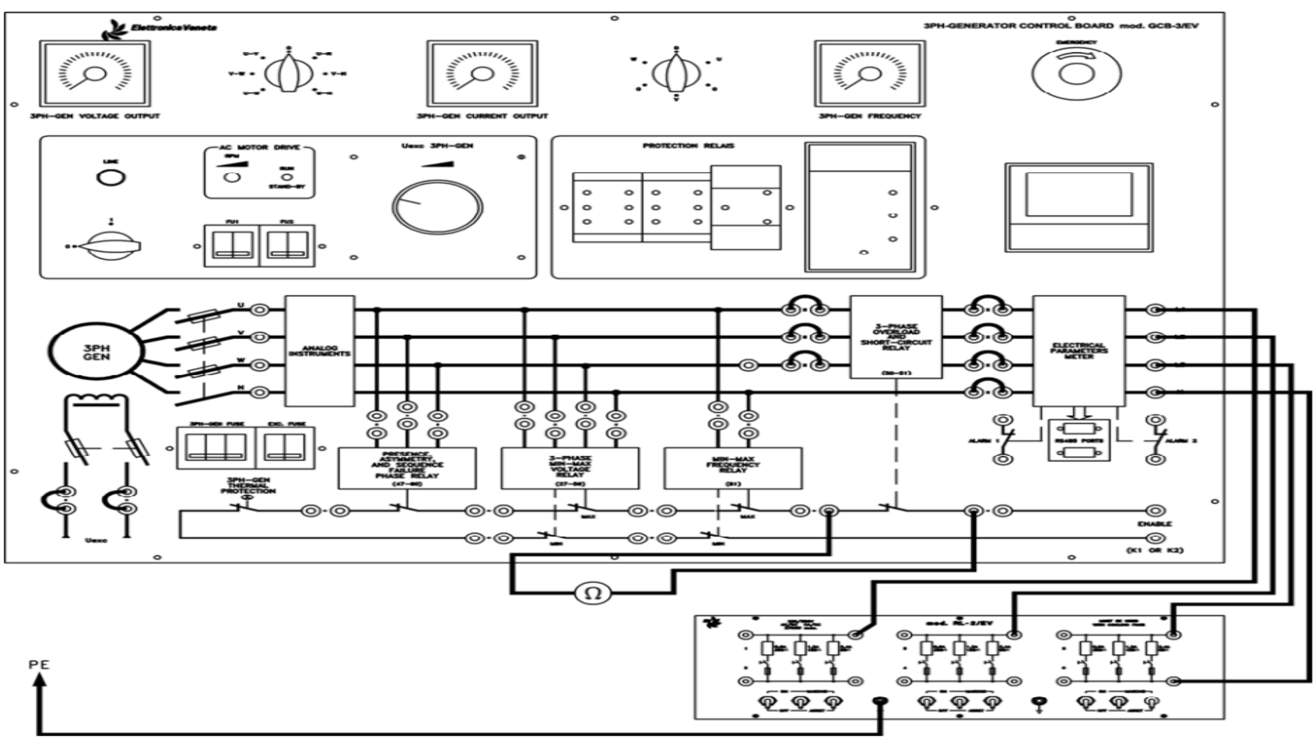


Figure (4)

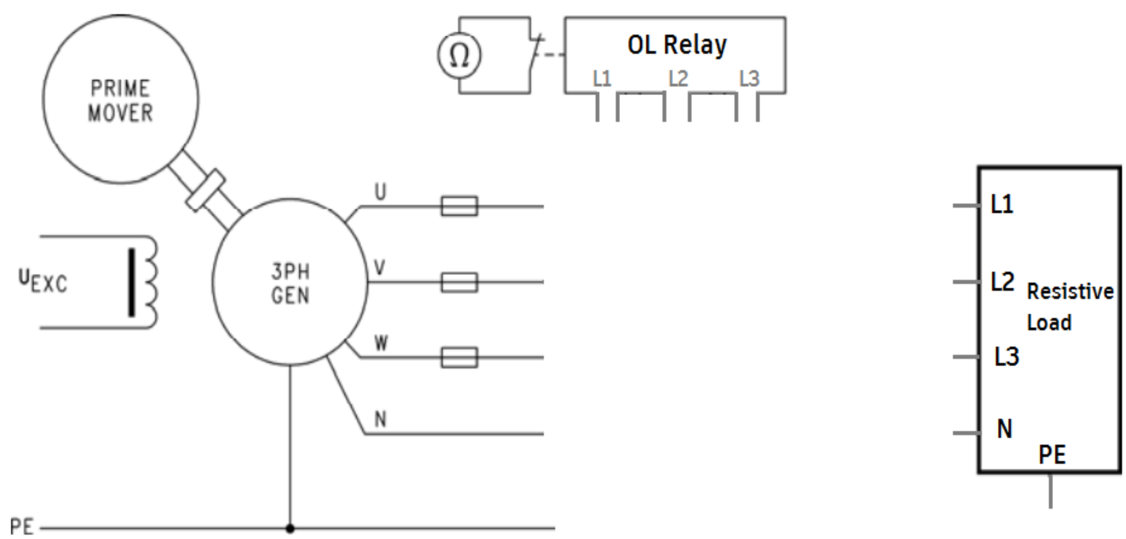
3. Increase the test current by adding resistive load, measure the load current and record the time between the "overcurrent" and the output relay tripping.

Resistive Load in Ω	Overload threshold (A)	Load current (A)	Intervention delay	Measured delay (Sec)
A	0.5		5 sec	
A||B	0.5		5 sec	
C	0.6		5 sec	
A||B||C	0.8		5 sec	

Questions:

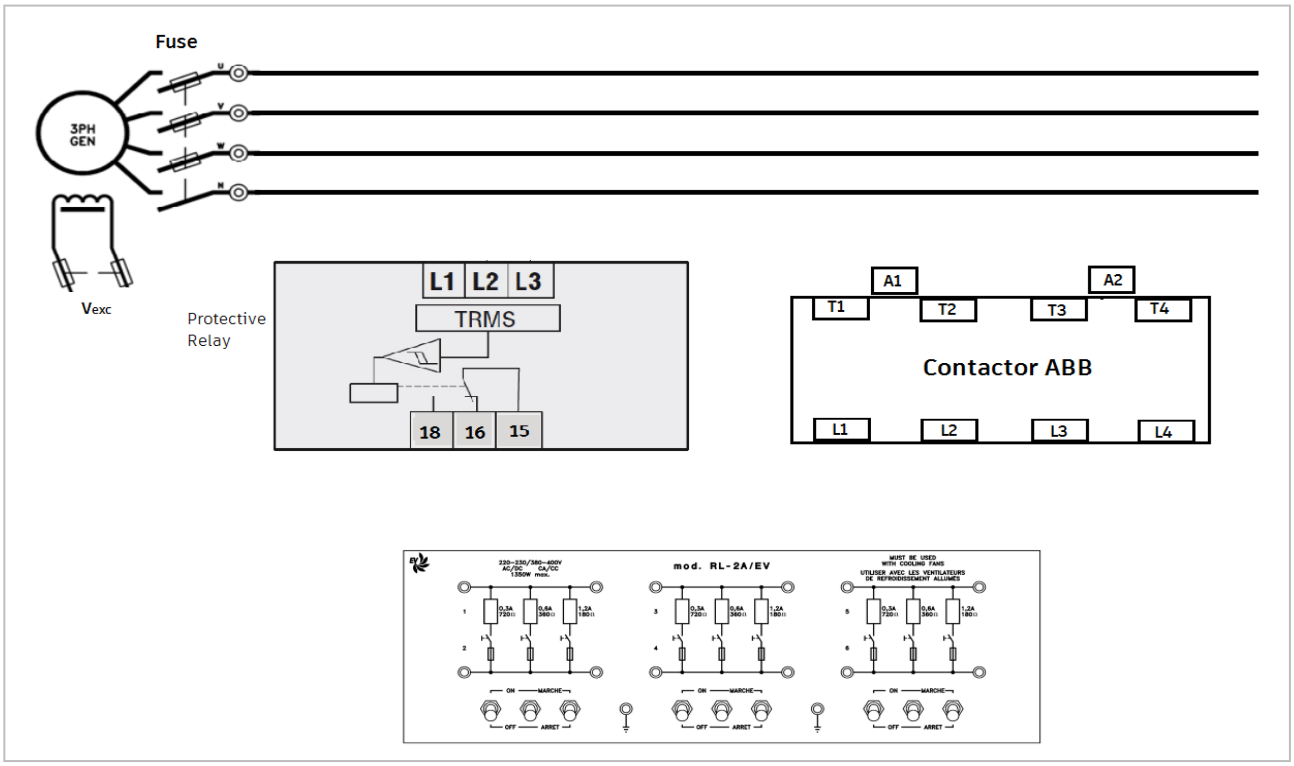
1. Describe the effect of the following on the synchrouns generator?
   (a) Phase failure;
   (b) Phase sequence;
   (c) Voltage Asymmetry;
   (d) Over and under voltage;
   (e) Over and under frequency;
   (f) Over load.

2. Based on the overload relay experiment answer the following questions:
   (a) Sketch the connection needed to connect synchrouns generator with:
      1. Relay;
      2. Variable three-phase resistive load.



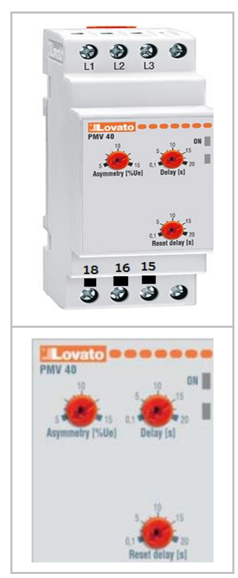
   (b) If the load attached on the synchronous generator is (B||C = 120Ω) and the load current measured is 889mA, Put the settings of the overload relay as: overload current = 0.7A with intervention delay of 5 second.
      1) Explain how to put the settings of the relay?
      2) Explain the operation of the relay after the load attached?

3. Based on the relay for phase sequence, phase failure and voltage asymmetry experiment answer the following questions:
   (a) Sketch the connection needed to connect synchrouns generator with:
   1. Relay;
   2. 4-pole contactor (on-off) (to switch off the **load** when phase sequence or phase failure or voltage asymmetry occur);
   3. Variable three-phase resistive load.



(b) If the load attached on the synchronous generator is (C,A,A) and the settings of the relay are:

- Asymmetry = 10%;
- Delay = 10 Second;
- Reset delay = 0.1 Sec.



The measurements from the power analyzer are:

Line voltages (V)		
V_a	V_b	V_c
312	347	345

1. Explain how to put the settings of the relay?
2. Explain the operation of the relay in this case?

Experiment (3)	Parallel operation of two Synchronous Generators

Objectives:

1. To understand the conditions required to parallel two synchronous generators.
2. To understand the procedures for paralleling two synchronous generators.
3. To understand the effect of increasing the frequency of one of the generators on the system.
4. To understand the effect of increasing the field current of one of the generators on the system.
5. To understand how the real power sharing between two generators can be controlled independently of the system frequency and vice versa.
6. To understand how the reactive power sharing between two generators can be controlled independently of the terminal voltage and vice versa.

Theory and concepts:

Figure 1 shows a synchronous generator G1 supplying power to a load, with another generator G2, about to be paralleled with G1, by closing the switch S1. If the switch is closed arbitrarily at some moment, the generators are liable to be severely damaged, and the load may lose power. If the voltages are not exactly the same in each conductor being tied together, there will be a very large current flow when the switch is closed. To avoid this problem, each of the three phases must have exactly the same voltage magnitude and phase angle as the conductor to which it is connected. In other words, the voltage in phase a must be exactly the same as the voltage in phase a', and so forth for phases b-b' and c-c'.

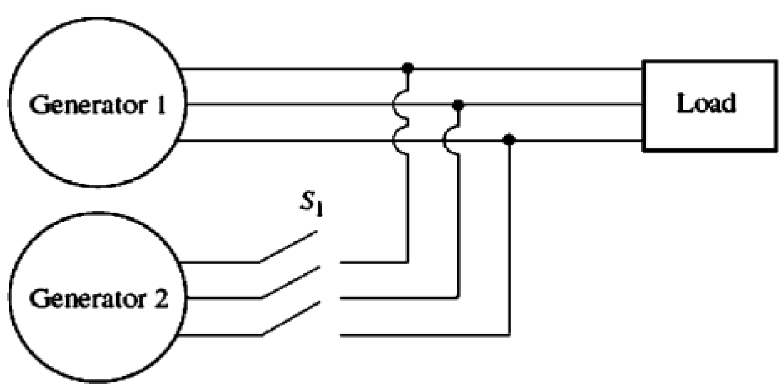


Figure (1)

The conditions required for paralleling two Alternators:

1. **Equal phase sequence:** the voltage triads of the 2 generators must run in the same direction. The direction is pre-set by the proper connections and checked with the **3-lamp method**. If the 2 triads do not run in the same direction, **the 3 lamps never light off simultaneously**.

2. **Equal frequencies:** This can be seen in the frequency meters of each generator. Actually, G2 is set at a little higher speed than G1 (this because when "taking load", the prime mover will naturally drop the rpm).

3. **Equal effective voltages**: this occurs in the voltmeters of each generator.

4. **Equal phase angles:** the phase angles of the two *a* phases must be equal. It is obvious that if the rotation speeds of both machines are exactly equal, **the phases will be never be equal.**

A **synchroscope** is a meter that measures the difference in phase angle between the phases of the two systems. The face of a synchroscope is shown in Figure 2. The dial shows the phase difference between the two a phases, with 0 (meaning in phase) at the top and 180^o at the bottom. Since the frequencies of the two systems are slightly different, the phase angle on the meter changes **slowly**. If the oncoming generator or system is faster than the running system, then the phase angle advances and the synchroscope needle rotates **clockwise**. If the oncoming machine is slower, the needle rotates **counterclockwise**. When the synchroscope needle is in the vertical position, the voltages are **in phase**, and the switch can be shut to connect the system.

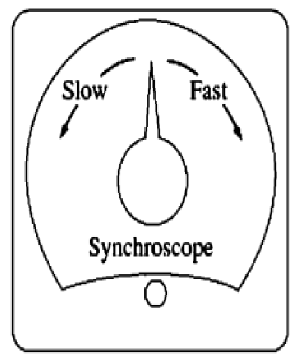


Figure (2)

If a generator is connected in parallel with another one of the same size, the basic constraint is that the sum of the real and reactive powers supplied by the two generators must equal the P and Q demanded by the load. The system frequency is not constrained to be constant, and neither is the power of a given generator constrained to be constant. The total power P_{total} (which is equal to P_{load}) is given by:

$$\mathbf{P_{total} = P_{load} = P_{G1} + P_{G2}}$$

And the total reactive power is given by

$$\mathbf{Q_{total} = Q_{load} = Q_{G1} + Q_{G2}}$$

Necessary Material:

1. **PCB-3/EV:** Generator parallel board mod.
2. **GCB-3/EV:** Control board for the generating set mod.
3. **MSG-3/EV:** Synchronous generator-motor unit mod.
4. **RL-2/EV:** Variable resistive load mod.
5. **IL-2/EV:** Variable inductive load mod.

Experimental Procedures:

Part I: Parallel operation of two synchronous generators.

1. Connect the circuit as shown in figure 3. Be sure that all the step switches of each phase are in position of load excluded (OFF).

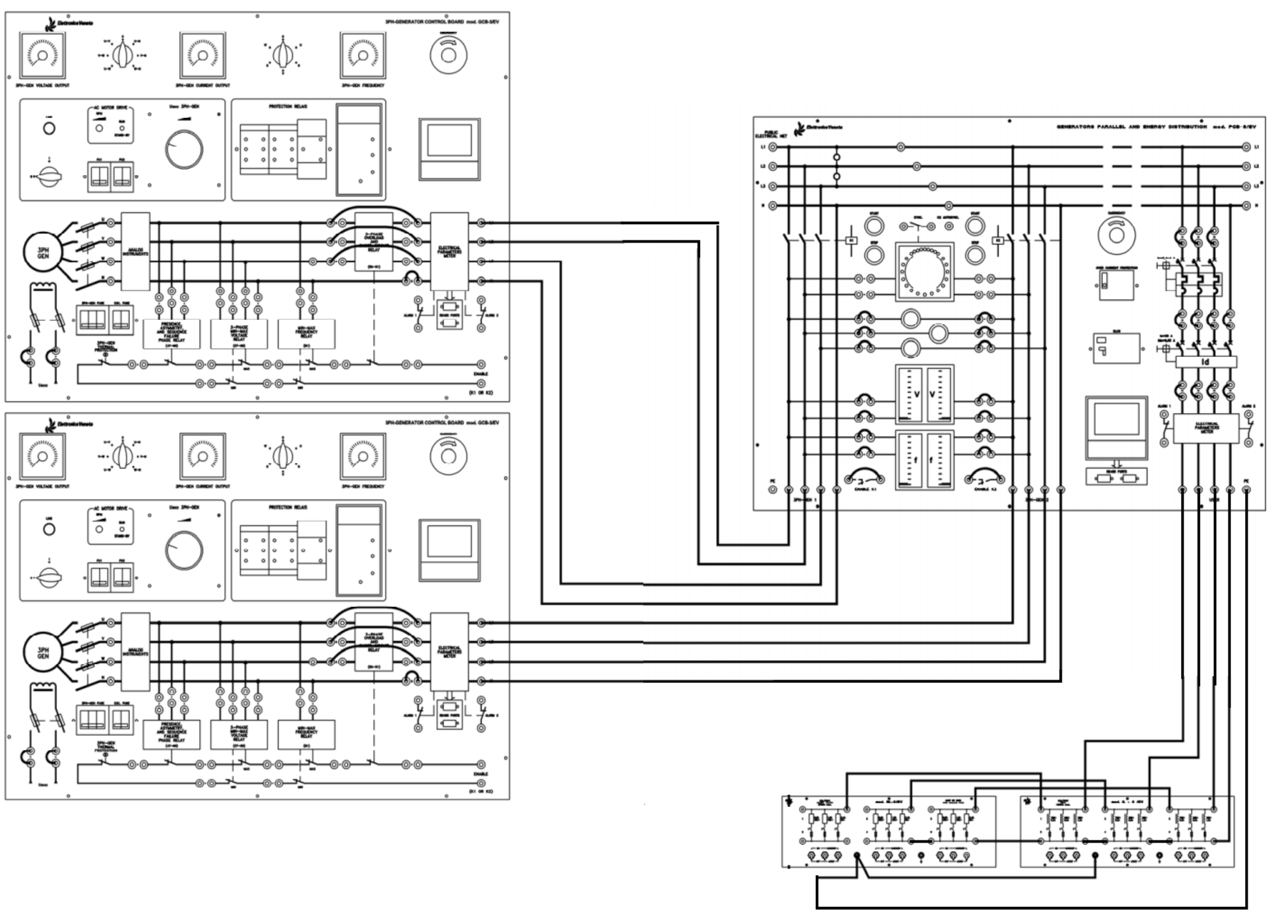


Figure (3)

2. Start the prime mover of the set 1 and adjust the speed to obtain the rated frequency 50.0 Hz, with the potentiometer RPM set to AC motor drive, and adjust the excitation of the synchronous generator to obtain a rated voltage equal to 400 V.
3. Press the START button of the contactor **K1** to connect the triad of voltages output by the generator 1, with the main bars.
4. Start the prime mover of the set 2 and adjust the speed to obtain the rated frequency 50.0 Hz, with the potentiometer RPM set to AC motor drive, and adjust the excitation of the synchronous generator to obtain a rated voltage equal to 400 V.

Note: Do not enable the contactor K2 for any reason until reaching the stage of synchronization.

Ideal Moment for carrying out the Parallel Connection:

5. Check that the two voltage triads are of approximately 400 V and almost equal between them.
6. Check the phase sequence by using the three-lamp method. If all three bulbs get bright and dark together, then the systems have the same phase sequence.
7. In the exact moment when the **3 lamps are actually off** and the LED SYNC is lightning in the **Green Zone**. Enable the contactor **K2** to lead the generators to be connected in parallel.

Part I: The effect of increasing the prime mover speed of one of the generators on the system.

1. At **no-load condition** measure the frequency and power of G1 and G2 then tabulate the results in the following table.
2. Set the synchronous generator under load with the insertion of the resistive-inductive load (R = 360 Ω - Switch B and L= 1.15 H – Switch B).
3. Increase the frequency of **G1** gradually and measure the following using the power analyzer:

Condition	Generator 1		Generator 2		Load	
	f_{G1} (Hz)	P_{G1} (W)	f_{G2} (Hz)	P_{G2} (W)	f_{system} (Hz)	P_{Load} (W)
No-Load						
No-Change						
Increase f_1						
Increase f_1						

Part II: The effect of increasing the prime mover speed of G1 while decreasing it of G2 on the system.

1. Return back to the normal operation values and keep the two generators to be synchronized with each other.
2. Set the synchronous generator under load with the insertion of the resistive-inductive load (R = 360 Ω - Switch B and L= 1.15 H – Switch B).
3. Increase the frequency of G1 and decrease it for G2 **in a small amount** and measure the following using the power analyzer:

Generator 1		Generator 2		Load	
f_{G1} (Hz)	P_{G1} (W)	f_{G2} (Hz)	P_{G2} (W)	f_{system} (Hz)	P_{Load} (W)

Part III: The effect of changing the prime mover speed of both generators on the system.

1. Return back to the normal operation values and keep the two generators to be synchronized with each other.
2. Set the synchronous generator under load with the insertion of the resistive-inductive load (R = 360 Ω - Switch B and L= 1.15 H – Switch B).
3. Increase or decrease the frequency of both generators **in a small amount** and measure the following using the power analyzer:

Generator 1		Generator 2		Load	
f_{G1} (Hz)	P_{G1} (W)	P_{G2} (W)	f_{G2} (Hz)	f_{system} (Hz)	P_{Load} (W)

Part IV: The effect of increasing the excitation current of one of the generators on the system.

1. Return back to the normal operation values and keep the two generators to be synchronized with each other.
2. Set the synchronous generator under load with the insertion of the resistive-inductive load (R = 360 Ω - Switch B and L= 1.15 H – Switch B).
3. Increase the excitation current of **G1** gradually and measure the following using the power analyzer:

Condition	Generator 1		Generator 2		Load	
	V_{G1} (V)	Q_{G1} (VAR)	V_{G2} (V)	Q_{G2} (VAR)	V_{system} (V)	Q_{Load} (VAR)
No-Load						
No-Change						
Increase I_{f1}						
Increase I_{f1}						

Part V: The effect of increasing the excitation current of G2 while decreasing it of G1 on the system.

1. Return back to the normal operation values and keep the two generators to be synchronized with each other.
2. Set the synchronous generator under load with the insertion of the resistive-inductive load (R = 360 Ω - Switch B and L= 1.15 H – Switch B).
3. Increase the excitation current of G1 and decrease it for G2 **in a small amount** and measure the following using the power analyzer:

Generator 1		Generator 2		Load	
V_{G1} (V)	Q_{G1} (VAR)	V_{G2} (V)	Q_{G2} (VAR)	V_{system} (V)	Q_{Load} (VAR)

Part VI: The effect of increasing the excitation current of both generators on the system.

1. Return back to the normal operation values and keep the two generators to be synchronized with each other.
2. Set the synchronous generator under load with the insertion of the resistive-inductive load (R = 360 Ω - Switch B and L= 1.15 H – Switch B).
3. Increase or decrease the excitation current of both generators **in a small amount** and measure the following using the power analyzer:

Generator 1		Generator 2		Load	
V_{G1} (V)	Q_{G1} (VAR)	V_{G2} (V)	Q_{G2} (VAR)	V_{system} (V)	Q_{Load} (VAR)

Questions:

1. Draw the corresponding house diagram at the moment G2 is paralleled with the G1.

2. Explain with drawing (house diagram) the effect of increasing the frequency of G2 on the operation of the system.

3. Explain with drawing (house diagram) the effect of increasing the frequency of G2 and decreasing it of G1 on the operation of the system.

4. Explain with drawing (house diagram) the effect of increasing or decreasing the frequency of both generators on the operation of the system.

5. Explain with drawing (house diagram) the effect of increasing the excitation current of G2 on the operation of the system.

6. Explain with drawing (house diagram) the effect of increasing the excitation current of G2 and decreasing it of G1 on the operation of the system.

7. Explain with drawing (house diagram) the effect of increasing or decreasing the excitation current of both generators on the operation of the system.

Experiment (4)	Parallel operation of a Synchronous Generator with public mains

Objectives:

1. To understand the conditions required to parallel synchronous generator with mains.
2. To understand the procedures for paralleling synchronous generator with mains.
3. To understand the effect of increasing the frequency of the generator on the system.
4. To understand the effect of increasing the field current of the generator on the system.

Theory and concepts:

When a generator is connected in parallel with another generator or a large system as shown in Figure.1, the frequency and terminal voltage of all the machines must be the same, since their output conductors are tied together. When a generator operated in parallel with an infinite bus, the frequency and terminal voltage were constrained to be constant by the infinite bus, and the real and reactive powers were varied by the governor set points and the field current. The basic constraint is that the sum of the real and reactive powers supplied by the generator and the infinite bus must equal the P and Q demanded by the load.

The total power P_{total} (which is equal to P_{load}) is given by:

$$P_{total} = P_{load} = P_G + P_{IB}$$

And the total reactive power is given by

$$Q_{total} = Q_{load} = Q_G + Q_{IB}$$

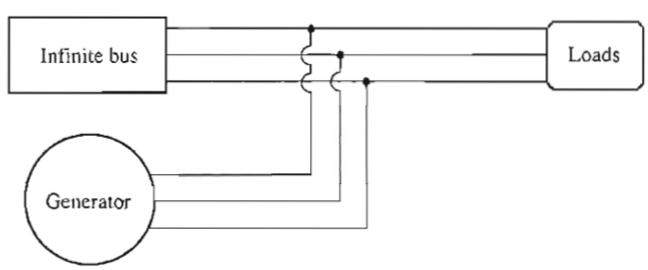


Figure (1)

Necessary Material:

1. **PCB-3/EV:** Generator parallel board mod.
2. **GCB-3/EV:** Control board for the generating set mod.
3. **MSG-3/EV:** Synchronous generator-motor unit mod.
4. **AMT-3/EV:** Variable three-phase power supply mod.
5. **RL-2/EV:** Variable resistive load mod.
6. **IL-2/EV:** Variable inductive load mod.

Experimental Procedures:

Part I: Parallel operation of synchronous generator and Public mains.

1. Connect the circuit as shown in figure 2. Be sure that all the step switches of each phase are in position of load excluded (OFF).

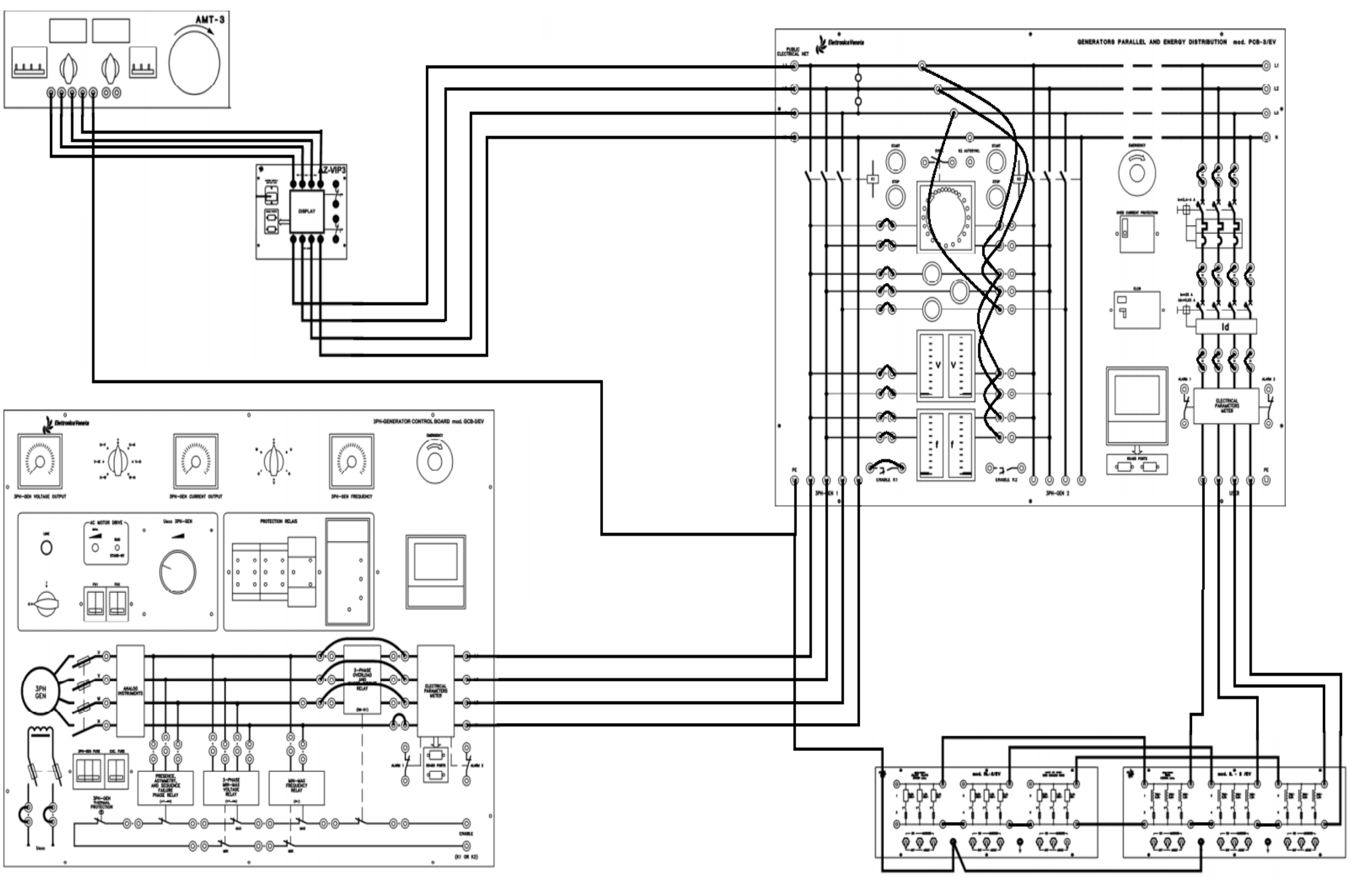


Figure (2)

2. Enable the public mains with the variable power supply mod. AMT-3/EV adjusting the voltage to approximately 3 x 400 V.
3. Start the prime mover of the G1 and adjust the speed to obtain the rated frequency 50.0 Hz, with the potentiometer RPM set to AC motor drive, and adjust the excitation of the synchronous generator to obtain a rated voltage equal to 400 V.
4. Don't press the START button of the contactor **K1** to connect the triad of voltages output by the generator 1, with the main bars.

Ideal Moment for carrying out the Parallel Connection:

5. Check that the two voltage triads are of approximately 400 V and almost equal between them.
6. Check the phase sequence by using the three-lamp method. If all three bulbs get bright and dark together, then the systems have the same phase sequence.
7. In the exact moment when the **3 lamps are actually off** and the LED SYNC is lightning in the **Green Zone**. Enable the contactor **K1** to lead the generator to be connected in parallel with the mains.

Part II: The effect of changing the prime mover speed of the generators on the system.

1. Set the synchronous generator under load with the insertion of the resistive-inductive load (R = 720 Ω - Switch A and L= 2.3 H – Switch A).
2. Change the frequency of **G1** (increase or decrease) gradually and measure the following using the power analyzer:

Generator			Main	Load	
Frequency of Generator	f_{G1} (Hz)	P_{G1} (W)	P_M (W)	f_{system} (Hz)	P_{Load} (W)
No-Change					
Increase frequency of Generator					
Decrease frequency of Generator					

Part III: The effect of increasing the excitation current of one of the generators on the system.

1. Return back to the normal operation values and keep the synchronous generator to be synchronized with the public main.
2. Set the synchronous generator under load with the insertion of the resistive-inductive load (R = 720 Ω - Switch A and L= 2.3 H – Switch A).
3. Change the excitation current of G1(increase or decrease) in a **small amount** and measure the following using the power analyzer:

Generator			Main	Load	
Field current of Generator	V_{G1} (V)	Q_{G1} (VAR)	Q_M (VAR)	V_{system} (V)	Q_{Load} (VAR)
No change					
Increase field current of Generator					
Decrease field current of Generator					

Questions:

1. Why must the oncoming generator on a power system be paralleled at a higher frequency than that of the running system?

2. Once the generator has been connected, explain with drawing (house diagram) what happens when its frequency is increased or decreased?

3. Once the generator has been connected, explain with drawing (house diagram) what happens when its field current is increased or decreased?

Chapter 2

Transmission lines Experiments

Contents

Experiment (1)	Transmission Line under no-load condition

Objectives:

1. To study the operation of a power transmission line in no-load condition. (short, medium and long transmission lines).
2. To study the behavior in series of the no-load power transmission lines (medium and long transmission lines).
3. To demonstrate the concept of **Ferranti effect** for a transmission line (medium and long transmission lines).

Theory and concepts:

No-Load Transmission line:

In this condition, only an equivalent total capacitance is being considered, for an easier study. It is because the parameter is directly proportional to the length of the transmission line. Theoretically, the value of transmission loss in this load condition is assumed to be zero. However, in real practice, the parameters (capacitance and resistance) of a transmission line are distributed, which is crossing the line resistors. Subsequently, the capacitive currents will provoke power losses even when the transmission line is in no-load condition. Figure 1 shows a single-phase equivalent circuit for no-load condition.

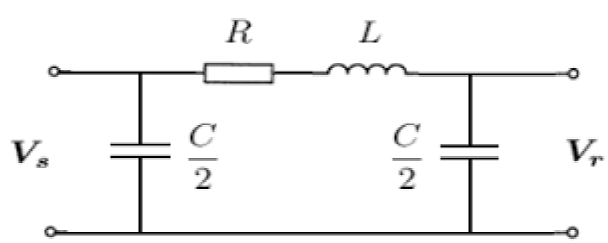


Figure (1)

In this no-load condition, only charging current will flow. Hence, power that involves is called charging power. In some cases, voltages at the end of transmission line will increases to impermissible values because of the equivalent total capacitance.

Ferranti Effect in Transmission lines:

During light-load or no-load condition, receiving end voltage is greater than sending end voltage in medium and long transmission line. This happens due to very high line charging current. This phenomenon is known as **Ferranti Effect**. A charged open circuit line draws significant amount of current due to capacitive effect of the line. This is more in HV long transmission line.

Sending end voltage of a TL is:

$$\mathbf{V}_S = \mathbf{A}\mathbf{V}_R + \mathbf{B}\mathbf{I}_R$$

Under no-load condition; $I_R = 0$, therefore: $V_R = Vs/A$;
Since A<1 so **V_R is greater than Vs**.

The capacitance (and charging current) is negligible in **short line** but significant in medium line and appreciable in long line. Therefore this phenomenon occurs in medium and long lines.

Consider the figure given below shows phasor diagram of Ferranti effect of transmission line. Receiving end voltage as reference phasor;

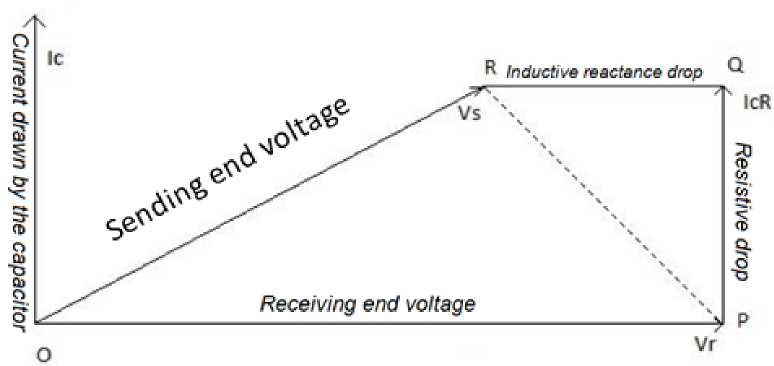


Figure (2)

From figure it is easily observed that sending end voltage (Vs) is less than receiving end voltage (Vr).

Necessary Material:

1. **SEL-1/EV:** Simulator of electric lines mod.
2. **AMT-3/EV:** Variable three-phase power supply mod.
3. **P14A/EV:** Three-phase transformer mod.

Experimental Procedures:

Part I: Short Transmission Line under no-load condition.

1. Start this experiment considering the transmission LINE 1 with the following parameters: R= 25 Ω; C= 0.2 μF; L= 72 mH; Length = 50 km.
2. Connect with the variable three-phase power supply by inserting the three-phase insulation transformer,
3. Connect the jumpers with the set of left capacitors, only in the LINE 1, to reproduce the capacitance between conductors (called C_L).
4. Connect the jumpers with the set of right capacitors, only in the LINE 1, to reproduce the capacitance between the conductors and the ground (called C_E).
5. Connect the circuit as shown in Figure 3.

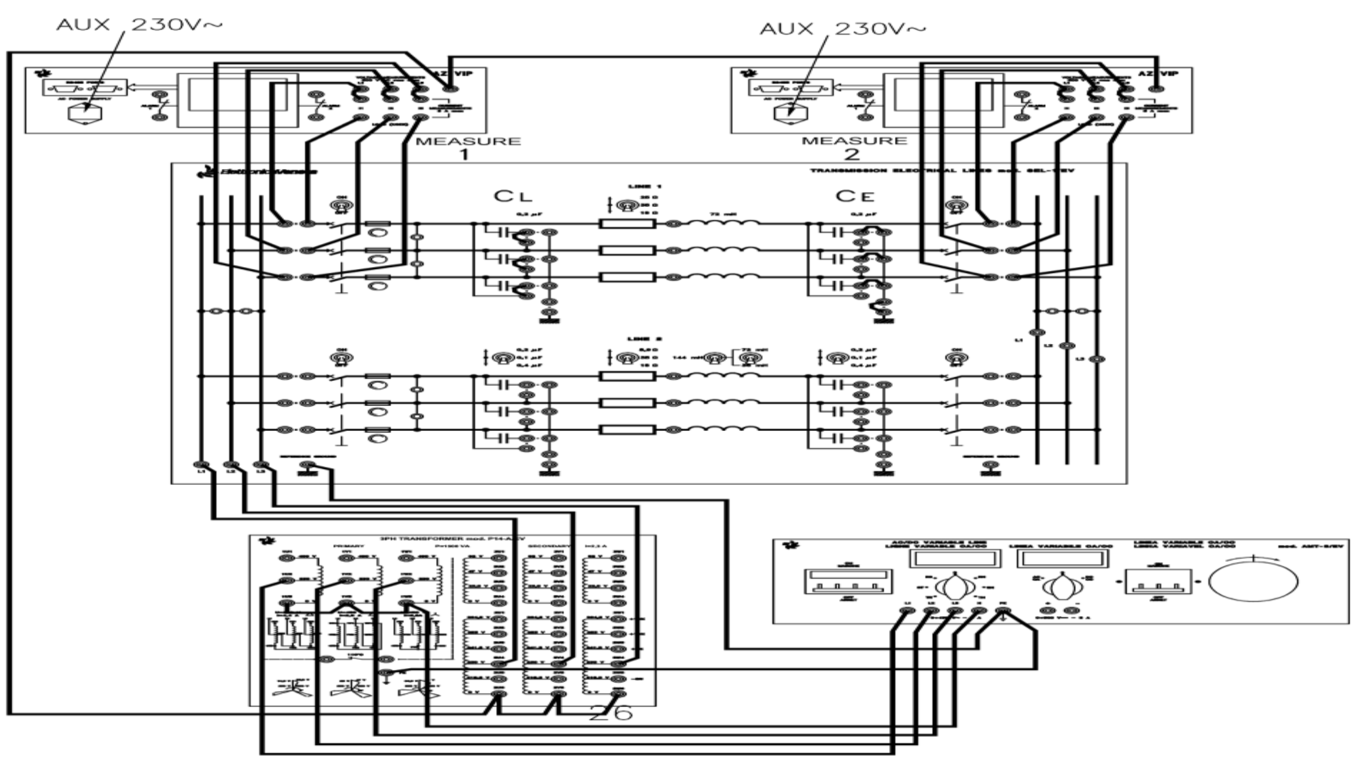


Figure (3)

Connection 1:

1. Connect the capacitors at the sending end point of the transmission line in Δ-connection.
2. Connect the capacitors at the receiving end point of the transmission line in Y-connection.
3. Enable and adjust the voltage of the power supply at 380 V.
4. Turn the breaker at the origin and at the end of the Line 1 to ON in sequence.
5. Read the electric quantities on the measuring instruments and write them down in the following table.

Sending End Voltage (Vs) (V)	Line Current (I) (mA)	Sending End Reactive Power (Q_s) (Var)	Sending End Active Power (P_s) (W)	Receiving End Voltage (V_R) (V)

Connection 2:

1. Connect the capacitors at the sending end point of the transmission line in Δ-connection.
2. Disconnect the capacitors at the receiving end point of the transmission line.
3. Enable and adjust the voltage of the power supply at 380 V.
4. Turn the breaker at the origin and at the end of the Line 1 to ON in sequence.
5. Read the electric quantities on the measuring instruments and write them down in the following table.

Sending End Voltage (Vs) (V)	Line Current (I) (mA)	Sending End Reactive Power (Q_s) (Var)	Sending End Active Power (P_s) (W)	Receiving End Voltage (V_R) (V)

Connection 3:

1. Connect the capacitors at the sending end point of the transmission line in Δ-connection.
2. Connect the capacitors at the receiving end point of the transmission line in Δ-connection.
3. Enable and adjust the voltage of the power supply at 380 V.
4. Turn the breaker at the origin and at the end of the Line 1 to ON in sequence.
5. Read the electric quantities on the measuring instruments and write them down in the following table.

Sending End Voltage (Vs) (V)	Line Current (I) (mA)	Sending End Reactive Power (Q_s) (Var)	Sending End Active Power (P_s) (W)	Receiving End Voltage (V_R) (V)

Part II: Series connection of two transmission lines at no-load.
Case 1: Medium Transmission line under no load condition. (Study the Ferranti effect of a TL)

1. Consider two lines with equal current-carrying capacity, but different length, for this experiment, that is the Line 1 parameters are: R= 18 Ω; L= 72mH; C= 0.2μF; Length = 50 km; and Line 2 constants are: R = 18 Ω; L= 72mH; C= 0.2μF; Length = 50 km.
2. Connect the circuit as shown in Figure 4.

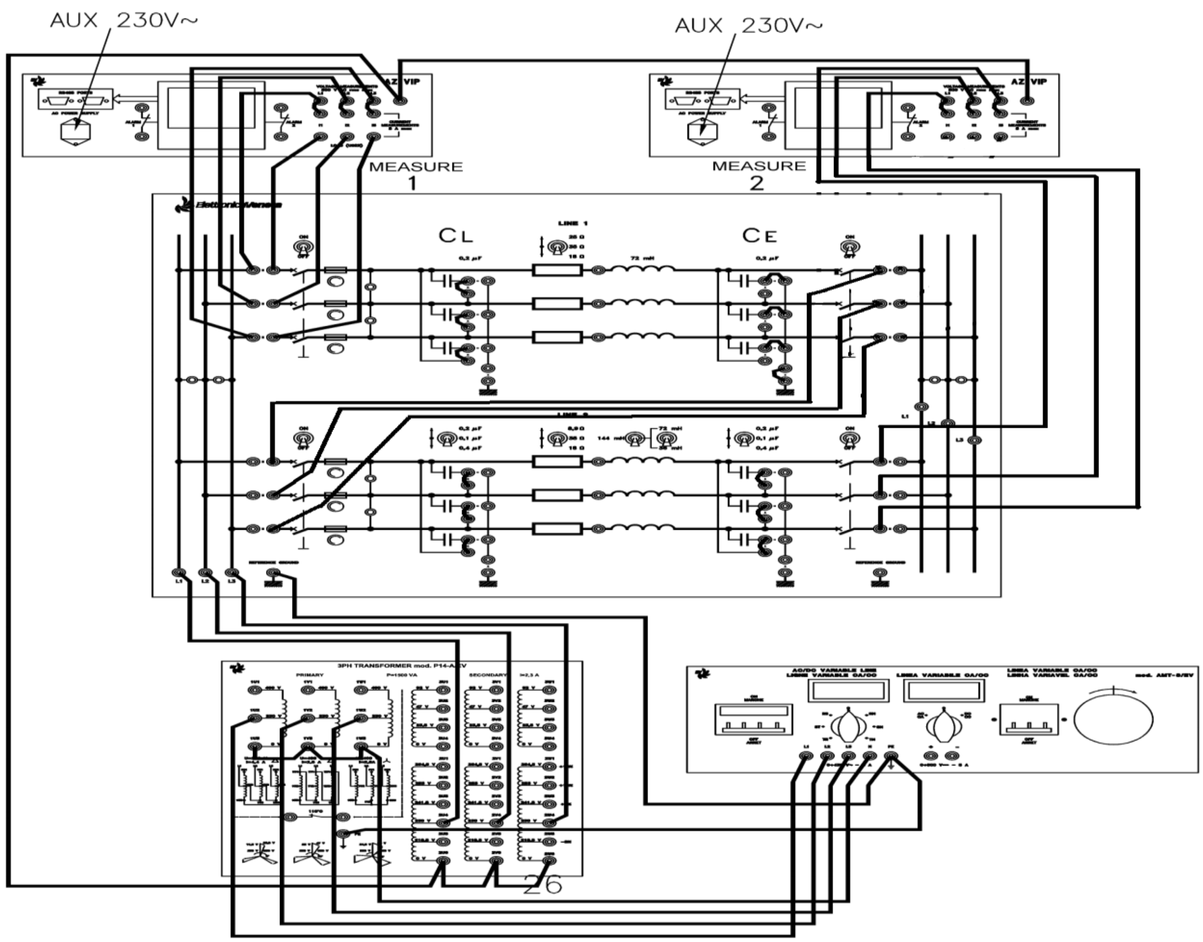


Figure (4)

Connection1:

1. Connect the capacitors at the sending end point of the LINE 1 in Δ-connection.
2. Connect the capacitors at the receiving end point of the LINE 1 in Y-connection.
3. Connect the capacitors at the sending end point of the LINE 2 in Δ-connection.
4. Connect the capacitors at the receiving end point of the LINE 2 in Y-connection.
5. Enable and adjust the voltage of the power supply at 360 V.

6. Turn the origin and end breakers of the LINE 1 to ON, in sequence, then turn the origin and end breakers of the LINE 2 to ON;
7. Read the electric quantities on the measuring instruments and write them down in the following table.

Sending End Voltage (Vs) (V)	Line Current (I) (mA)	Sending End Reactive Power (Q_s) (Var)	Sending End Active Power (P_s) (W)	Receiving End Voltage (V_R) (V)

Connection2:

1. Connect the capacitors at the sending end point of the LINE 1 in Δ-connection.
2. Connect the capacitors at the receiving end point of the LINE 1 in Δ-connection.
3. Connect the capacitors at the sending end point of the LINE 2 in Δ-connection.
4. Connect the capacitors at the receiving end point of the LINE 2 in Δ-connection.
5. Enable and adjust the voltage of the power supply at 360 V.
6. Turn the origin and end breakers of the LINE 1 to ON, in sequence, then turn the origin and end breakers of the LINE 2 to ON;
7. Read the electric quantities on the measuring instruments and write them down in the following table.

Sending End Voltage (Vs) (V)	Line Current (I) (mA)	Sending End Reactive Power (Q_s) (Var)	Sending End Active Power (P_s) (W)	Receiving End Voltage (V_R) (V)

Case 2: Long Transmission line under no load condition. (Study the Ferranti effect of a TL)

1. Consider four lines with equal current-carrying capacity, but different length, for this experiment, that is the
   Line 1 parameters are: R= 18 Ω; L= 72mH; C= 0.2μF; Length = 50 km;
   Line 2 parameters are: R = 36 Ω; L= 144mH; C= 0.4μF; Length = 100 km.
   Line 3 parameters are: R = 18 Ω; L= 72mH; C= 0.2μF; Length = 50 km. and
   Line 4 parameters are: R = 36 Ω; L= 144mH; C= 0.4μF; Length = 100 km.
2. Connect the circuit as shown in Figure 5.

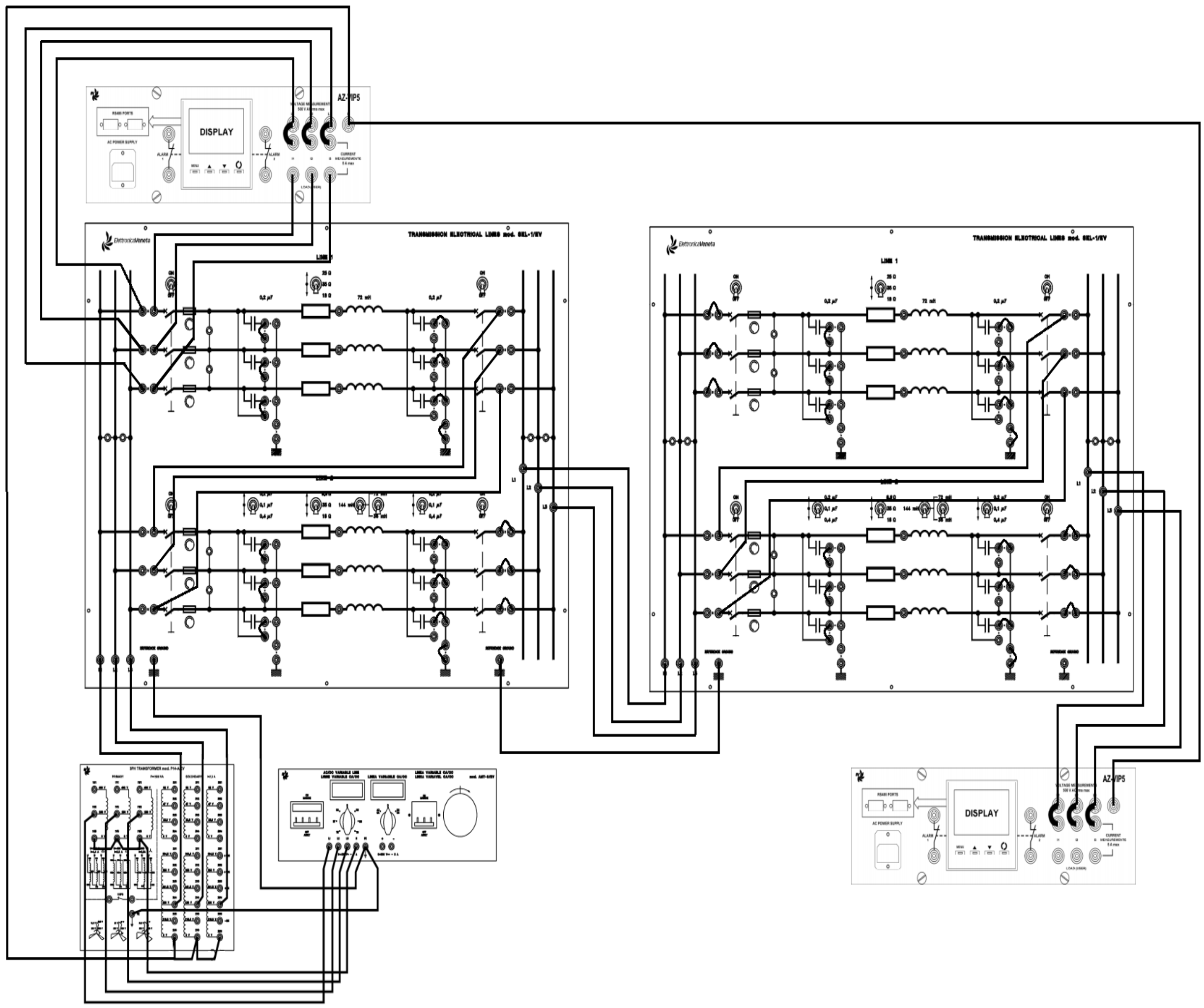


Figure (5)

3. Connect the capacitors at the sending end point of the LINES 1,2 ,3 and 4 in Δ-connection.
4. Connect the capacitors at the receiving end point of the LINES 1,2 ,3 and 4 in Y-connection.
5. Enable and adjust the voltage of the power supply at 360 V.
6. Turn the origin and end breakers of the LINE 1 to ON, in sequence, then turn the origin and end breakers of the LINE 2,3 and 4 to ON, in sequence.
7. Read the electric quantities on the measuring instruments and write them down in the following table.

Sending End Voltage (Vs) (V)	Line Current (I) (mA)	Sending End Reactive Power (Q_s) (Var)	Sending End Active Power (P_s) (W)	Receiving End Voltage (V_R) (V)

Questions:

1. Calculate the reactive power generated by the capacitors and compare it with the reactive power measured on the line:
   (a) (Part I – Connection 1);
   (b) (Part I – Connection 2);
   (c) (Part I – Connection 3);
   (d) (Part II – Case 1 – Connection 1);
   (e) (Part II – Case 1 – Connection 2);
   (f) (Part II – Case 2);

2. What is the cause of the increase voltage at the receiving end of the transmission line during no-load condition?

3. Explain the relation between the increasing of the length of transmission line and the receiving end voltage?

4. Draw the voltage profile of a medium and long TL under no-load condition and suggest a way to decrease the receiving end voltage (Part II)?

Experiment (2)	Performance of Transmission Line under different load conditions

Objectives:

1. To study the behavior of a power transmission line (short, medium and long) at different load conditions.
2. To determine the various electrical quantities at sending and receiving end for a loaded line.
3. To observe the flow of real and reactive power in a three phase transmission line under different load conditions.

Theory and concepts:

The important considerations in the design and operation of a TL are the determination of voltage drop, line losses and efficiency of transmission. These values are greatly influenced by line constants R, L and C of the TL. For instance, the voltage drop in the line depends upon the values of above three line constants. Similarly, the resistance of TL conductors is the most importance cause of power loss in the line and determines the transmission efficiency.

Percent Voltage Regulation

The voltage regulation of the line is defined by the increase in voltage when full load is removed, that is,

$$\text{Percentage of voltage regulation} = \frac{|\mathbf{V}_S| - |\mathbf{V}_R|}{|\mathbf{V}_R|} \times 100$$

or

$$\text{Percentage of voltage regulation} = \frac{|\mathbf{V}_{R,\text{NL}}| - |\mathbf{V}_{R,\text{FL}}|}{|\mathbf{V}_{R,\text{FL}}|} \times 100$$

Where:
$|\mathbf{V}_S|$ = magnitude of sending-end phase (line-to-neutral) voltage at no load
$|\mathbf{V}_R|$ = magnitude of receiving-end phase (line-to-neutral) voltage at full load
$|\mathbf{V}_{R,NL}|$ = magnitude of receiving-end voltage at no load
$|\mathbf{V}_{R,FL}|$ = magnitude of receiving-end voltage at full load with constant $|\mathbf{V}_S|$

Power

- Sending End Active Power: Ps= $\sqrt{3} * V_S * I_S * PF_S$
- Sending End Active Power: Qs= $\sqrt{3} * V_S * I_S * \sin(\phi)$
- Receiving End Active Power: P_R= $\sqrt{3} * V_R * I_R * PF_R$
- Receiving End Active Power: Q_R= $\sqrt{3} * V_R * I_R * \sin(\phi)$
- Transmission Losses: $P_{loss} = 3I^2R = Ps - P_R$ $Q_{loss} = 3I^2X = Qs - Q_R$

Efficiency:

$$\eta = \frac{\text{output}}{\text{input}} \qquad \eta = \frac{P_R}{P_S} \qquad \eta = \frac{\text{output}}{\text{output} + \text{losses}}$$

Necessary Material:

1. **SEL-1/EV:** Simulator of electric lines mod.
2. **AMT-3/EV:** Variable three-phase power supply mod.
3. **P14A/EV:** Three-phase transformer mod.
4. **RL-2/EV:** Variable resistive load mod.
5. **IL-2/EV:** Variable inductive load mod.
6. **CL-2/EV:** Variable capacitive load mod.

Experimental Procedures:

Part I: Study the performance of a short-TL under different load conditions.

1. Start this experiment considering the transmission LINE 2 with the following parameters: R= 8.9 Ω; L= 36 mH; C= 0.1 μF; Length = 25 km.
2. Connect with the variable three-phase power supply by inserting the three-phase insulation transformer.
3. Connect the capacitors at the sending end point of the LINE 2 in Δ-connection.
4. Connect the capacitors at the receiving end point of the LINE 2 in Y-connection.
5. Connect the circuit as shown in Figure 1.

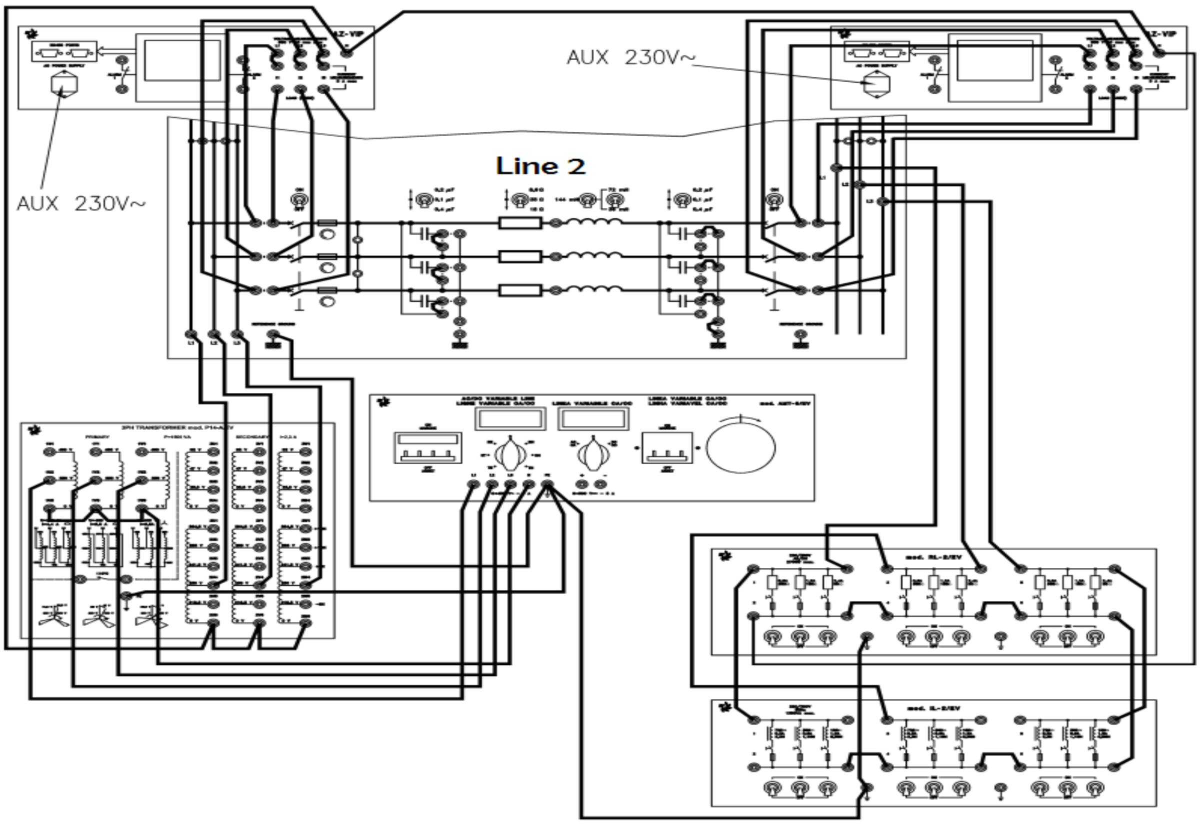


Figure (1)

Part I-1: Study the performance of the short-TL under resistive load.

1. Enable and adjust the voltage of the power supply at 350 V.
2. Turn the breakers at the origin and at the end of the LINE 2, to ON.
3. Connect the various steps of the resistive load (apply a balanced load using the same step for the three phases).
4. Read the electric quantities on the instruments and write them down in the following table.

Load	**Sending End quantities**					**Receiving End quantities**				
R-(Ω)	Vs	Is	Ps	Qs	PFs	V_R	I_R	P_R	Q_R	PF_R
No load	350									
A	350									
B	350									
A||B	350									

5. Calculate the Voltage drop, percentage voltage regulation, total power loss and the efficiency of the Transmission line.

R-(Ω)	Voltage drop VD	Voltage Regulation VR%	P_{losses}	Q_{losses}	Efficiency η
A					
B					
A||B					

Part I-2: Study the performance of the short-TL under Resistive-Inductive load.

1. Enable and adjust the voltage of the power supply at 350 V.
2. Turn the breakers at the origin and at the end of the LINE 2, to ON.
3. Connect the various steps of the resistive- inductive load (with different values of the inductive load).
4. Read the electric quantities on the instruments and write them down in the following table.

Load		Sending End quantities					Receiving End quantities				
RL		Vs	Is	Ps	Qs	PFs	V_R	I_R	P_R	Q_R	PF_R
A	A	350									
A	B	350									
A	A||B	350									

5. Calculate the Voltage drop, percentage voltage regulation, total power loss and performance of the Transmission line.

RL Load		Voltage drop VD	Voltage Regulation VR%	P_{losses}	Q_{losses}	Efficiency η
A	A					
A	B					
A	A||B					

Part I-3: Study the performance of the short-TL under Resistive-Capacitive load.

1. Enable and adjust the voltage of the power supply at 350 V.
2. Turn the breakers at the origin and at the end of the LINE 2, to ON.
3. Connect the various steps of the resistive-capacitive load (with different values of the capacitive load).
4. Read the electric quantities on the instruments and write them down in the following table.

Load		Sending End quantities					Receiving End quantities				
RC		Vs	Is	Ps	Qs	PFs	V_R	I_R	P_R	Q_R	PF_R
A	A	350									
A	B	350									

5. Calculate the Voltage drop, percentage voltage regulation, total power loss and performance of the transmission line.

RC load		Voltage drop VD	Voltage Regulation % VR%	P_{losses}	Q_{losses}	Efficiency η
A	A					
A	B					

Part II: Study the performance of the medium-TL under different load conditions.

1. Start this experiment considering the transmission LINE 2 with the following parameters: R= 36 Ω; L= 144 mH; C= 0.4 µF; Length = 100 km.
2. Connect with the variable three-phase power supply by inserting the three-phase insulation transformer,
3. Connect the capacitors at the sending end point of the LINE 2 in Δ-connection.
4. Connect the capacitors at the receiving end point of the LINE 2 in Y-connection.
5. Connect the circuit as shown in Figure 1.

Part II-1: Study the performance of the medium-TL under Resistive-Inductive load.

1. Enable and adjust the voltage of the power supply at 350 V.
2. Turn the breakers at the origin and at the end of the LINE 2, to ON.
3. Connect the various steps of the resistive-inductive load (with different values of the inductive load).

4. Read the electric quantities on the instruments and write them down in the following table.

Load		Sending End quantities					Receiving End quantities				
RL		Vs	Is	Ps	Qs	PFs	V_R	I_R	P_R	Q_R	PF_R
No load		350									
A	A	350									
A	B	350									
A	A||B	350									

5. Calculate the Voltage drop, percentage voltage regulation, total power loss and performance of the Transmission line.

RL load		Voltage drop	Voltage Regulation VR%	P_{losses}	Q_{losses}	Efficiency η
No load						
A	A					
A	B					
A	A||B					

Part II-2: Study the performance of the medium-TL under Resistive-Capacitive load.

1. Enable and adjust the voltage of the power supply at 350 V.
2. Turn the breakers at the origin and at the end of the LINE 2, to ON.
3. Connect the various steps of the resistive-capacitive load (with different values of the capacitive load).
4. Read the electric quantities on the instruments and write them down in the table shown below.

Load		Sending End quantities					Receiving End quantities				
RC		Vs	Is	Ps	Qs	PFs	V_R	I_R	P_R	Q_R	PF_R
A	A	350									
A	B	350									

5. Calculate the Voltage drop, percentage voltage regulation, total power loss and performance of the transmission line.

RC load		Voltage drop	Voltage Regulation VR%	P_{losses}	Q_{losses}	Efficiency η
A	A					
A	B					

Part III: Study the performance of the Long-TL under different load conditions.

1. Consider four lines with different length, for this experiment, that is the
   Line 1 parameters are: R= 18 Ω; L= 72mH; C= 0.2µF; Length = 50 km;
   Line 2 parameters are: R = 36 Ω; L= 144mH; C= 0.4µF; Length = 100 km.
   Line 3 parameters are: R = 18 Ω; L= 72mH; C= 0.2µF; Length = 50 km. and
   Line 4 parameters are: R = 36 Ω; L= 144mH; C= 0.4µF; Length = 100 km.
2. Connect with the variable three-phase power supply by inserting the three-phase insulation transformer,
3. Connect the capacitors at the sending end point of the LINES 1,2 ,3 and 4 in Δ-connection.
4. Connect the capacitors at the receiving end point of the LINES 1,2 ,3 and 4 in Y-connection.
5. Connect the circuit as shown in Figure 2.

Part III-1: Study the performance of the Long-TL under Resistive-Inductive load.

1. Enable and adjust the voltage of the power supply at 350 V.
2. Turn the breakers at the origin and at the end of the LINE 2, to ON.
3. Connect the various steps of the resistive-inductive load (with different values of the inductive load).
4. Read the electric quantities on the instruments and write them down in the following table.

Load		Sending End quantities					Receiving End quantities				
RL		Vs	Is	Ps	Qs	PFs	V_R	I_R	P_R	Q_R	PF_R
No load		350									
A	A	350									
A	B	350									
A	A||B	350									

5. Calculate the Voltage drop, percentage voltage regulation, total power loss and performance of the Transmission line.

RL Load		Voltage drop	Voltage Regulation VR%	P_{losses}	Q_{losses}	Efficiency η
No load						
A	A					
A	B					
A	A||B					

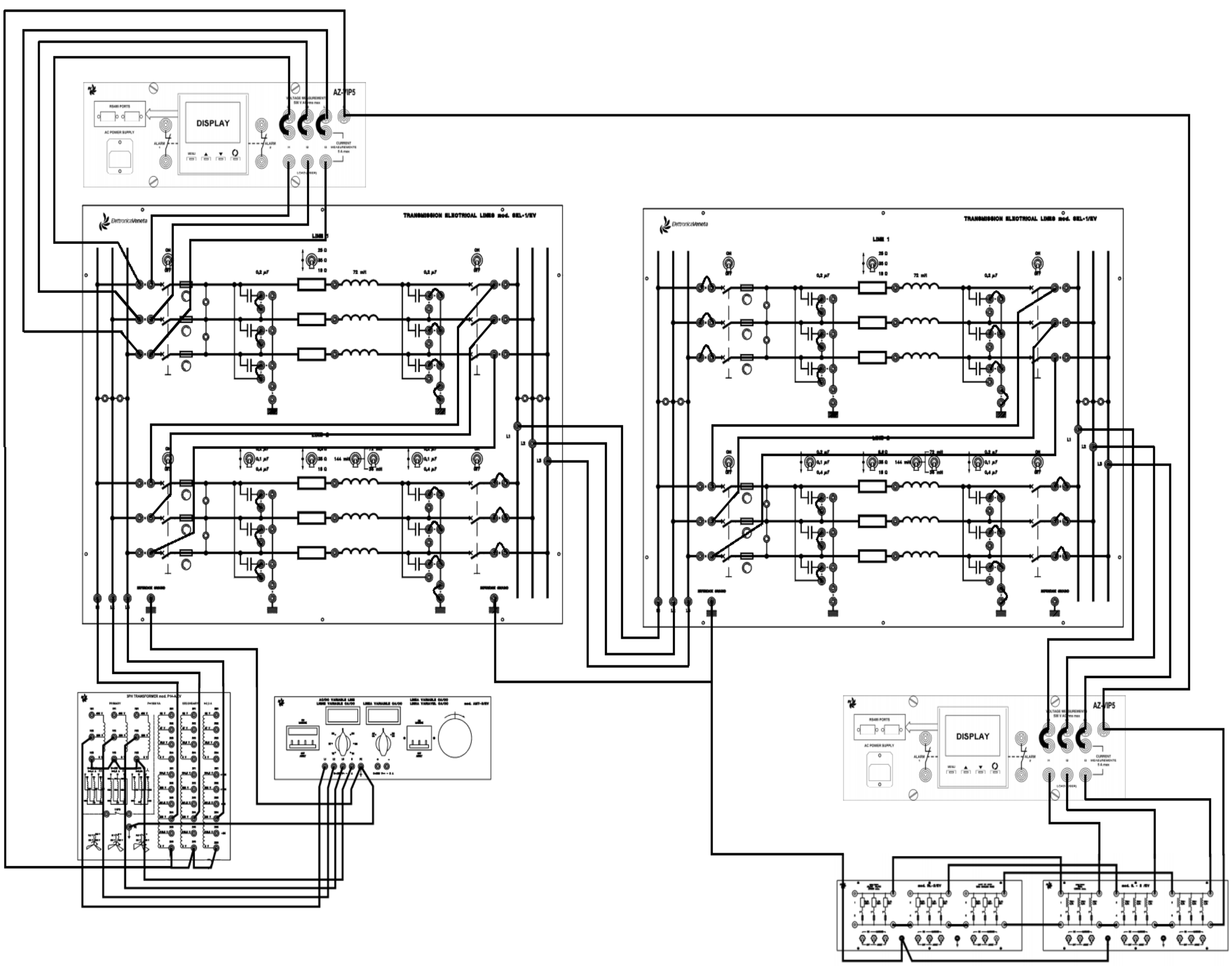


Figure (2)

Part III-2: Study the performance of the Long-TL under Resistive-Capacitive load.

1. Enable and adjust the voltage of the power supply at **320 V**.
2. Turn the breakers at the origin and at the end of the LINE 2, to ON.
3. Connect the various steps of the resistive-inductive load (with different values of the capacitive load).
4. Read the electric quantities on the instruments and write them down in the following table.

Load		**Sending End quantities**					**Receiving End quantities**				
RL		Vs	Is	Ps	Qs	PFs	V_R	I_R	P_R	Q_R	PF_R
No load		320									
A	A	320									
A	B	320									

5. Calculate the Voltage drop, percentage voltage regulation, total power loss and performance of the Transmission line.

RL Load		**Voltage drop**	**Voltage Regulation VR%**	P_{losses}	Q_{losses}	**Efficiency η**
No load						
A	A					
A	B					

Questions:

1. What does a positive/negative voltage regulation indicate?

2. For all load conditions (R, RL and RC) Explain and plot on the same graph the relation between (short, medium and long transmission lines):
   (a) Sending end voltage and sending end current (V_S versus I_S).
   (b) Receiving end voltage and current (V_R versus I_R).
   (c) Voltage drop and receiving end current (VD versus I_R).
   (d) Efficiency of transmission and receiving end current (η versus I_R).

3. What is the effect of load power factor on regulation and efficiency of a transmission line?

4. Draw the phasor diagram for the short TL (Part I) under:
   (a) Lagging PF Load;
   (b) Unity PF Load;
   (c) Leading PF Load.

5. Draw the phasor diagram for the medium TL (Part II) under:
   (a) Lagging PF Load;
   (b) Leading PF Load.

6. Determine the characteristic Impedance for the long TL (Part III)?

7. Draw the voltage profile for the Long TL under resistive – inductive load and suggest a way to increase the receiving end voltage under heavy load condition (Part III-1)?

Experiment (3)	Parallel Operation of Transmission Lines

Objectives:

1. To study the parallel behavior of the power transmission lines.
2. To study the Automatic mode of DBB system;
   - ☑ Simulate main line failure.
   - ☑ Simulate overloading main line.

Theory and concepts:

In order to guarantee continuity in the electrical power distribution service, very often, the "system" is built up with spare components that can be activated when needed. On this purpose, not only the generation machines and the transformers for the elevation/reduction of voltages, but also the most important power lines have a "reserve line". The parallel line, so, can be used to satisfy a power increase request, but very often it is used as reserve line to be used instead of the normal one to enable maintenance operations on the power line. Usually, the maintenance is programmed, that is, it is carried out in particular periods where the power request is lower. Besides the ordinary maintenance, the reserve line can be activated in case of faults on the normal line. In the exposed hypothesis, the study of the electrode is to be made on a single line except for the few instants the lines are set in parallel to prevent power interruption. In the following experiment, we will analyze the behavior of two lines in parallel between them in ordinary operation.

Necessary Material:

1. **DBB-2E/EV:** Simulator of electric lines mod.
2. **P14A/EV:** Three-phase transformer mod.
3. **RL-2/EV:** Variable resistive load mod.
4. **RL-2K/EV:** Inductive resistive load mod.
5. **IL-2/EV:** Variable inductive load mod.

Experimental Procedures:

Part I: Study the parallel behavior of the two power transmission lines.

1. In order to carry out the experiment, consider two equal 50-km lines having the following parameters: R= 18 Ω, L= 72 mH, C= 0.2 µF.
2. Turn the selector operation mode to **MANUAL**.
3. Connect the circuit as shown in Figure 1.

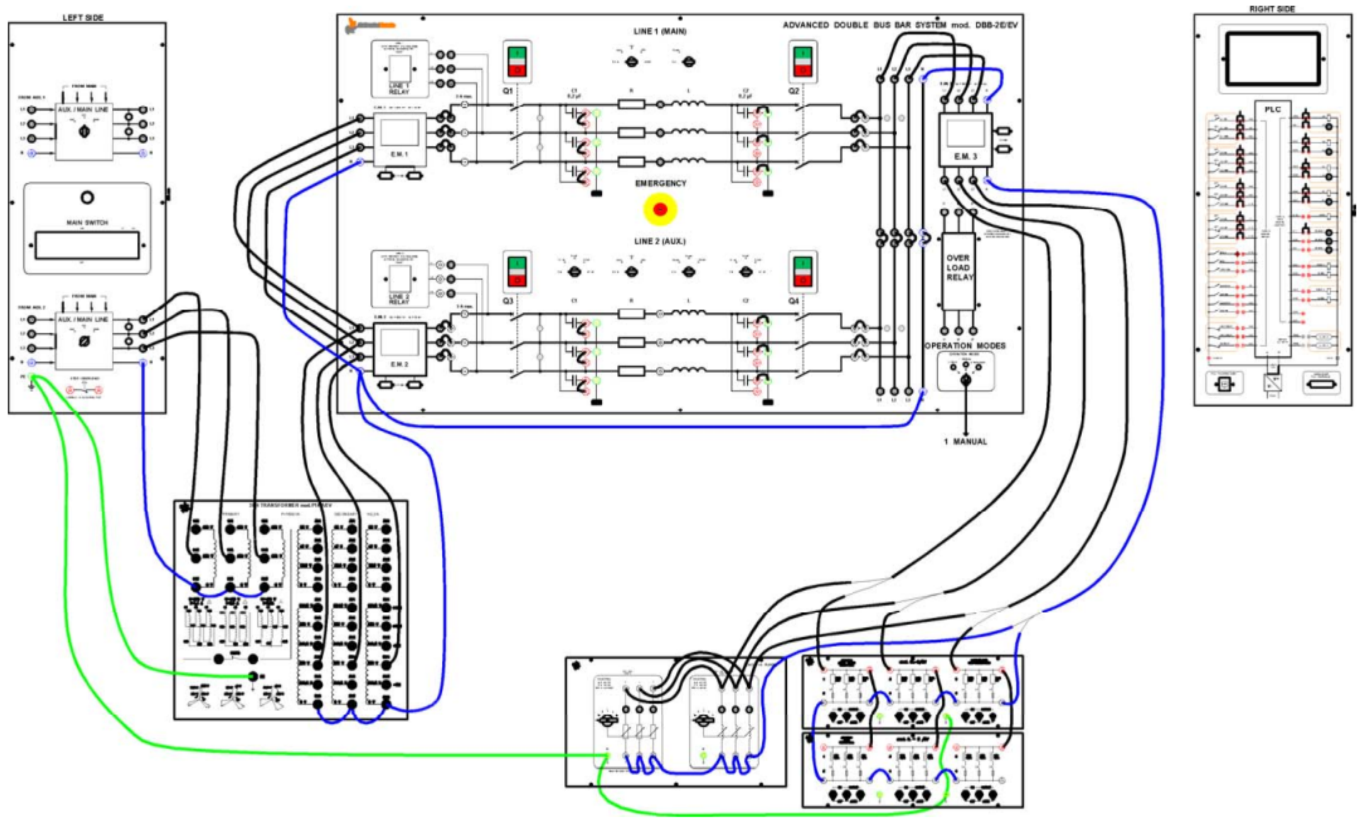


Figure (1)

4. Turn ON the main switch (left side panel).
5. Turn the lower selector AUX / MAIN LINE (left side panel) to MAIN.
6. Turn ON switch Q3 at the beginning of the line 2 and switch Q4 at the end of the line 2.
7. Turn the upper selector AUX / MAIN LINE (left side panel) to MAIN.
8. Turn ON switch Q1 at the beginning of the line 1 and switch Q2 at the end of the line 1.
9. Connect the various steps of the resistive load (apply a balanced load using the same step for the three phases).

10. Read the electric quantities on the instruments and write them down in the following table.

Load	**Line 2 – Auxiliary line (EM.2)**			**Line 1 – Main line (EM.1)**		**Load (EM.3)**	
R-(Ω)	V_{S1-2}	I_{S2}	P_{S2}	I_{S1}	P_{S2}	V_R	I_R
R1							
R2							
R3							

11. Calculate the Voltage drop, and performance of the transmission line.

Resistive Load	**Voltage drop VD**	**Efficiency η**
R1		
R2		
R3		

12. Disconnect one of the two lines in parallel and repeat the measurements, then calculate the Voltage drop, and performance of the transmission line.

Load	**Line 2 – Auxiliary line (EM.2)**			**Load (EM.3)**			**Voltage drop**	**Efficiency**
R-(Ω)	V_S	I_S	P_S	V_R	I_R	P_R	**VD**	**η**
R1								
R2								
R3								

Part II: Study the Automatic mode of DBB system.

In this Mode the Protection Relays are **fully operative,** and together with the PLC, they control the panel. Contactors Q1-Q2 (LINE 1) and Q3-Q4 (LINE 2) cannot be controlled manually with the red/green pushbuttons.

1. Start this experiment considering the transmission LINE 1 and LINE 2 with the following constants: R= 18 Ω, L= 72 mH, C= 0.2 µF, Length = 50 km.
2. Connect the circuit as shown in Figure 2.

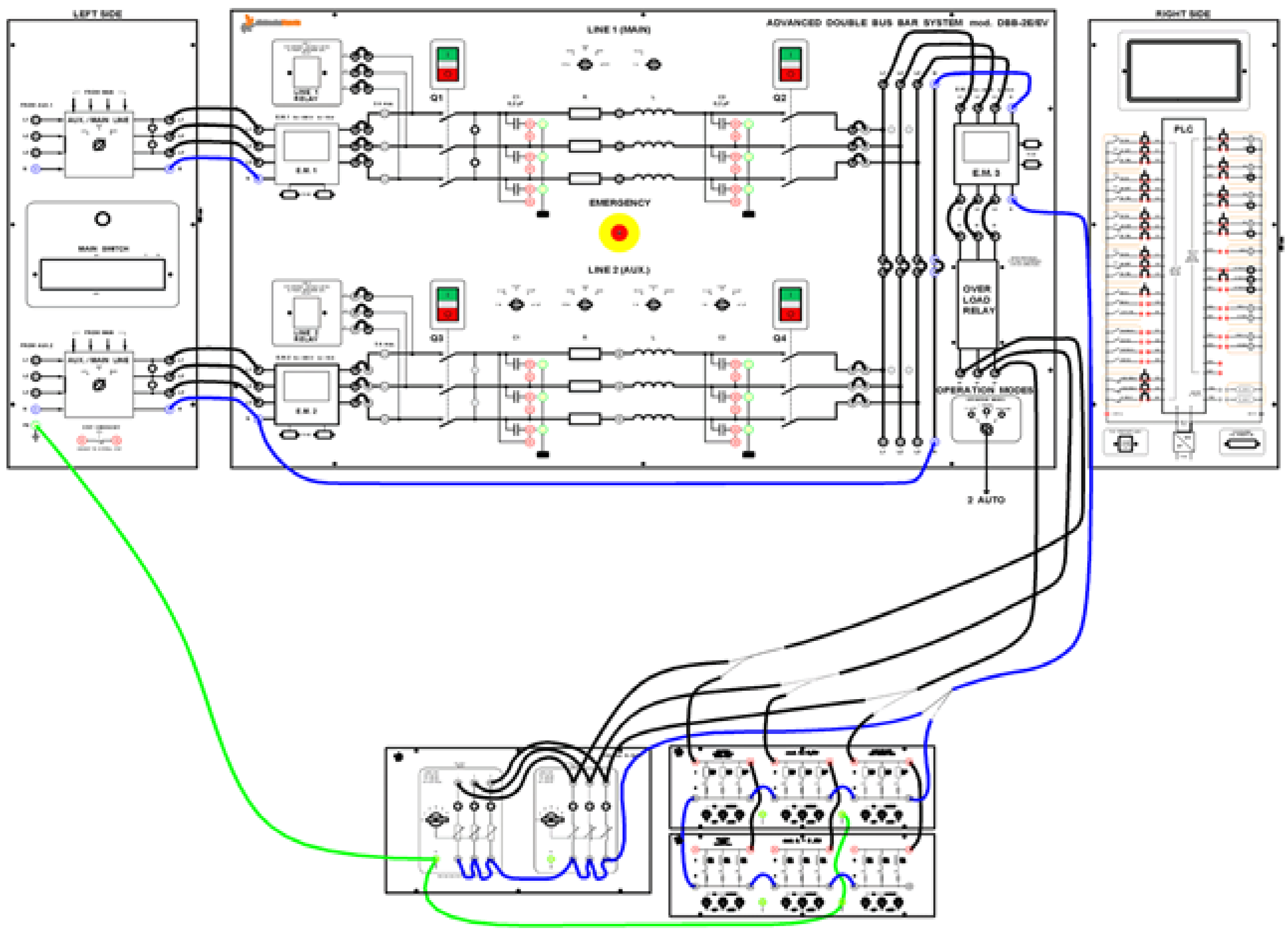


Figure (2)

3. Turn ON the main switch (left side panel).
4. Turn the lower selector AUX / MAIN LINE (left side panel) to MAIN.
5. Turn the upper selector AUX / MAIN LINE (left side panel) to MAIN.
6. Turn the selector operation mode to **AUTO**.

Part II-1: Main Line Normal Operation:

This implies the following conditions that should be fulfilled all simultaneously:

1. **LINE 1 RELAY:** should give its consensus to **close Q1**: there is voltage present in the MAINS and it is within the Max/Min preset range; the voltage sequence is correct and the Asymmetry among phases is within its limits.
2. **OL RELAY**: does not sense any current overload.
3. If above conditions are fulfilled, contactor **Q1 closes contactor Q2.**

Fill the following table:

Service Condition	Main Line			Auxiliary line			OL Relay
	Line 1 Relay	Q1	Q2	Line 2 Relay	Q3	Q4	
Normal operation							
Line Relay: (OK: there is voltage present) Contactors: (C: closed, O: open) OL Relay: (OK: does not senses any current overload)							

Part II-2: Main Line Failure:

The MAIN LINE becomes inoperative, and LINE 2 (AUX) becomes operative, replacing LINE 1 feeding the load.

1. Disconnect one phase of LINE 1.
2. **LINE 1 RELAY:** senses there is no voltage in LINE 1 and after a preset time (in the PLC) contactors **Q1 and Q2 are opened.**
3. **LINE 2 RELAY:** if there is voltage in LINE 2, this relay, via PLC, closes Q3 contactor. LINE 2 RELAY allows **Q3 to close if** there is voltage feeding LINE 2, the voltage is within the Max/Min preset range; the voltage sequence is correct and the Asymmetry among phases is within its limits.
4. After a preset time, and if there is no OL condition, the PLC **closes Q4**.
5. Now the load is fed from the AUX LINE.

Fill the following table:

Service Condition	Main Line			Auxiliary line			OL Relay
	Line 1 Relay	Q1	Q2	Line 2 Relay	Q3	Q4	
Main Line Failure							
Line Relay: (OK: there is voltage present) Contactors: (C: closed, O: open) OL Relay: (OK: does not senses any current overload)							

Part II-3: Main Line Restored:

The MAIN LINE becomes operative again, replacing LINE 2 feeding the load.

- **LINE 1 RELAY:** senses that again there is correct power in LINE 1.
- After a preset time (that confirms effectively the voltage presence in LINE 1), **contactors Q3 and Q4 are opened.**
- **Then Q1 is closed** and if there is no OL condition, **Q2 closes again**; the load is fed again from LINE 1.
- The system is returned back to state 1 (**Part II-1)**.

Service Condition	**Main Line**			**Auxiliary line**			**OL Relay**
	Line 1 Relay	**Q1**	**Q2**	**Line 2 Relay**	**Q3**	**Q4**	
Main Line Restored							
Line Relay: (OK: there is voltage present) Contactors: (C: closed, O: open) OL Relay: (OK: does not senses any current overload)							

Part II-4: Main Line Overloaded:

- Simulate the OL condition by connecting an external load so that the current is OVER the preset current limit of the OL RELAY.
- Reduce the current setting of the OL RELAY, by setting all current dip-switches to zero (the current setting is now 2.5 A).
- **Q2 opens**, but contactor **Q1 keeps closed**.
- As the **OL RELAY** has manual RESET, it is required to solve the OL condition before resetting the relay.

Service Condition	**Main Line**			**Auxiliary line**			**OL Relay**
	Line 1 Relay	**Q1**	**Q2**	**Line 2 Relay**	**Q3**	**Q4**	
Main Line Overloaded							
Line Relay: (OK: there is voltage present) Contactors: (C: closed, O: open) OL Relay: (OK: does not senses any current overload)							

Part II-5: Auxiliary Line Overloaded:

- The OL condition can be simulated similarly as explained in state 4 (**Part II-4**).
- Contactor **Q3 keeps closed**; but **Q4 opens**.
- As the OL RELAY has manual RESET, it is required to solve the OL condition before resetting the relay.

Service Condition	Main Line			Auxiliary line			OL Relay
	Line 1 Relay	Q1	Q2	Line 2 Relay	Q3	Q4	
Auxiliary Line Overloaded							
Line Relay: (OK: there is voltage present) Contactors: (C: closed, O: open) OL Relay: (OK: does not senses any current overload)							

Questions:

1. For the two cases (Double TL and Single TL) (Part I) Explain and plot the relation between:
   (a) Receiving end voltage and current (V_R versus I_R).
   (b) Sending end active power and receiving end current (P_S versus I_R).
   (c) Voltage drop and receiving end current (VD versus I_R).
   (d) Efficiency of transmission and receiving end current (η versus I_R).

2. How the currents distribute in the two transmission lines?

3. What are the advantages and disadvantages of parallel transmission?

Experiment (4)	Transmission line in condition of SLG fault

Objectives:

1. To study the behavior of a power transmission line with insulated neutral in condition of ground fault.
2. To study the behavior of a power transmission line with compensated neutral conductor (Peterson coil) in condition of ground fault.

Theory and concepts:

Ungrounded (insulated) system:

In an electrical system insulated from ground (ungrounded), the SLG fault current goes back across the ground capacitors of the phases (C_E) and consequently its value is not very high. In the systems with insulated neutral, Figure1, the ground fault current increases with the ground capacitance (C_E), the capacitance to ground (C_E) is higher for the cable lines so much that in case of much extended networks, the ground current reaches values of hundreds of ampere.

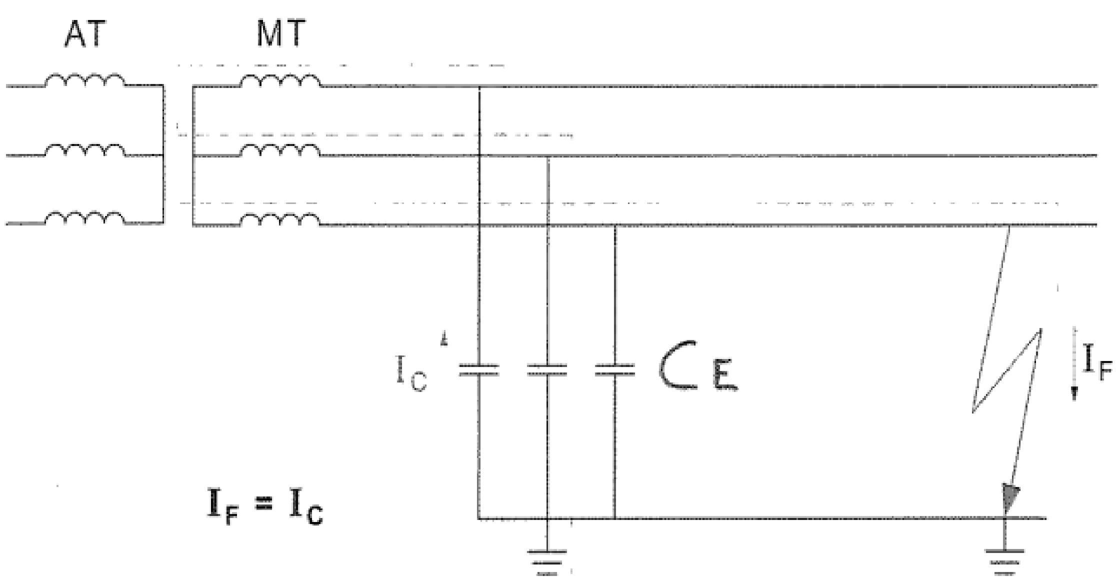


Figure (1)

Reactance grounded system:

An alternative to the insulated neutral is its grounding made using an inductance (Peterson coil, or arc-suppression coil). The operating principle of Petersen coil is shown in the Figure. 2 where the resistance R_N represents the ground resistance of the station and the set of capacitors C_E represents the ground capacitance of each sound phase. The single-phase ground fault current I_F will result from the sum of the currents I_L crossing the coil, and I_C closing through the capacitance of the phases not suffering ground fault. Choosing the value of the inductance L so that the component I_L is equal to the component I_C, as they are out of phase of 180°, will lead to $I_F = 0$ (condition of compensation or resonance).

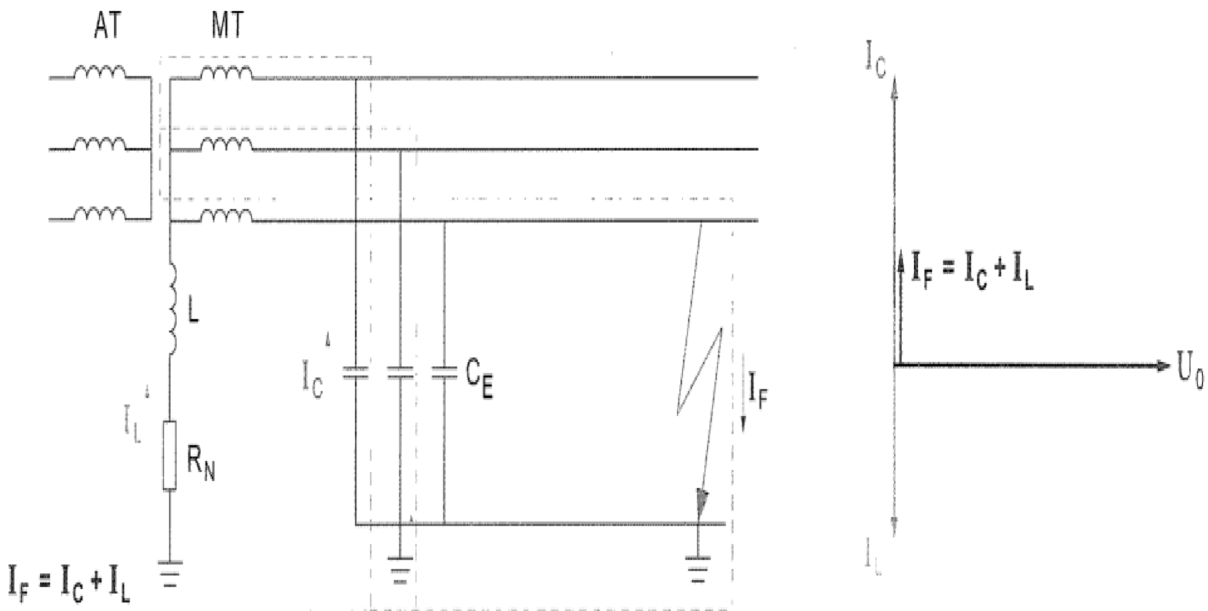


Figure (2)

Necessary Material:

1. **SEL-1/EV:** Simulator of electric lines mod.
2. **P14A/EV:** Three-phase transformer mod.
3. **AMT-3/EV:** Variable three-phase power supply mod.
4. **IL-2/EV:** Variable inductive load mod.
5. **RL-2K/EV:** Inductive resistive load mod.

Experimental Procedures:

Part I: Study the behavior of power transmission line with insulated neutral in condition of SLG fault.

1. Consider and set the LINE 2 with the following constants: R= 18 Ω; L= 72 mH; C_{ES}= 0.1 and C_{ER}= 0.1 μF; Length= 50 km.
2. Connect the circuit as shown in Figure 3.

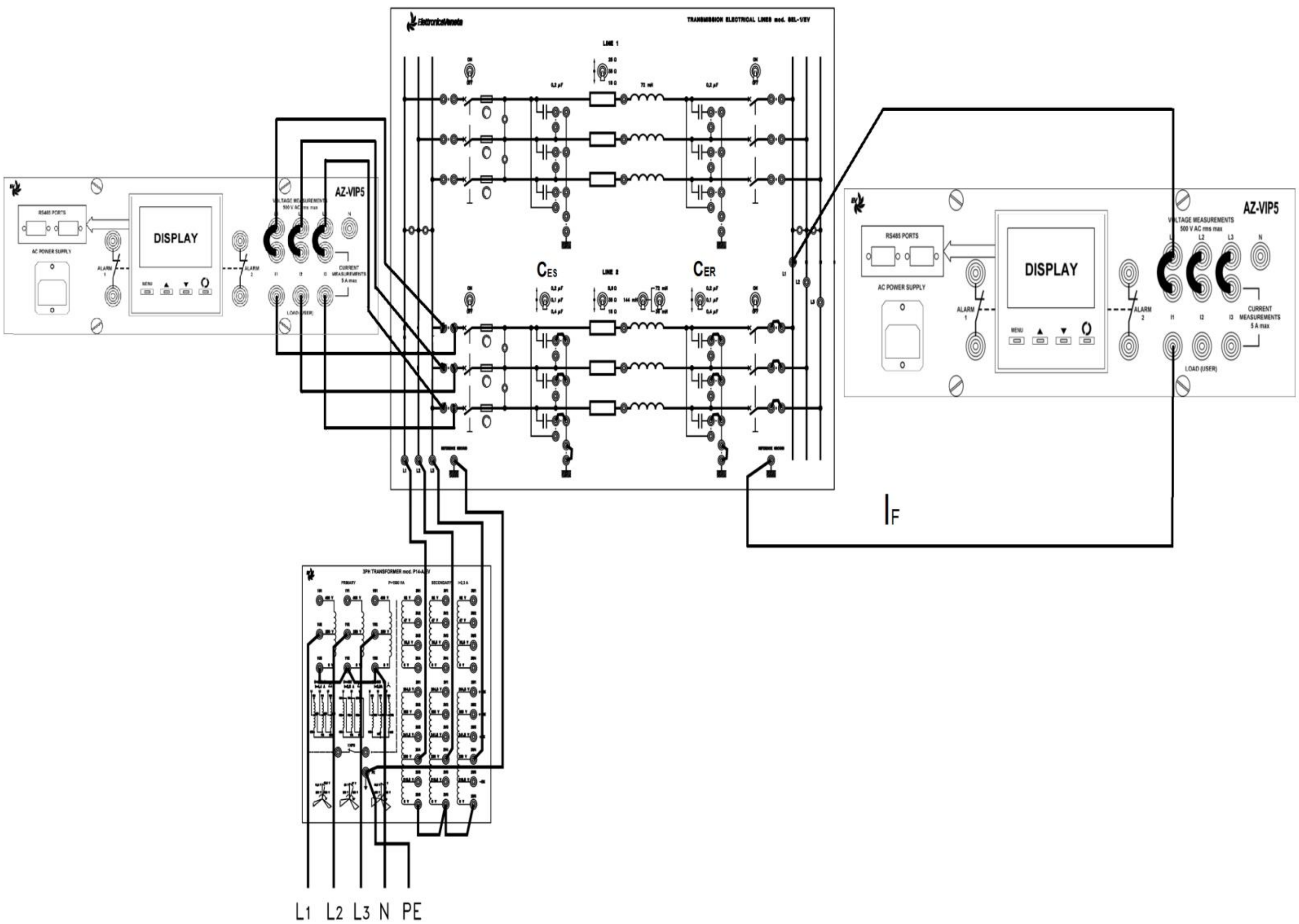


Figure (3)

3. Enable and adjust the voltage of the power supply at 380 V.
4. Turn the origin and end breakers of the LINE 2 to ON, in sequence.
5. Change the capacitors value C_{Es} and C_{ER} and tabulate your results in the following table.

Sending end C_{ES} and receiving end C_{ER} capacitors (μF)		Total Capacitance (μF)	Sending end Voltage (V)	Ground fault current (mA)
C_{ES} (μF)	C_{ER} (μF)	$C_{total} = C_{ES} + C_{ER}$	Vs	I_F
0.1	0.1	0.2	380	
0.1	0.2	0.3	380	
0.2	0.2	0.4	380	
0.1	0.4	0.5	380	
0.2	0.4	0.6	380	
0.4	0.4	0.8	380	

Part II: Studying the operation of a power transmission line with compensated neutral conductor (Peterson coil) in condition of SLG fault.

1. Consider and set the LINE 2 with the following constants: R= 18 Ω; L= 72 mH; C_{ES}= 0.2 and C_{ER}= 0.2 μF; Length = 50 km.
2. Connect the circuit as shown in Figure 4.

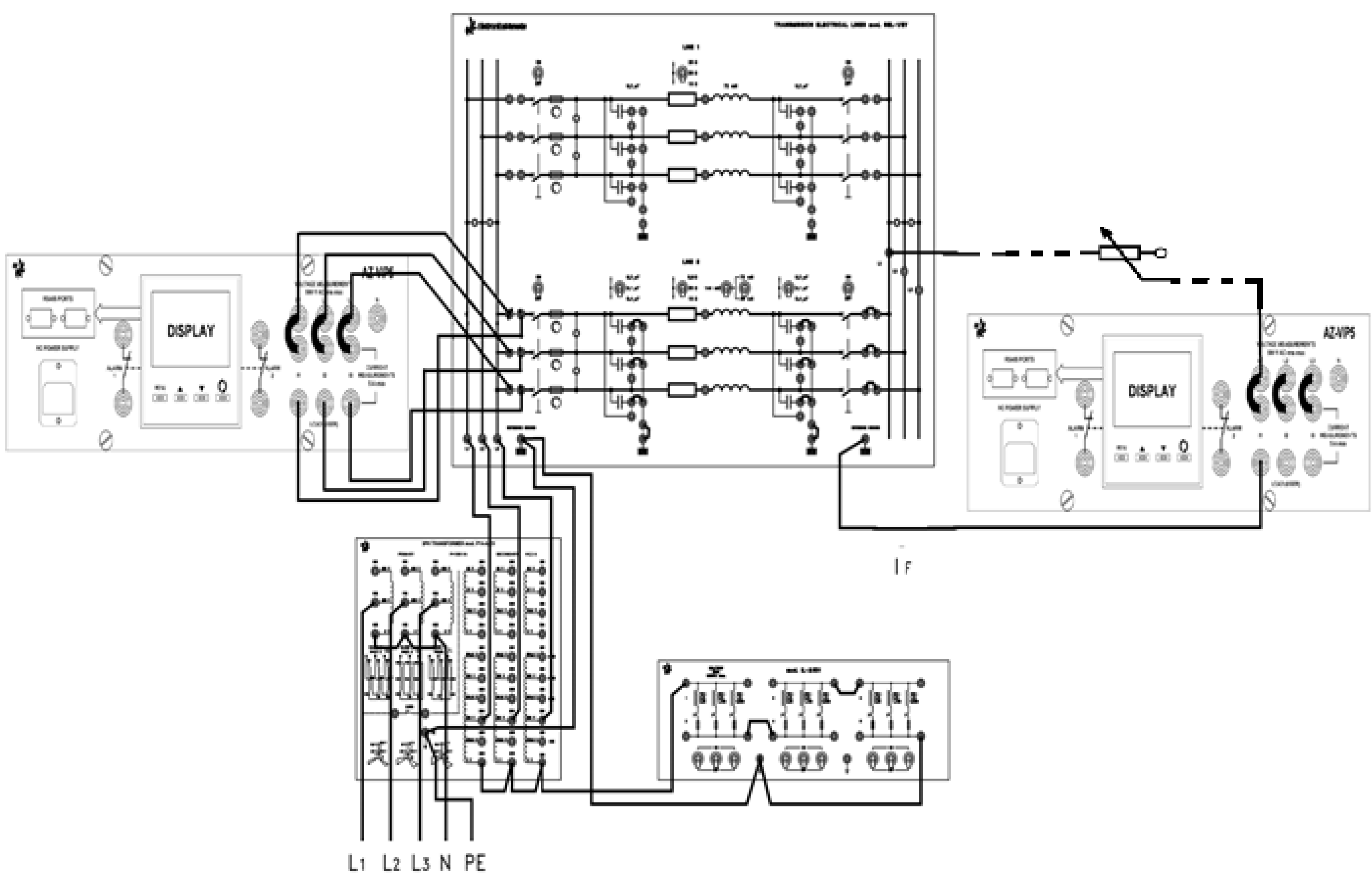


Figure (4)

3. Enable and adjust the voltage of the power supply at 380 V.
4. Turn the origin and end breakers of the LINE 2 to ON, in sequence.
5. Modify the value of inductance selecting among those available in the inductive load and carry out the ground fault again, read the crossing fault current on the multimeter and tabulate the results in the following table.
6. Now carry out a ground fault with a resistor in series (non free fault) with (R_1) 540Ω, read the crossing fault current on the multimeter and tabulate the results in the following table.

Inductance of the compensation coil (H)	**Total Capacitance (µF)**	**Sending end Voltage (V)**	**Ground fault current (mA) (free)**	**Ground fault with a resistor (mA)**
L	$C_{total} = C_{ES} + C_{ER}$	Vs	I_F	I_{FR}
(C,C,C) = 1.74	0.4	380		
(B,C,C) = 2.30	0.4	380		
(A,C,C) = 3.46	0.4	380		
(A,B,C) = 4.03	0.4	380		
(A,A,C) = 5.18	0.4	380		
(A,A,B) = 5.75	0.4	380		
(A,A,A) = 6.90	0.4	380		

7. Change the value of C_{total} to 0.8 µF (C_{ES}= 0.4, C_{ER}= 0.4) then insert the data obtained with the measurements in the following table:

Inductance of the compensation coil (H)	**Total Capacitance (µF)**	**Sending end Voltage (V)**	**Ground fault current (mA)**	**Ground fault with a resistor (mA)**
L	$C_{total} = C_{ES} + C_{ER}$	Vs	I_F	I_{FR}
(C,C,C) = 1.74	0.8	380		
(B,C,C) = 2.30	0.8	380		
(A,C,C) = 3.46	0.8	380		
(A,B,C) = 4.03	0.8	380		
(A,A,C) = 5.18	0.8	380		
(A,A,B) = 5.75	0.8	380		
(A,A,A) = 6.90	0.8	380		

Questions:

1. Plot a graph to show the behavior of the ground fault current according to the value of the line to ground capacitance (I_F versus C_{total}) (Part I).

2. What is the main objective for determining the ground fault current of the system with insulated neutral conductor (Part I)?

3. Which value of the compensation coil gives the best result (Part II)?

4. Explain the effect of increasing the value of Peterson coil on the fault current (Part II)?

5. Plot figures that show the relation between the fault current and the inductance compensating inductor for different values of capacitance (I_F versus L) (Part II).

6. Compare between the behavior of a power transmission line with compensated neutral conductor and power transmission line with insulated neutral in condition of SLG fault.

7. Explain the effect of inserting resistor in series with the faulted line (SLG fault through resistor)?

Experiment (5)	Protection of Transmission lines

Objectives:

1. Protection against overcurrents in a power transmission line using overcurrent relay SR1/EV.
2. To configure the protection device SR16/EV with the use of the DIGSI software as:
   - ☑ Instantaneous [50] and delayed [51] maximum current relay to protect a no-load power transmission line against phase-phase faults.
   - ☑ Instantaneous [50N] and delayed [51N] maximum homopolar current relay to protect a no-load power transmission line against phase-ground faults.
   - ☑ Max ground directional current relay [67N], to protect a no-load power transmission line against phase-ground faults.
   - ☑ Distance relay [21], protection against phase-ground and phase-phase fault in a no-load power transmission line.

Theory and concepts:

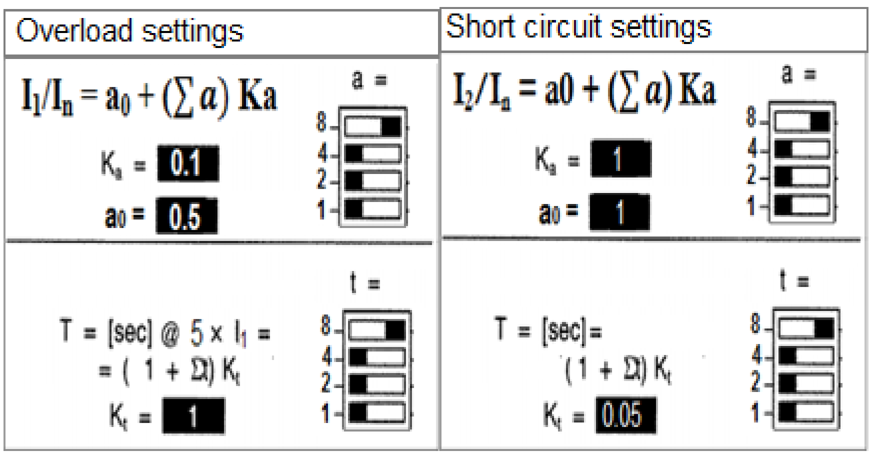
Sometimes the current crossing the conductors of a power transmission line may be higher than the rated current. These situations occur when the line is overloaded, because too many users are connected with the line or some users require greater power at the same time, and when there are short circuits due to breaks in the supports of bare conductors or to insulation losses between active conductors. An overload occurs when the line is crossed by a current exceeding the rated current (generally it is approximately 10 times as high); this provokes the overheating of conductors and devices, and it can be borne for a certain time. The current/time relation may be fixed: when a certain current value is exceeded, after a certain time of tolerance the protection relay will control the power device (switch) to put the line out of commission. But this protection ratio may also be of inverse time/current type where a shorter intervention time corresponds to a higher current. Short circuits generate a very strong current with thermal and mechanical phenomena and destructive electric arcs, therefore the reaction time of the protection relay must be instantaneous. The Impedance Relay (IR) is one of the most important protection relays against short circuits. It is mainly used when the current overload relays do not provide adequate protection; these relays can work even when the short circuit current is low and the overload relays could not operate safely. Additionally, the speed operation of the IR is independent from the short circuit current value. Basically, it is a relay that senses the current and voltage of the protected device. With these values, the IR calculates the impedance

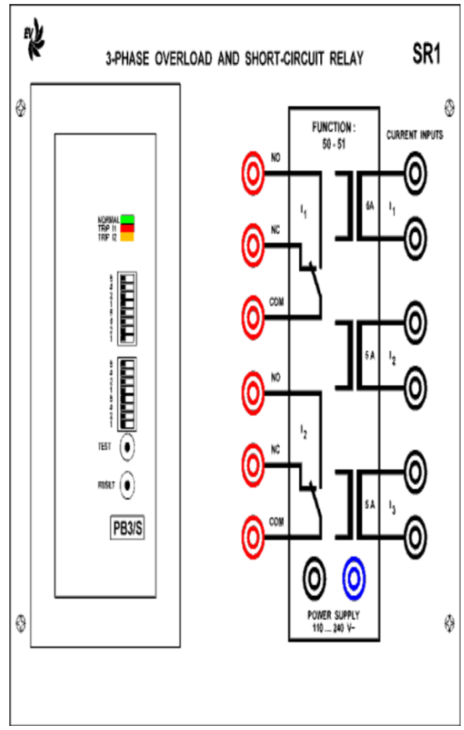
Z of the device. The IR compares the real impedance Z of the protected device against Z_0; if Z is equal or less tan Z_0, it means that a failure has occurred (could be a solid or not short-circuit). When the measured impedance of the protected device Z_{med} is greater or equal to Z_0, it is the normal condition. **In the opposite case, the protected device is in abnormal condition, and the IR will trip.**

SR1-EV Max current three-phase relay description:

Three-phase maximum-current (overload and short-circuit) relay at definite time and three-phase short-circuit.

Overcurrent Relay settings/Current and time settings (overload and short circuit):





Necessary Material:

1. **SEL-1/EV:** Simulator of electric lines mod.
2. **P14A/EV:** Three-phase transformer mod.
3. **Contactor** with On-Off control
4. **AMT-3/EV:** Variable three-phase power supply mod.
5. **SR-1/EV:** Overcurrent relay.
6. **IL-2/EV:** Variable inductive load mod.
7. **RL-2K/EV:** Inductive resistive load mod.
8. **PC** with **DIGSI** software installed.
9. **SR16/EV**: Distance relay mod.
10. **SR20/EV:** Power transmission line simulator mod.
11. **SR21/EV:** Isolation transformer mod.
12. **UAT/EV:** Fixed Power supply mod.
13. **RC3-PT/EV:** Rheostat mod.

Experimental Procedures:

Part I: Protection against overcurrents in a power transmission line using overcurrent relay SR1.

1. Start this experiment considering the LINE 2 with the following constants: R= 8.9 Ω; L = 36 mH C = 0.1 µF; Length = 25 km.
2. Connect the circuit as shown in Figure 1.

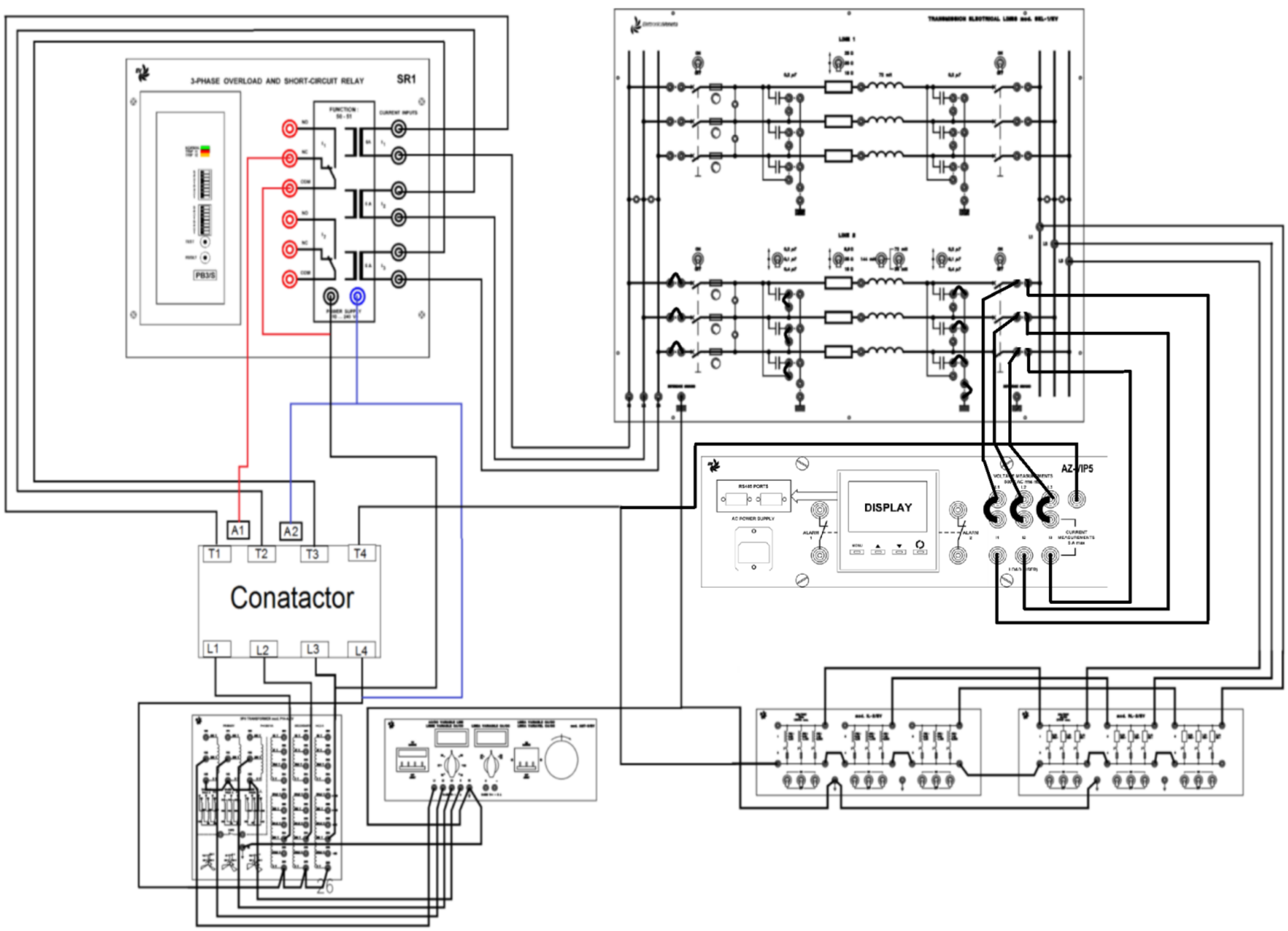


Figure (1)

3. Enable and adjust the voltage of the power supply at 380 V.
4. Turn the breaking-control switches at the origin and at the end of the LINE 2 to ON.
5. Adjust the SR-1/EV settings as required.
6. Start to add different values of the resistive-inductive load in steps; then insert the data obtained with the measurements in the following table:

Load	Settings of the overload relay		Line current (mA)	Tripping time (sec)
R-(Ω)	$I_{setting}$ (A)	T (sec)	I_{line}	T
A	0.5	5		
B	0.5	5		
A || B	0.6	5		

Part II: Configuration of SR16 as maximum current relay [50], [51], [50N] and [51N]

1. Perform the electrical connections following the electrical diagram of figure 2 and 3.

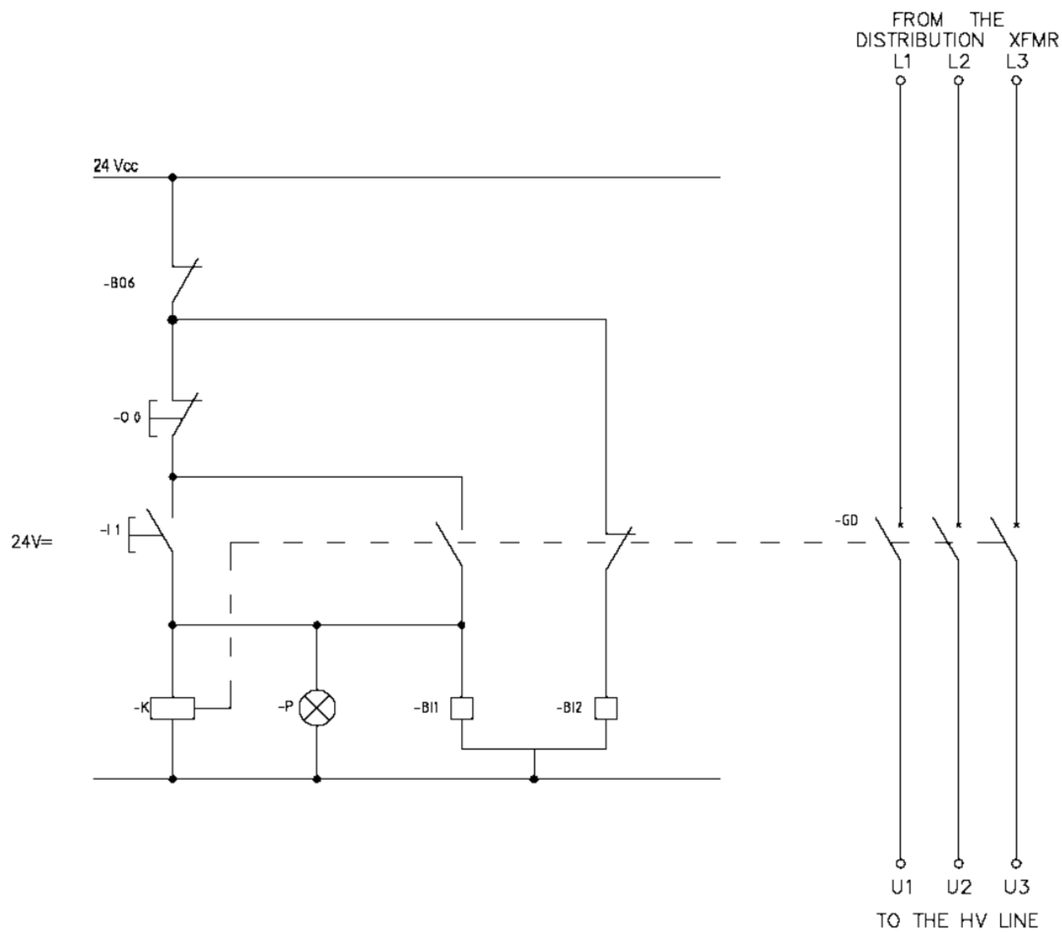


Figure (2)

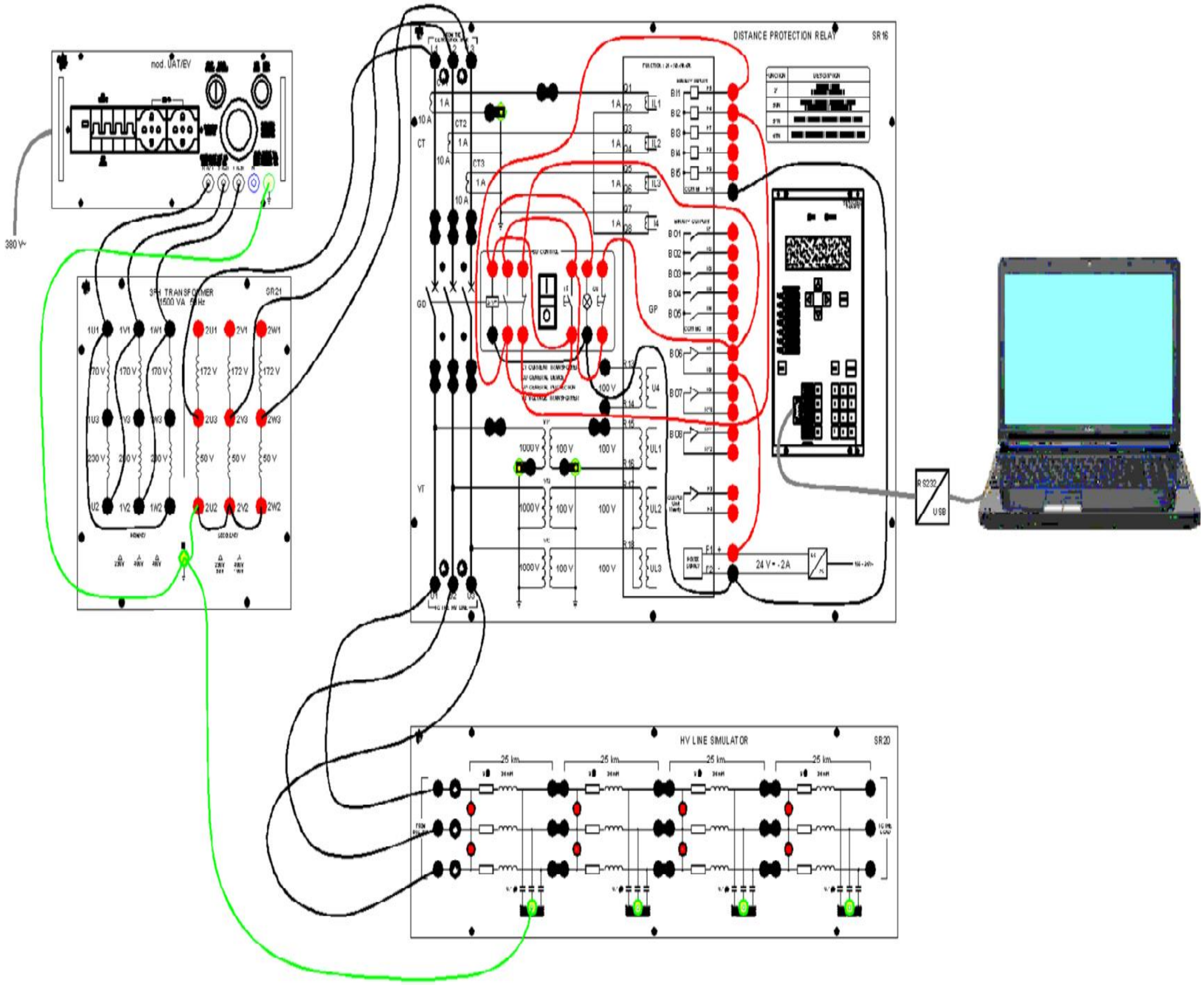


Figure (3)

2. Set the Parameters of the protection device SR16/EV and power system data using DIGSI software as follows:

(A) Power System Data 1:

1. Rated primary voltage [No. 203] = 1 kV
2. Rated secondary voltage [No. 204] = 100 V
3. CT Rated primary current [No. 205] = 10 A
4. CT Rated secondary current [No. 206] = 1 A

(B) Setting Group A – Power System Data 2:

1. Measurement: Full Scale Voltage (100%) [No. 1103] = 1 kV
2. Measurement: Full Scale Current (100%) [No. 1104] = 100 V
3. Line Angle [No. 1105] = 85^o
4. X'-Line reactance per length unit [No. 1110] = 0.4522
5. Line length [No. 1111] = 100 km

(C) Setting Group A – Backup Overcurrent:

***(a)* General :**

1. Operating mode [No. 2601] = ON, Always Active

***(b)* Setup the protection parameters [50]:**

1. Click on I>> ;
2. Pick up current [No. 2610: I_{ph}>>Pickup] = 0.3 A
3. Time delay [No. 2611: T I_{ph}>>Time delay] = 0 Sec (Instantaneous intervention).

***(c)* Setup the protection parameters [50N]:**

1. Click on I>>;
2. Pick up current [No. 2612: $3I_0$>>Pickup] = 0.1 A
3. Time delay [No. 2613: T $3I_0$>>Time delay] = 0 Sec (Instantaneous intervention).

***(d)* Setup the protection parameters [51]:**

1. Click on I>;
2. Pick up current [No. 2620: I_{ph} >>Pickup] = 0.1 A
3. Time delay [No. 2621: T I_{ph}>>Time delay] = 2 Sec.

***(e)* Setup the protection parameters [51N]:**

1. Click on I>;
2. Pick up current [No. 2622: $3I_0$>>Pickup] = 0.07 A
3. Time delay [No. 2623: T $3I_0$>>Time delay] = 2 Sec.

(D) Configuration matrix (Masking I/O):

1. P. System Data 2

(a) CB 3p Closed [No. 00379] → BI1 (Binary input 1) → H (High)→ Led (1) : U (Unlatched)
(b) CB 3p Open [No. 00380] → BI2 (Binary input 2) → H (High) → Led (2) : U (Unlatched)
(c) Relay TRIP [No. 00511] → BO6 (Binary output 6) → U (Unlatched)

2. Back-Up O/C

(a) O/C TRIP I>> [No. 07221] → Led (4) : L (latched)
(b) O/C TRIP I> [No. 07222] → Led (5) : L (latched)

3. Turn ON the power supply mod. UAT/EV
4. Push the NO button 1I on panel mod. SR16/EV.

Part II-1: Phase – Phase Fault

1. Connect the T.M.C.B. between 2 phases, as shown in figure 4.
2. Turn ON the switch to perform a phase-phase fault, respectively at 25, 50, 75 and 100 km.
3. Measure the fault current with **SIGRA** program.

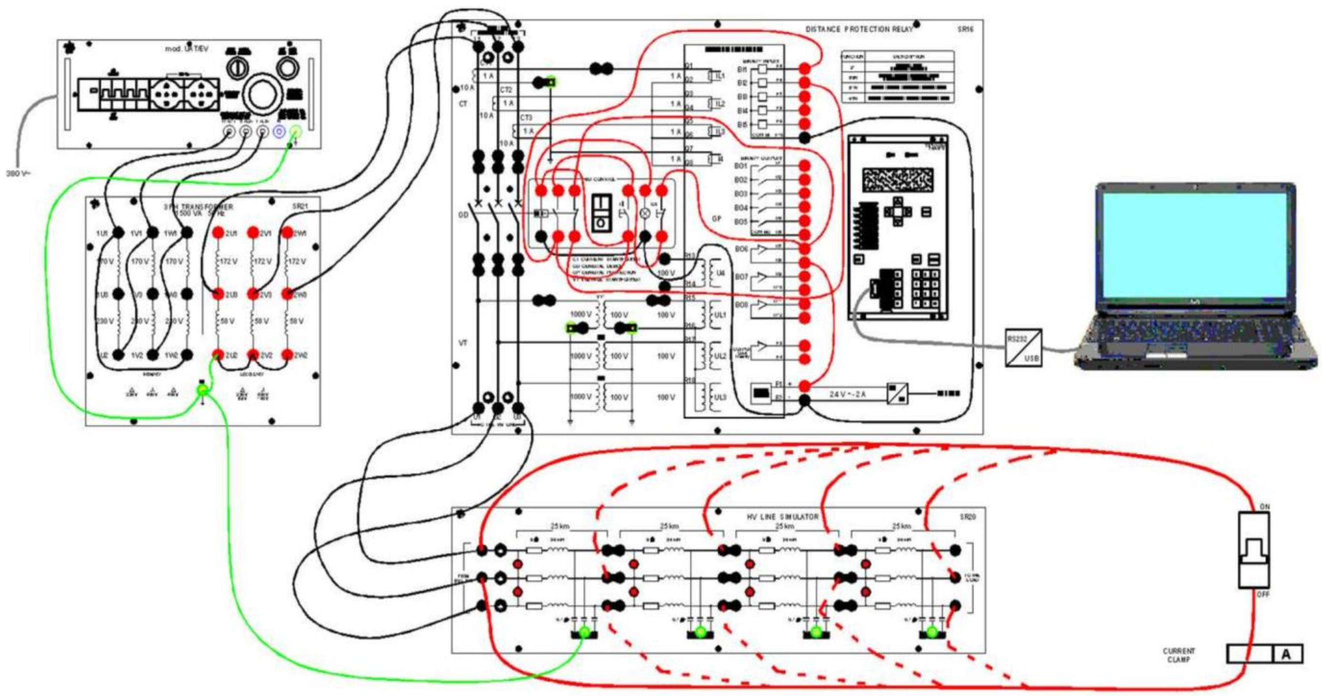


Figure (4)

4. Insert the data obtained with the measurements in the following table:

Phase – Phase Fault					
PH-PH fault	**Line (km)**	**T start (ms)**	**T trip (ms)**	**Fault Current (A)**	**Protection intervetion**
L1 – L2	100				
L2 – L3	75				
L3 – L1	50				
L1 – L2	25				

Part II-2: Phase – Ground Fault

1. Connect the T.M.C.B. between the phase and ground, as shown in figure 5.
2. Turn ON the switch to perform a phase-ground fault, respectively at 25, 50, 75 and 100 km.
3. Measure the fault current with **SIGRA** program.

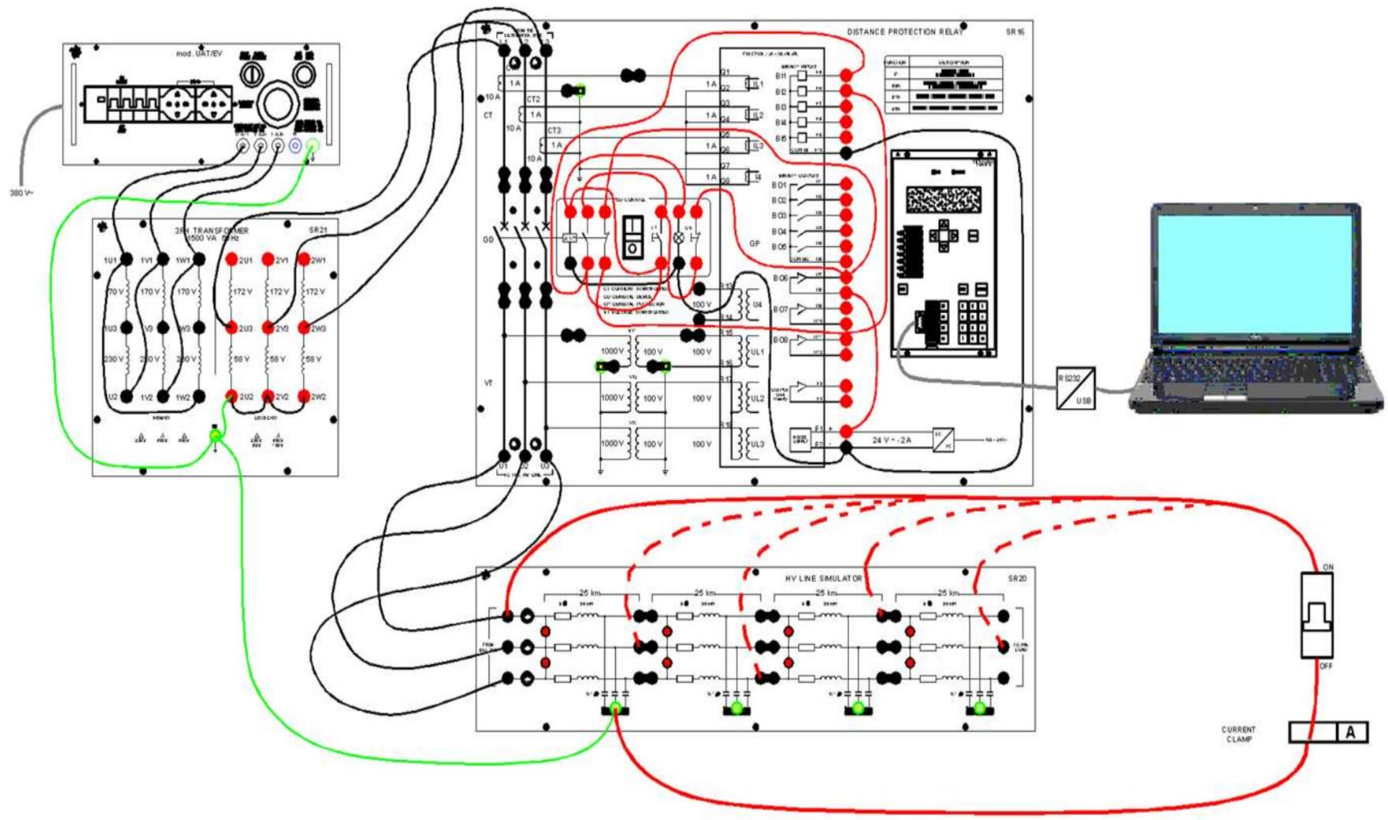


Figure (5)

4. Insert the data obtained with the measurements in the following table:

Phase – ground Fault					
PH-E fault	**Line (km)**	**T start (ms)**	**T trip (ms)**	**Fault Current (A)**	**Protection intervetion**
L1 – E	100				
L2 – E	75				
L3 – E	50				
L1 – E	25				

Part III: Configuration of SR16 as maximum ground directional current relay [67N]

1. Perform the electrical connections following the electrical diagram of figure 6.

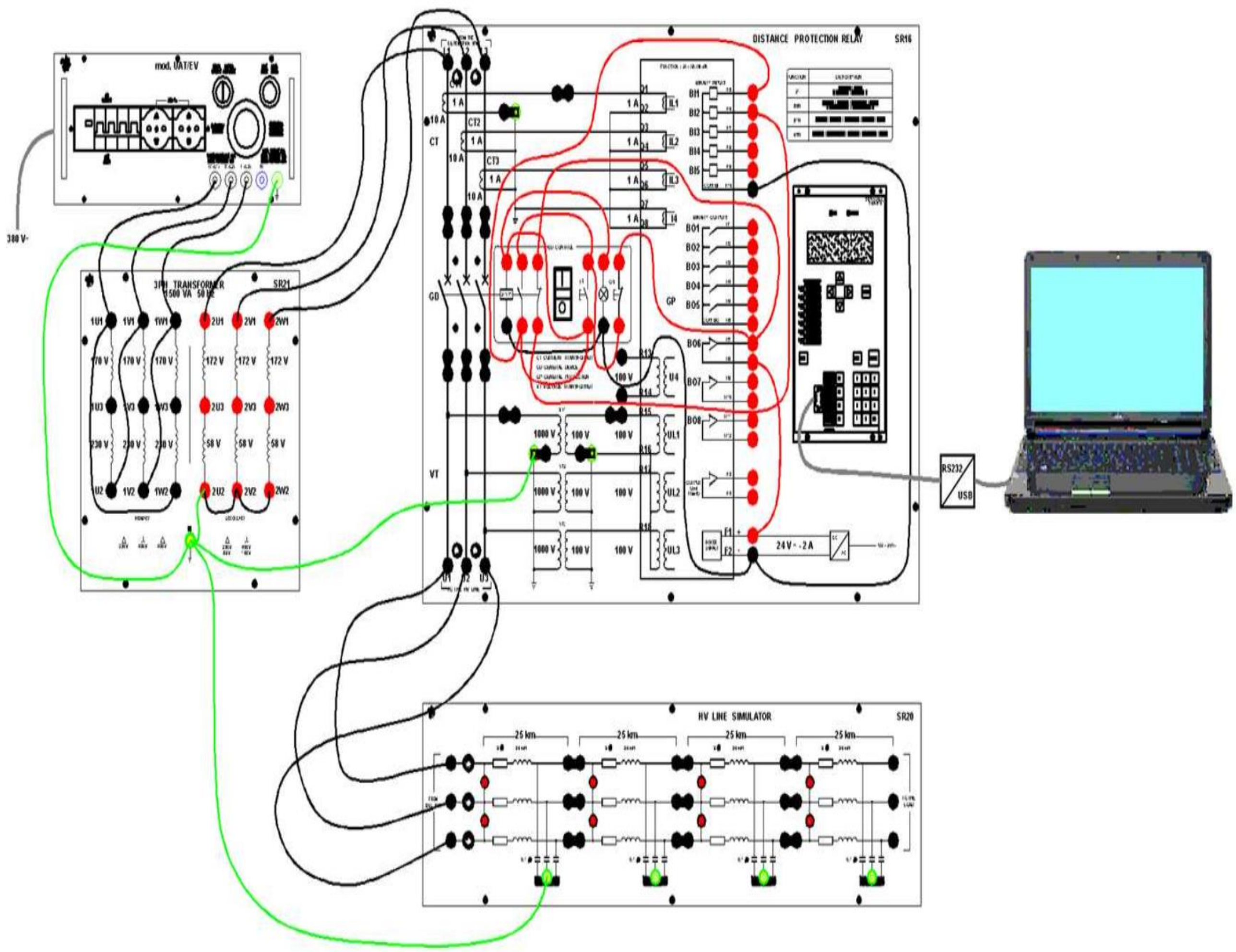


Figure (6)

2. Set the Parameters of the protection device SR16/EV and power system data using DIGSI software as follows:

   (A) Setting Group A – Earth Fault Overcurrent:

   ***(a)* General :**

   1. Earth Fault Overcurrent function [No. 3103] = ON

   ***(b)* 3I0>>>:**

   1. Operating mode [No. 3110] = Forward
   2. Pick up current [No. 3111: 3I0>>> Pickup] = 0.07A
   3. Time delay [No. 3112: T 3I0>>Time delay] = 0 Sec (Instantaneous Intervention).

(c) **Direction:**

1. Polarization [No. 2611]: With U0 +IY or U2
2. ALPHA, Lower angle for forward direction [No. 3612A]= 338^o
3. BETA, Upper angle for forward direction [No. 3613A]= 122^o
4. Min. zero seq. voltage 3U0 for polarizing [No. 3164]= 0.5 V

(B) Configuration matrix (Masking I/O):

1. **Earth Fault O/C**
   (a) EF Trip [No. 01361] → Led (6) : L (latched)

3. Turn ON the power supply mod. UAT/EV
4. Push the NO button 1I on panel mod. SR16/EV.
5. Connect the T.M.C.B. between the phase and ground, as shown in figure 7.
6. Turn ON the switch to perform a phase-phase fault, respectively at 25, 50, 75 and 100 km.
7. Measure the fault current with **SIGRA** program.

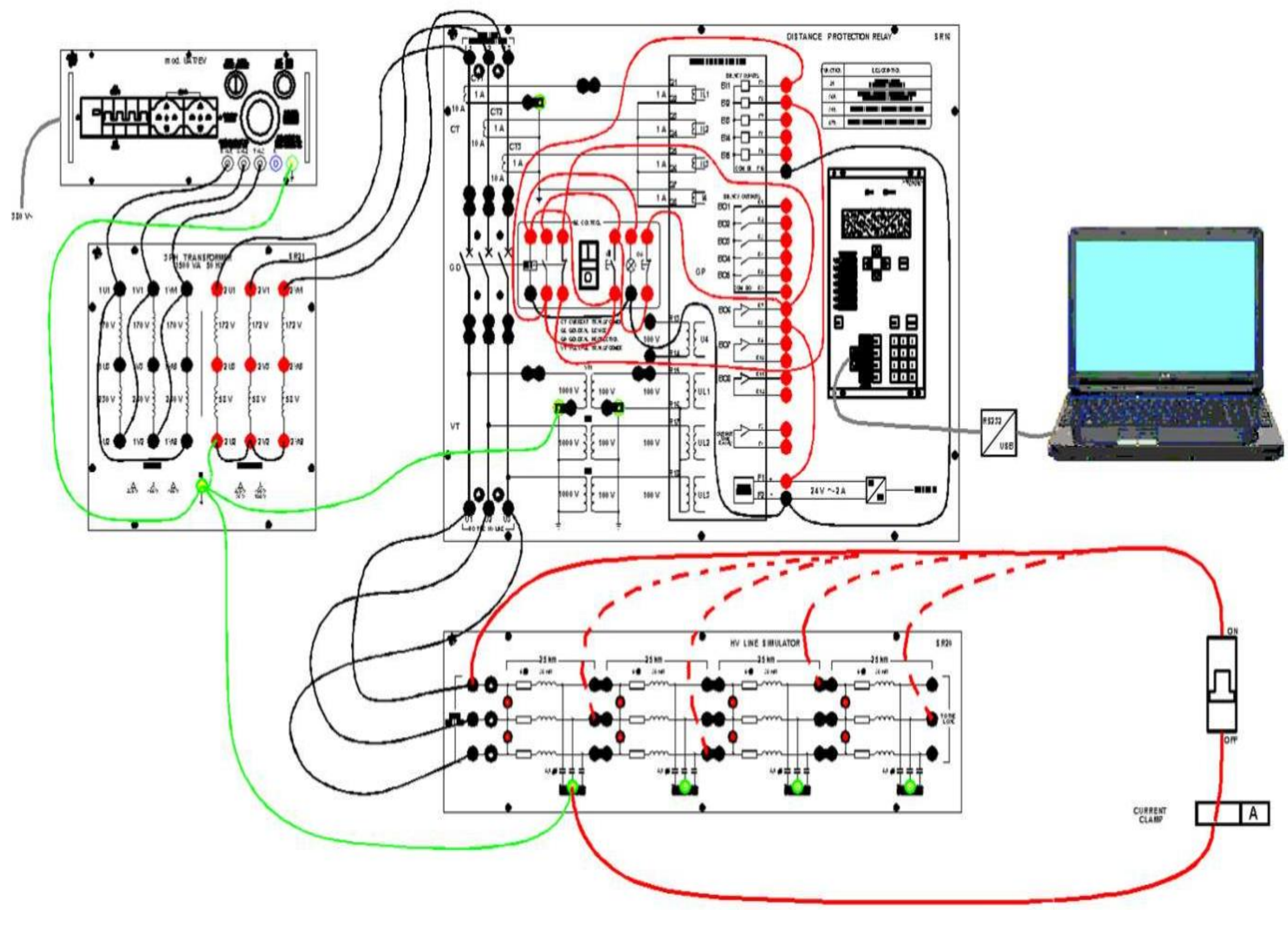


Figure (7)

8. Insert the data obtained with the measurements in the following table:

Phase – Ground Fault					
PH-PH fault	**Line (km)**	**T start (ms)**	**T trip (ms)**	**Fault Current (A)**	**Protection intervetion**
L1 – E	100				
L2 – E	75				
L3 – E	50				
L1 – E	25				

Part IV: Configuration of SR16 as distance relay [21]

1. Perform the electrical connections following the electrical diagram of figure 6.
2. Set the Parameters of the protection device SR16/EV and power system data using DIGSI software as follows:
   (A) Setting Group A – distance protection – General settings:
   1. Distance protection [No. 1201] = ON
   2. Phase current threshold for dist. Meas. [No. 1202]= 0.1 A
   3. Angle of inclination, distance characteristic [No. 1211]= 52^{o}

   (B) Setting Group A – distance zones (quadrilateral)-:
   1. **Zone Z1:**
      (a) Operating mode Z1[No. 1301] = Forward
      (b) R(Z1), Resistance for PH-PH faults [No. 1302] = 42.000 ohm
      (c) X(Z1), Reactance [No. 1303] = 49.000 ohm
      (d) RE(Z1), Resistance for PH-E faults [No. 1304] = 42.000 ohm

   (C) Configuration matrix (Masking I/O):
   1. **Dis. General**
      (a) Dis.Gen. Trip [No. 03801] → Led (3) : L (latched)

3. Turn ON the power supply mod. UAT/EV
4. Push the NO button 1I on panel mod. SR16/EV.

Part IV-1: Phase – Phase Fault

1. Connect a 20 Ω resistor in series to the T.M.C.B between two phases as shown in Figure. 8.
2. Turn ON the switch to perform a phase-phase fault, respectively at 25, 50, 75 and 100 km.
3. Measure the fault current with **SIGRA** program.

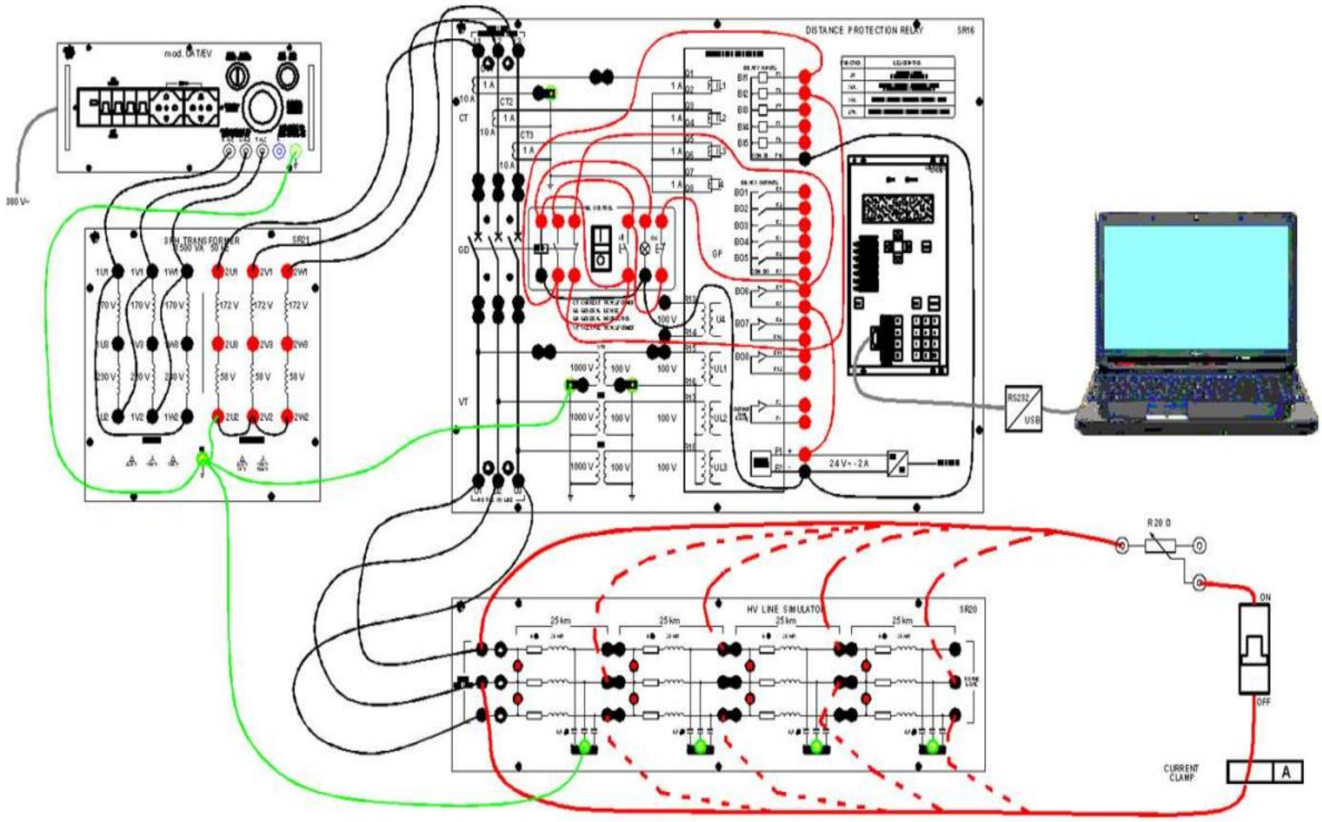


Figure (8)

4. Insert the data obtained with the measurements in the following table:

Phase – Phase Fault						
PH-PH fault	**Line (km)**	**Measured line distance (km)**	**T start (ms)**	**T trip (ms)**	**Fault Current (A)**	**Protection intervetion**
L1 – L2	100					
L2 – L3	75					
L1 – L3	50					
L1 – L2	25					

Part IV-2: Phase – Ground Fault

1. Connect a 20 Ω resistor in series to the T.M.C.B between the phase and ground as shown in Figure 9.
2. Turn ON the switch to perform a phase-phase fault, respectively at 25, 50, 75 and 100 km.
3. Measure the fault current with **SIGRA** program.

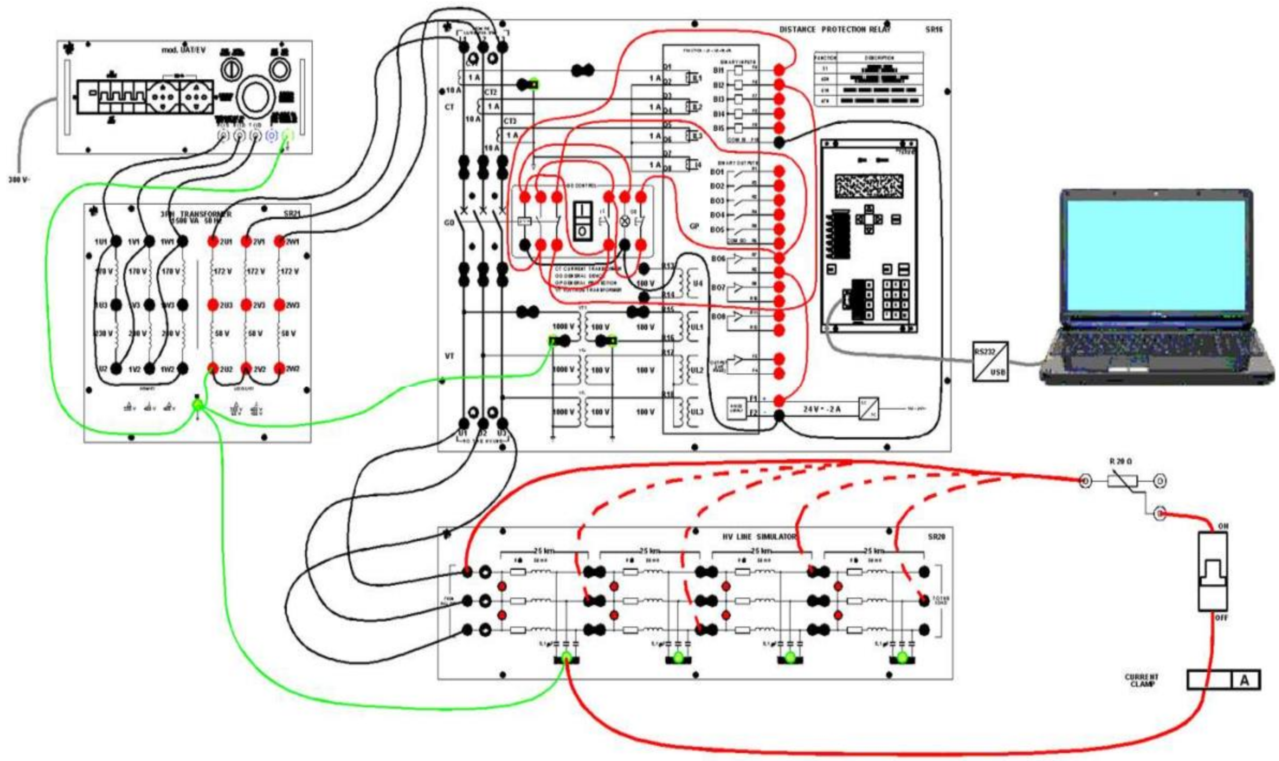


Figure (9)

4. Insert the data obtained with the measurements in the following table:

Phase – Ground Fault						
PH-PH fault	**Line (km)**	**Measured line distance (km)**	**T start (ms)**	**T trip (ms)**	**Fault Current**	**Protection intervetion**
L1 – E	100					
L2 – E	75					
L3 – E	50					
L1 – E	25					

Chapter 3

Power Factor Correction Experiments

Contents

Experiment (1)	Localized PF Correction of a single and three-phase networks

Objectives:

1. Carry out the localized electrical power factor correction installation of a single-phase user with low PF.
2. Carry out the localized electrical power factor correction installation of a three-phase user with low PF.

Theory and concepts:

With the same active power transferred to a load, by increasing the inductive reactive power it employs, the losses increase, so does the voltage drop in the line and across the user's terminals as there is more current across the line.

The power factor correction of electrical user installations concerns every kind of user even though the reactive power is charged only in average and large supplies where there are measurement groups counting the active and the reactive power, too. The maximum exploitation of the used power, in contractual terms as in terms of best use of the installed conductors, can be obtained when there is no reactive power or the required one is the minimum possible.

The power factor correction reduces the Joule losses in the transformers and the cables before the installation point; the losses reduction, with the same transmitted power, is the more consistent the lower was the cos ϕ before the power factor correction. The power factor correction increases the installation performances, so transformers and cables with the same Joule losses can transmit more power; in fact after the power factor correction, the current in the transformers and in the cables drops, so the active power transmitted can be increased with the same power loss.

The power factor correction reduces the voltage drop in cables and in transformers; in case of transformers, the dispersion reactance X is higher 3 or more times in respect to the resistor in the windings, so the voltage drop depends much on the reactive power Q the load requires from the network crossing the transformer.

If a triad of star or delta connected (three-phase load) capacitors with the right capacity are connected in parallel to the terminals of the resistive-inductive load, the capacitive current Ic they absorbs, resulting in advance quadrature in respect to the voltage **Vf**, will oppose the component in delay quadrature **Ig** reducing it to **I1** or resetting it, with consequent drop of the current across the line which will take the value **Ir**; the best situation is obtained when **Ic = Ig** and so **I** reduces to the single component in phase **If** ; Figure 1.

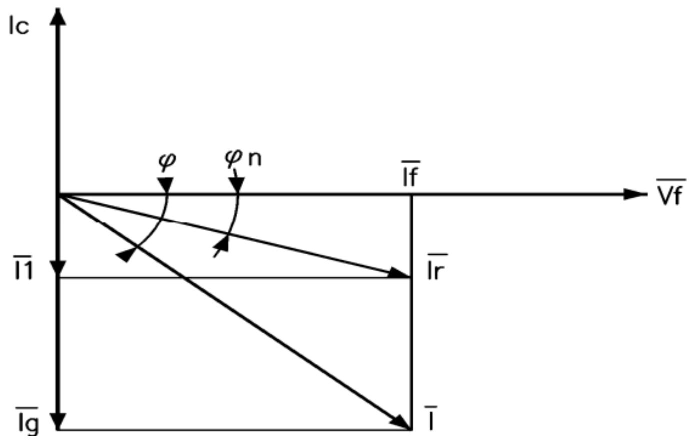


Figure (1)

In terms of power (triangle of the powers Figure 2) we get:

Active power **Po = Ao cosφo**

Reactive power **Qo = Po tgφo**

cosφ = P / A

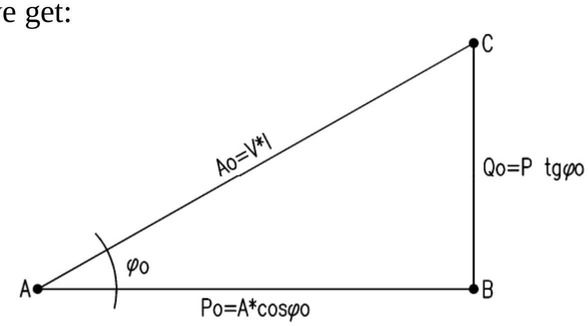


Figure (2)

It follows that to obtain a total power factor correction, the inductive reactive power **Q** absorbed by the users should be removed with the same capacitive reactive power **Qc**; actually it is very difficult to achieve this objective, except in particular cases of constant loads with constant cos ϕ, most of the users have active-inductive currents and powers variable in time.

So it is considered satisfactory to correct the power factor of an installation which is at cosϕ 0.95 in average considering the manufacturing costs and the advantages the power factor correction brings, Figure 3.

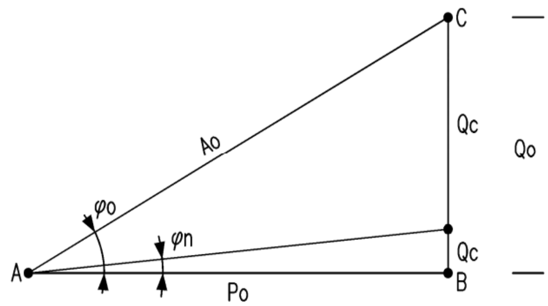


Figure (3)

The load reactive power after power factor correction is: **Qr = P tgϕr**
where ϕ**r** is the angle, chosen by the user of the power corrected current.

The reactive power of the set of capacitors will be:

$$Qc = Qo - Qr = P\,(tg\varphi o - tg\varphi r)$$

The power of the set of capacitors will:

(In case of single-phase capacitors) $Qc = V^2\ \omega\ C$

(In case of delta connected capacitors) $Qc = 3V^2\ \omega\ C$

So: $C = \dfrac{Qc}{\omega\ V^2}\ 10^6\ (\mu F)$ or: $C\Delta = \dfrac{Qc}{3\ \omega\ V^2}\ 10^6\ (\mu F)$

To calculate the capacitance to be inserted at 380-400 V, three 1-µF star connected capacitors use a reactive power of 45-50 Var while if delta connected the power becomes 135-150 Var.
Changing the voltage, the capacitors power changes proportionally to the square voltage.

Necessary Material:

1. **C-PF/EV**: Power Factor Correction mod.
2. **AMT-3/EV:** Variable three-phase power supply mod.
3. **RL- 2A/EV**: Variable resistive load mod.
4. **IL-2/EV:** Variable inductive load mod.
5. **RL-2K/EV:** Inductive resistive load mod.

Experimental Procedures:

Part I: Power Factor Correction of a single phase network.

1. Connect the circuit as shown in Figure 4.

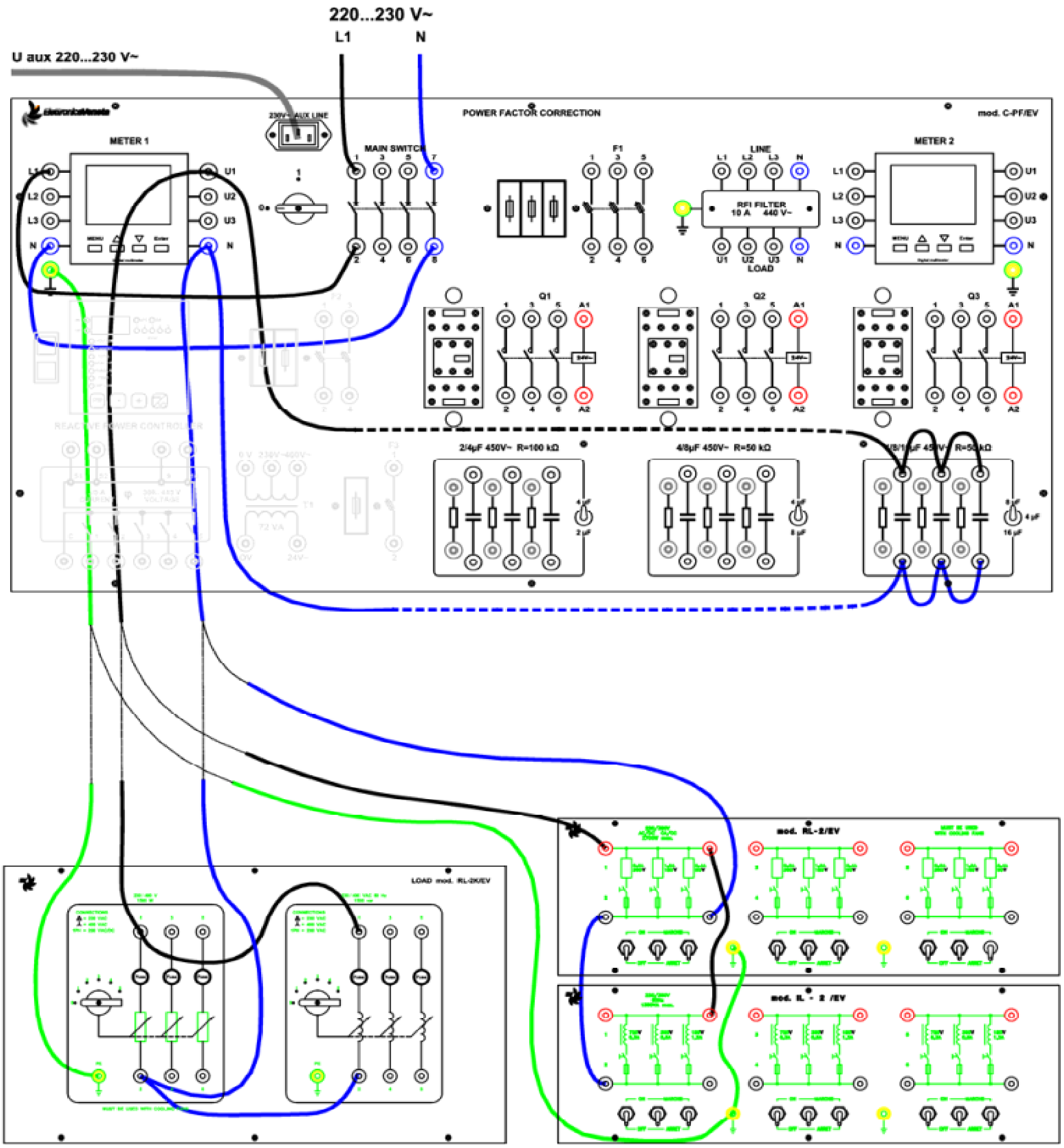


Figure (4)

2. Without using power factor correction measure the following electrical quantities then insert the data obtained with the measurements in the following table:

Measutments on the single-phase user line without PF correction												
Load				Voltage (V)	Current (A)	Active Power (W)	Reactive power (Var)	Appatent power (VA)	Frequency (Hz)	Cos ϕ	Tan ϕ
RL-2K		RL-2A									
R	L	R	L	V	I	P	Q	S	f	PF	/
2	1	B	-	230							
2	3	A	-	230							
3	3	-	B	230							

3. Calculate the capacitor value and the reactive power generated from the capacitor to be connected in parallel to improve the PF to 0.95, then insert the data obtained with the measurements in the following table:
You may use the following formulas:

$$Q_c = Q_o - Q_r = P(tg\varphi_o - tg\varphi_r) \qquad Q_c = V^2\ \omega\ C$$

Measutments on the single-phase user line after PF correction with tha capacitor C											
Load				Voltage (V)	Current (A)	Active Power (W)	Reactive power (Var)	Appatent power (VA)	Frequency (Hz)	Cos ϕ	C (μF)
RL-2K		RL-2A									
R	L	R	L	V	I	P	Q	S	f	PF	C
2	1	B	-	230							
2	3	A	-	230							
3	3	-	B	230							

Part II: Power Factor Correction of a three-phase network.

1. Connect the circuit as shown in Figure 5.

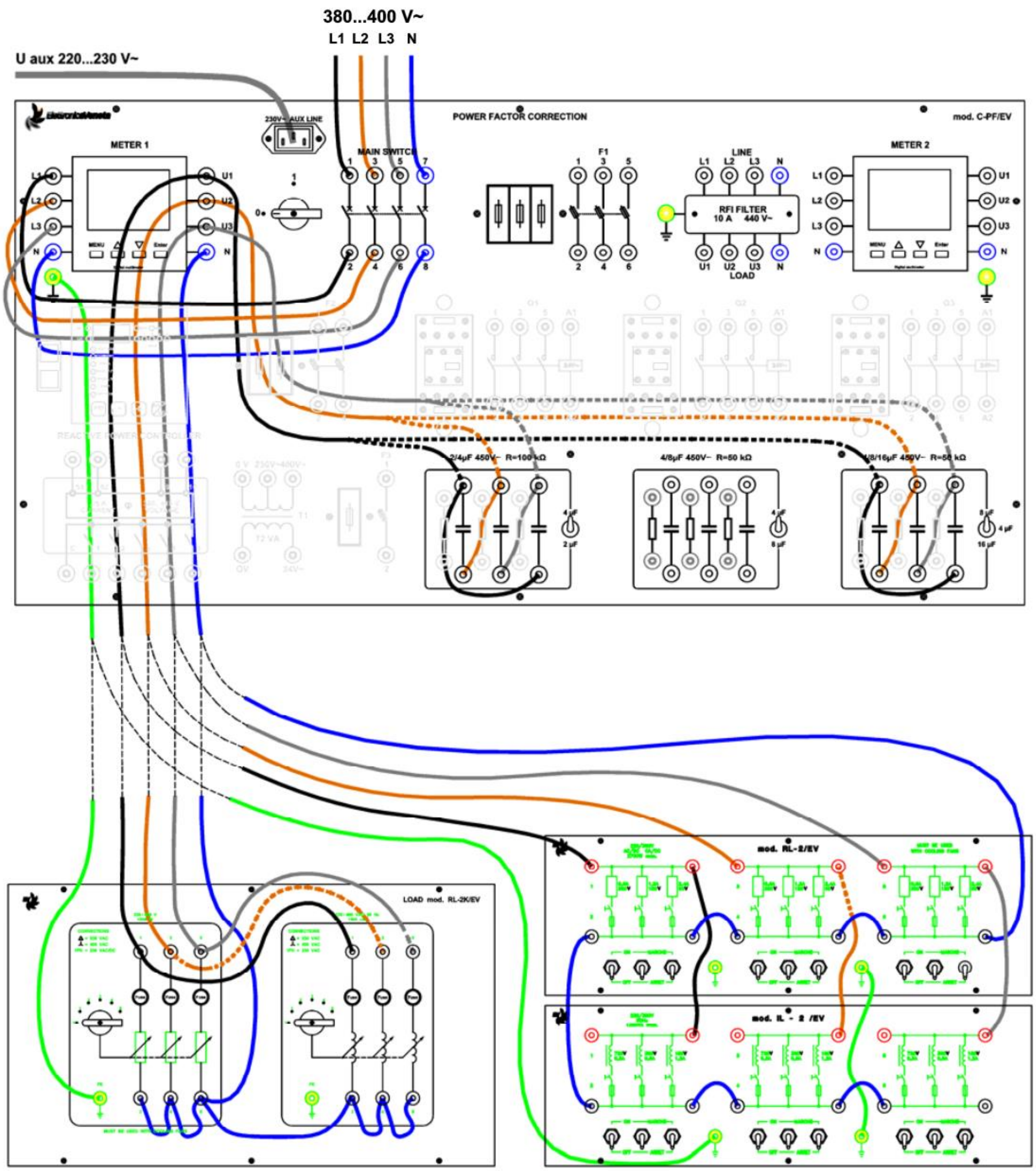


Figure (5)

2. Without using power factor correction measure the following electrical quantities then insert the data obtained with the measurements in the following table:

Measutments on the single-phase user line without PF correction												
Load				Voltage (V)	Current (A)	Active Power (W)	Reactive power (Var)	Appatent power (VA)	Frequency (Hz)	Cos ϕ	Tan ϕ
RL-2K		RL-2A									
R	L	R	L	V	I	P	Q	S	f	PF	/
1	2	A	-	390							
1	1	A	B	390							
1	2	-	B	390							

3. Calculate the capacitor value and the reactive power generated from the capacitor to be connected in parallel to improve the PF to **0.98** (Δ-connected), then insert the data obtained with the measurements in the following table:
You may use the following formulas:

$$Q_c = Q_o - Q_r = P\,(tg\varphi_o - tg\varphi_r) \qquad Q_c = 3V^2\,\omega\,C$$

Measutments on the single-phase user line after PF correction with tha capacitor C												
Load				Voltage (V)	Current (A)	Active Power (W)	Reactive power (Var)	Appatent power (VA)	Frequency (Hz)	Cos ϕ	C (µF)
RL-2K		RL-2A									
R	L	R	L	V	I	P	Q	S	f	PF	C
1	2	A	-	390							
1	1	A	B	390							
1	2	-	B	390							

Questions:

1. What are the causes of low Power Factor.

2. Why should the power factor be improved?

3. Discuss why a capacitor bank is usually connected to a three-phase network in a delta connection.

4. Two loads are connected across a 230-Vrms, 50-Hz source:
   Load 1: 150 W at 0.6 PF lagging.
   Load 2: 208 VA at 0.89 PF lagging.

   Find:

   (a) The total real and reactive power , the PF at the source and the total current.
   (b) The capacitance of the capacitor connected across the loads to improve the over all PF to 0.95 lagging.
   (c) Line current supplied by the source to feed these loads after connecting the capacitor bank.

5. Three loads are connected to a 3-phase, 390-Vrms, 50-Hz source:
   Load 1: 300 W at 0.77 PF lagging.
   Load 2: 400 W at 0.94 PF lagging.
   Load 3: 428VA at 0.6 PF lagging.

   Find:

   (a) The total real and reactive power , the PF at the source and the total current.
   (b) The capacitance of the capacitor connected across the loads to improve the over all PF to 0.98 lagging (Δ-connected).
   (c) Line current supplied by the source to feed these loads after connecting the capacitor bank.

Experiment (2)	Automatic Centralized three-phase PF Correction

Objectives:

1. Carry out an automatic centralized power factor correction installation with 3 steps of reactive capacitive power equal between them.
2. Carry out an automatic centralized power factor correction installation with 3 steps of reactive capacitive power one double the other.

Theory and concepts:

In most installations there is not a constant absorption of reactive power for example due to working cycles for which machines with different electrical characteristics are used. In such installations there are systems for automatic power factor correction which, thanks to a monitoring varmetric device and a power factor regulator, allow the automatic switching of different capacitor banks, thus following the variations of the absorbed reactive power and keeping constant the power factor of the installation constant. An automatic compensation system is formed by:

- Some sensors detecting current and voltage signals;
- An intelligent unit which compares the measured power factor with the desired one and operates the connection and disconnection of the capacitor banks with the necessary reactive power (power factor regulator);
- An electric power board comprising switching and protection devices;
- Some capacitor banks.

To supply a power as near as possible to the demanded one, the connection of the capacitors is implemented step by step with a control accuracy which will be the greater the more steps are foreseen and the smaller the difference is between them.

Necessary Material:

1. **C-PF/EV**: Power Factor Correction mod.
2. **AMT-3/EV:** Variable three-phase power supply mod.
3. **RL- 2A/EV**: Variable resistive load mod.
4. **IL-2/EV:** Variable inductive load mod.
5. **RL-2K/EV:** Inductive resistive load mod.

Experimental Procedures:

Part I-1: Manual Mode of PF correction with 3-equal capacitors (4-μF).

1. Connect the circuit as shown in Figure 1 and 2.
2. Put the settings of the Controller as follows:
   - To set the controller in manual mode: Long press on the **MAN/AUT** pushbutton.
   - To set the basic settings of the controller: Long press on the **mode** pushbutton.
   - To reach the functions P.01 to P.06: Use **MAN/AUT** pushbutton.
   - To set the advanced settings of the controller P.11 and P.16: Long press on **mode** pushbutton and then long press on the **+ &** - together, you may use **MAN/AUT** pushbutton to reach the function P.16.
   - The control of 3 equal sets with linear insertion and the last step as fan command.
     The programmed parameters are the following:
     - P.01 = 5 (as there should be a TA 5/5 A)
     - P.02 = 0.5 (Smaller step = 0.5 kvar)
     - P.03 = 400 (Rated voltage 400 V)
     - P.06 STEP 1 = 1 (0.5 kvar = Once P.02)
       P.06 STEP 2 = 1 (0.5 kvar = Once P.02)
       P.06 STEP 3 = 1 (0.5 kvar = Once P.02)
       P.06 STEP 4 = 0 (step disconnected)
       P.06 STEP 5 = Fan (contact for fan command).
     - P.11 = Three-phase (connection for three-phase lines)
     - P.16 = Lin (Linear insertion mode)
3. Set the desired PF on the controller = **0.94 Lagging**.
4. Insert the various steps of the Resistive and inductive loads then make the correction of the PF using manual mode by inserting the capacitor required parallel to the load and to check the proper value of these capacitors that match the PF of the system equal or near to the desired PF.
5. Read the electric quantities on the measuring instruments and write them down in the following table.

RL load	R_2, L_3	R_2, L_4	R_2, L_5, L_{AB}
C_1= 4µF (on/off)			
C_2= 4µF (on/off)			
C_3= 4µF (on/off)			
PF_{old}			
PF_{new}			
$P_{in(total)}$			
$Q_2 = Q_{old} = Q_{load}$			
$Q_1 = Q_{new}$			
I_1			
$I_2 = I_{load}$			

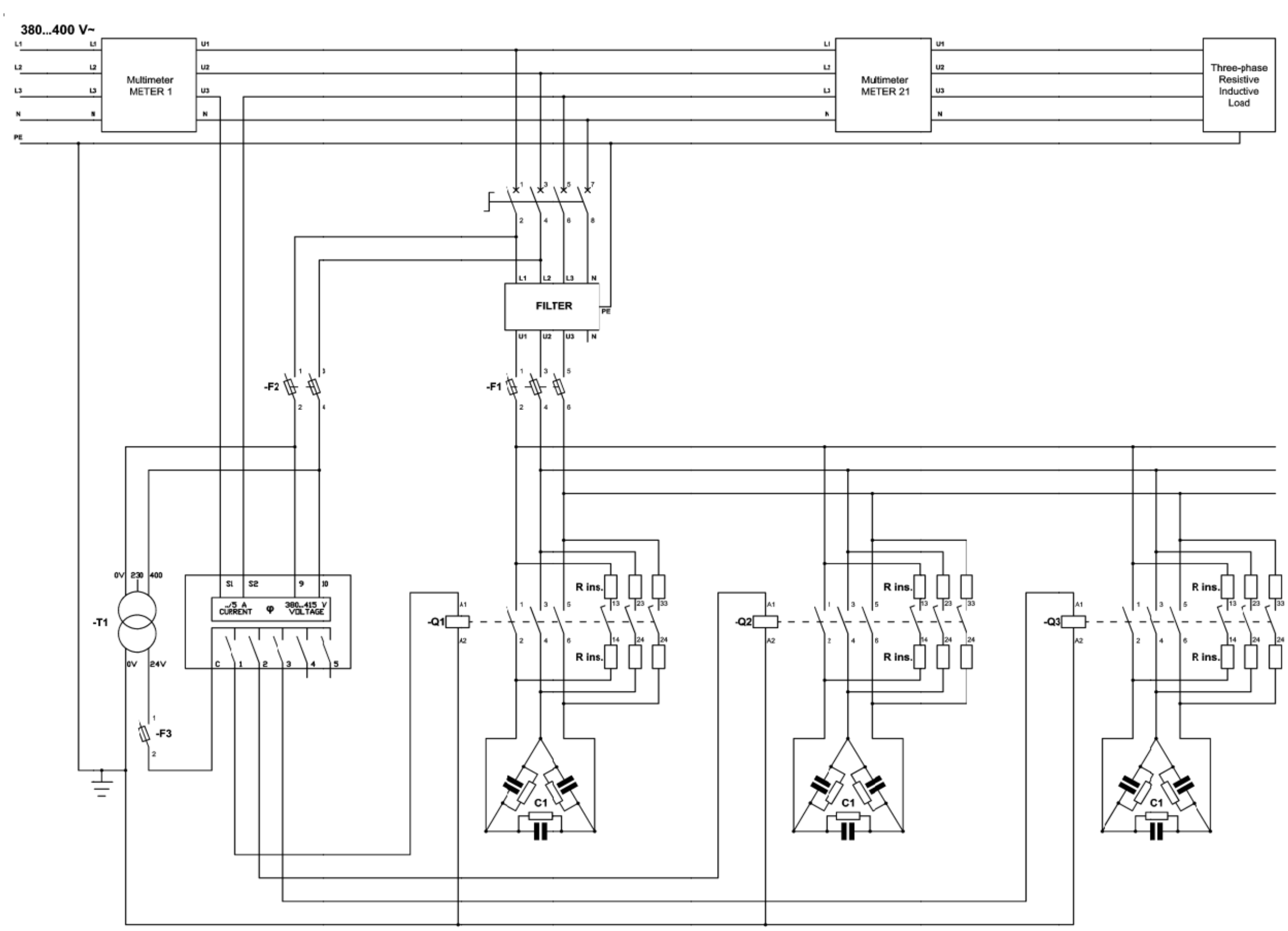


Figure (1)

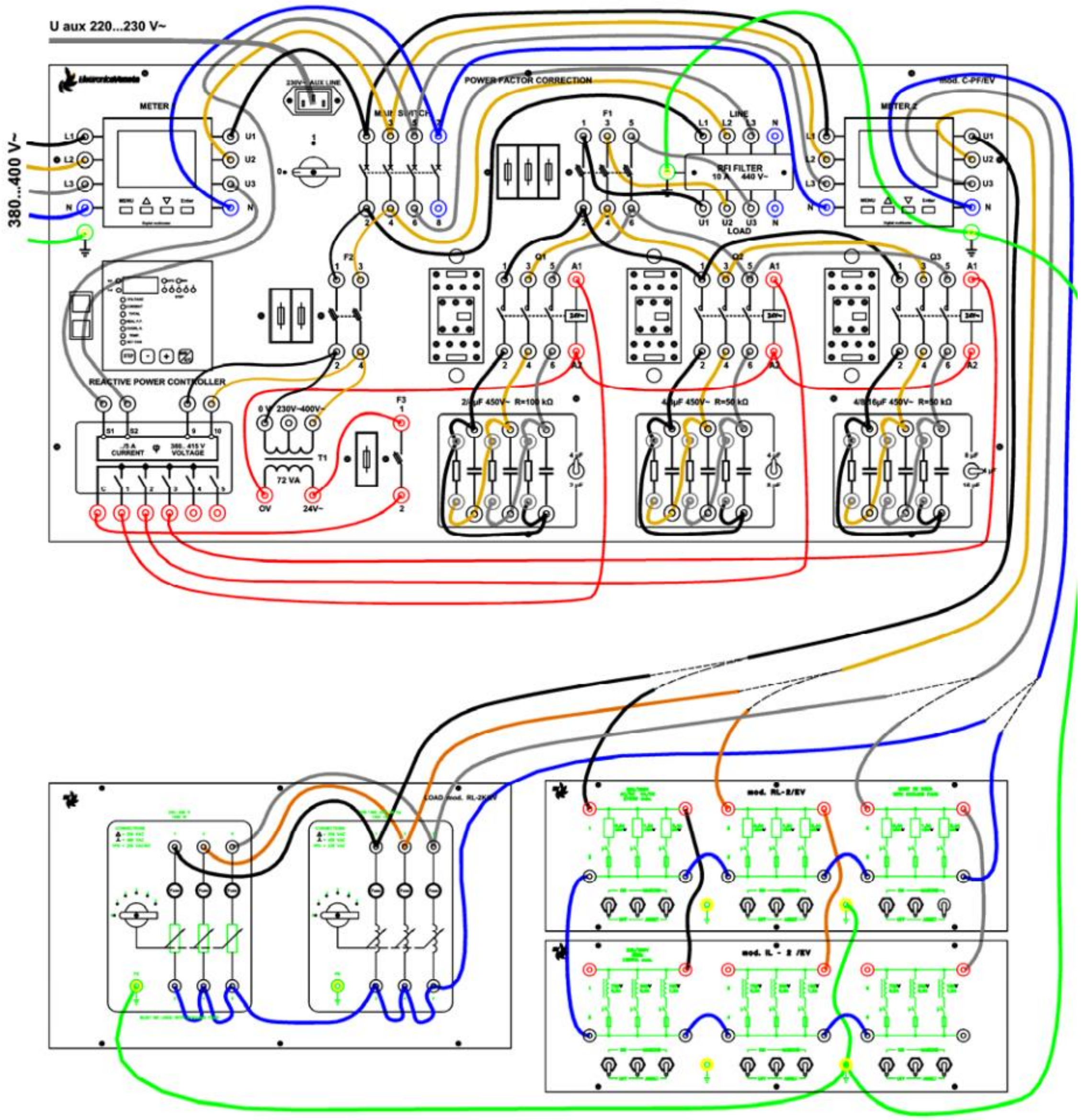


Figure (2)

Part I-2: Automatic Mode of PF correction with 3-equal capacitors (4-µF).

1. Turn off the system and return back to the no load condition with the same connection.
2. Restart the system and set the controller to **automatic mode** by Long press on the **MAN/AUT** pushbutton.
3. Change the Resistive-Inductive load in steps then read the electric quantities on the measuring instruments and write them down in the following table.

RL load	R_2, L_3	R_2, L_4	R_2, L_5, L_{AB}
C_1= 4µF (on/off)			
C_2= 4µF (on/off)			
C_3= 4µF (on/off)			
PF_{old}			
PF_{new}			
$P_{in(total)}$			
$Q_2 = Q_{old} = Q_{load}$			
$Q_1 = Q_{new}$			
I_1			
$I_2 = I_{load}$			

Part II-1: Manual Mode of PF correction with 3 steps of reactive capacitive power one double the other (C_1= 4-µF, C_2= 8-µF, C_3= 16-µF).

1. Turn off the system and return back to the no load condition with the same connection.
2. Change the settings of the Controller to:
   - **The programmed parameters to be changed are as follows:**
     - P.06 STEP 1 = 1 (0.5 kvar = Once P.02)
       P.06 STEP 2 = 2 (0.5 kvar = Once P.02)
       P.06 STEP 3 = 4 (0.5 kvar = Once P.02)
3. Insert the various steps of the Resistive and inductive loads then make the correction of the PF using manual mode by inserting the capacitor required parallel to the load and to check the proper value of these capacitors that match the PF of the system equal or near to the desired PF.
4. Read the electric quantities on the measuring instruments and write them down in the following table.

RL load	R_2, L_5, L_{AB}	R_2, L_5, L_{ABC} , L_B	R_1, L_5, L_{ABC} , L_{ABC}
C_1= 4μF (on/off)			
C_2= 4μF (on/off)			
C_3= 4μF (on/off)			
PF_{old}			
PF_{new}			
$P_{in(total)}$			
$Q_2 = Q_{old} = Q_{load}$			
$Q_1 = Q_{new}$			
I_1			
$I_2 = I_{load}$			

Part II-2: Automatic Mode of PF correction with 3 steps of reactive capacitive power one double the other (C_1= 4-μF, C_2= 8-μF, C_3= 16-μF).

1. Turn off the system and return back to the no load condition with the same connection.
2. Restart the system and set the controller to **automatic mode** by Long press on the **MAN/AUT** pushbutton.
3. Change the Resistive-Inductive load in steps then read the electric quantities on the measuring instruments and write them down in the following table.

RL load	R_2, L_5, L_{AB}	R_2, L_5, L_{ABC} , L_B	R_1, L_5, L_{ABC} , L_{ABC}
C_1= 4μF (on/off)			
C_2= 4μF (on/off)			
C_3= 4μF (on/off)			
PF_{old}			
PF_{new}			
$P_{in(total)}$			
$Q_2 = Q_{old} = Q_{load}$			
$Q_1 = Q_{new}$			
I_1			
$I_2 = I_{load}$			

Questions:

1. Calculate the required value of capacitance for each load and compare it with the values selected by controller (Part I-1)

2. Calculate the required value of capacitance for each load and compare it with the values selected by controller (Part I-2)

3. Compare between the results of manual mode with the results of the automatic mode (Part I).

4. Calculate the required value of capacitance for each load and compare it with the values selected by controller (Part II-1)

5. Calculate the required value of capacitance for each load and compare it with the values selected by controller (Part II-2)

6. Compare between the results of manual mode with the results of the automatic mode (Part II).

Experiment (3)	PF correction using Synchrouns compensator

Objectives:

1. Carry out the connections and the sequence of operations to enable the synchronous compensator.
2. Carry out the using of synchronous compensator to correct the power factor of a system.

Theory and concepts:

Synchronous Condenser/compensator/capacitor:

Being in load or no-load condition, an underexcited synchronous motor shows an **inductive** load to the mains. On the contrary, when overexcited, it is equivalent to a **capacitive** load (function of synchronous compensator).

The synchronous motor receives excitation in the rotor from an external **dc** adjustable source. The excitation voltage *determines the kind of power the motor absorbs from the network*:

- Reactive inductive power in **under-excitation conditions**;
- Reactive capacitive power in **over-excitation conditions**.

The synchronous motor is often used not only to move a mechanical load at constant speed, but simultaneously as power factor phase advancer of the networks, (***it operates in underexcitation conditions)***.

This is the typical method of power factor compensation used mainly in the electrical control stations, exploiting also the motor's capacities to move pumps, fans and other auxiliary services of the power plant.

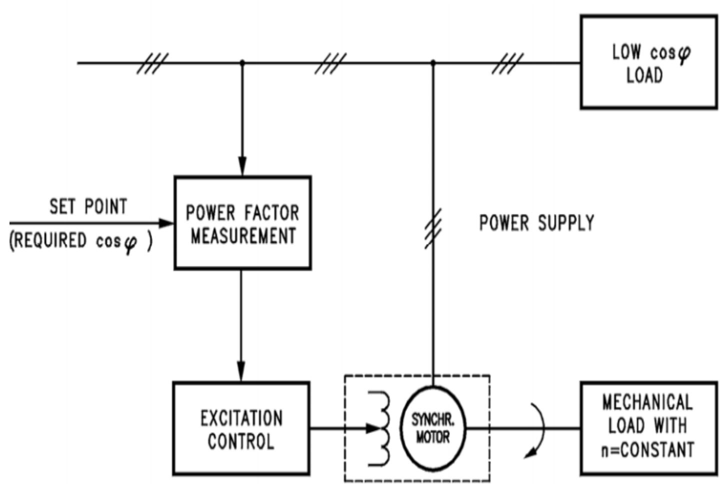
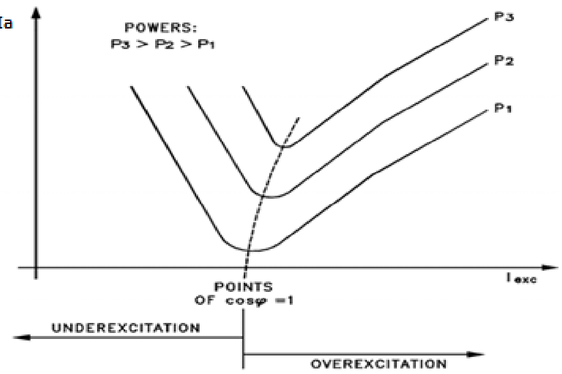


Figure 1

When used as synchronous phase advancer, its action can be controlled with closed feedback cycle (see Figure 1).

The values of the I_A are taken as function of the I_{exc}. Using different mechanical powers, (power as parameter), so the curves called "**V**" (for the shape they have) are detected.

The lower apexes correspond to the minimum I_A for each power. In this condition, the motor operates as a practically resistive load (power factor = 1).



On the right of these values, the motor operates in **overexcitation condition** (synchronous phase advancer), showing a Capacitive load to the mains. On the left of these values, the motor operates in **under-excitation conditions**, showing an inductive load to the mains.

Necessary Material:

1. **PCB-3/EV:** Generator parallel board mod.
2. **GCB-3/EV:** Control board for the generating set mod.
3. **MSG-3/EV:** Synchronous generator-motor unit mod.
4. **AMT-3/EV:** Variable three-phase power supply mod.
5. **RL-2/EV:** Variable resistive load mod.
6. **IL-2/EV:** Variable inductive load mod.

Experimental Procedures:

Part I: Enabling the Synchronous Machine used as Synchronous Compensator.

1. Connect the circuit as shown in Figure 2.
2. Start the prime mover of the set to make the synchronous compensator turn, adjust the synchronous generator to the rated frequency (50-Hz) and voltage (400-V) like in the case of a parallel connection of a generator with the mains.
3. Enable the public mains with the variable power supply mod. AMT-3/EV by adjusting the voltage to approximately 3 x 400 V.
4. Carry out the proper adjustments to find the best "**condition for the parallel connection**" and carry it out.
5. Without changing the excitation parameters (variac Uexc 3PH-GEN) of the synchronous compensator turn the switch **RUN / STAND-BY** to **STAND-BY**. This operation makes the AC motor "freewheel"; it does not drive the synchronous machine anymore and this becomes a **synchronous motor**.

Part II: Operation of Synchronous Compensator to improve the PF of the system.

6. Adjust the excitation current to get a PF equal to **unity** then measure the values of active and reactive power of the main supply and synchrnous motor.
7. Insert the inductive load (L= switch B), change the value of excitation current of the synchronous motor <u>in steps</u> to get the PF of the system equal to **0.96 Lagging**.
8. Read the electric quantities on the instruments and write them down in the following tables.

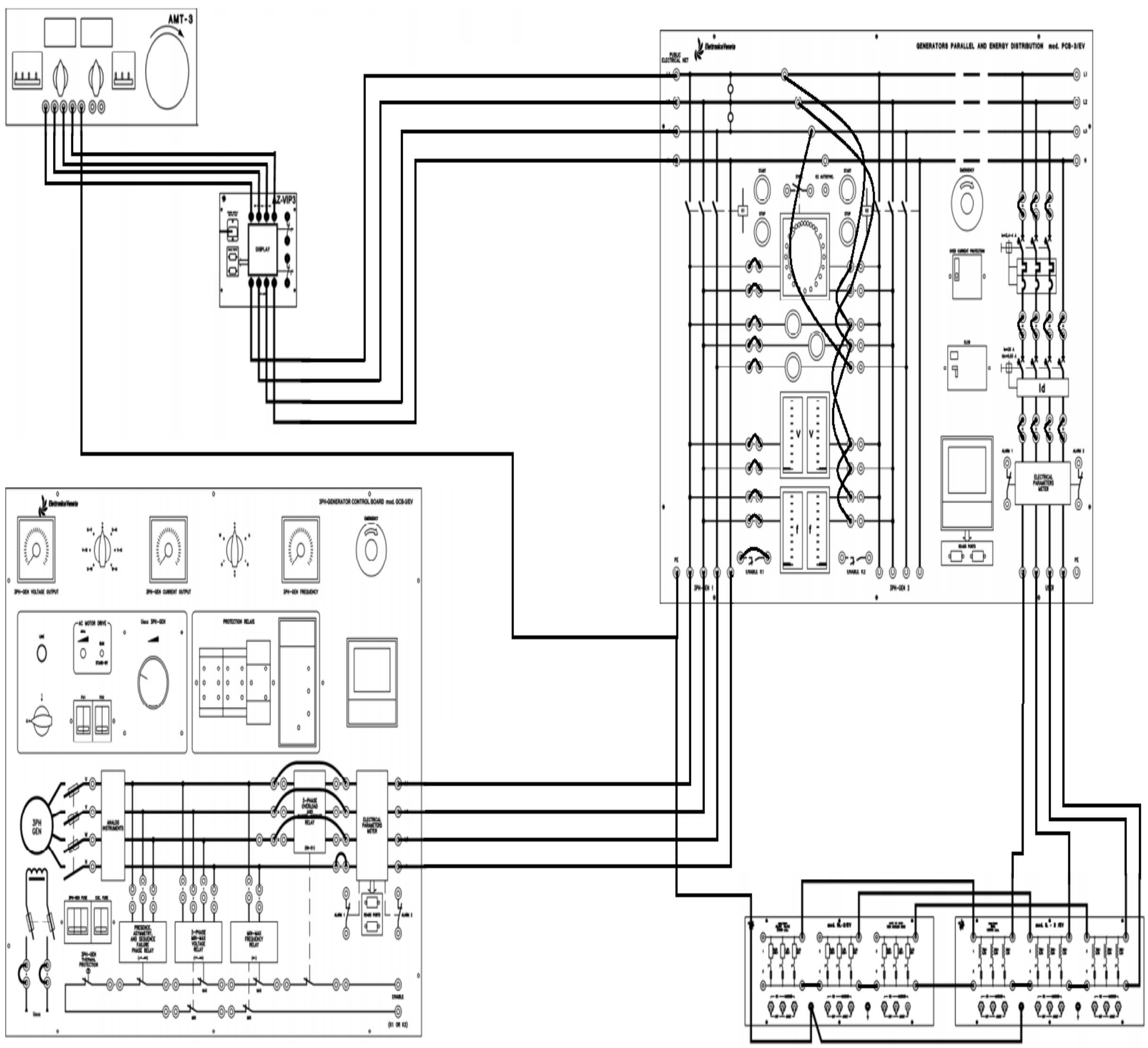


Figure (2)

Measutments / (Load)			
P_{load}	Q_{load}	PF_{load}	I_{load}

Measutments / (Inductive Load – B switch)								
I_f (mA)	Main Supply Measurments				Motor Measurments			
	P_s (W)	Q_s (Var)	PF_s	I_s (mA)	P_M (W)	Q_M (Var)	PF_M	I_M (mA)

Questions:

1. What is a synchronous capacitor? Why would one be used?
2. Explain what happen to the system PF and synchronous motor as its field current is varied?
3. Compare between using capacitor bank and using synchronous compensator for power factor correction.

Chapter 4

Overall Power System Experiments

Contents

Experiment (1)	Simulator of Production, Transmission and Use of Electric Power

Objectives:

1. Describing the different sections of a complete System of production, distribution and use of electric energy, and their operation.
2. Enabling an easy and intuitive learning by an interaction with the same System via control and display devices available in both Panel and Software.

Theory and concepts:

The normal operation of a network of electric power transport and distribution must also program the use of some power plants that produce an almost constant quantity of energy; this energy is carried and distributed on the territory and most power is absorbed by the big industrial or craft businesses and a lower part by the commercial and housing sectors.

As consumption is not constant during a day, when there is a high energy demand, the power distribution agency must set some power plants at work to produce the power demanded and avoid catastrophic black-outs.

The plants enabling to satisfy the energy peaks during the day are generally of medium power and are arranged in the territory near the users with considerable consumptions, when possible; they must reach their full operation in short times (some tens of minutes).

The great thermoelectric or nuclear power plants are distributed and connected in parallel on the territory, so that they can meet the normal demand of electric power, whereas peak demands can be satisfied (where possible) by medium power plants of thermoelectric, hydroelectric type or using renewable energies (wind power, solar energy, etc…), managed by personnel, or wholly automated.

Great power plants satisfy the normal daily demand; during the peaks of demand they are 'helped' or 'relieved' by the plants of medium power. During the night, consumptions of production activities are reduced, and power availability is used in hydroelectric plants to pump water back into the upper basin (even water is not available forever), as reserve for future needs.

Necessary Material:

1. **SEE-1/EV:** Simulator of the cycle of Electric Energy mod as shown in Figure 1.
2. **PC** with **SEE01** software installed.

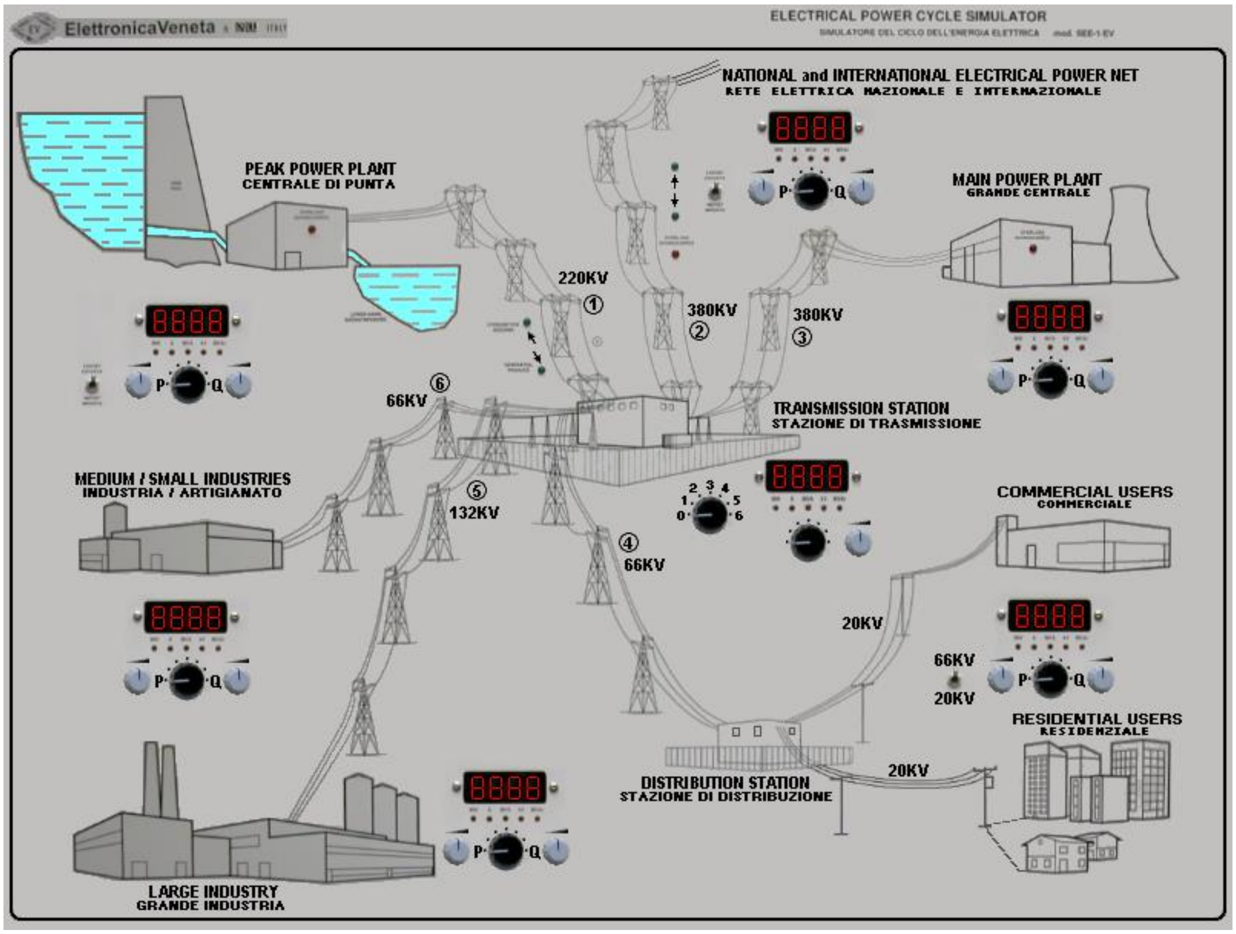


Figure (1)

Experimental Procedures:

Part I: National Electrical Power Net

This part concerns the automatic control of the distribution of electric power according to the daily demand of users.

1. Switch ON the computer.
2. Switch ON the simulator main switch.
3. Connect with USB cable the Simulator to PC.
4. Follow these commands:

   - Start → Programs → Simulator SEE → SEE

Figure 2 shows how this automatic control goes on in 24 hours (Daily load curve).

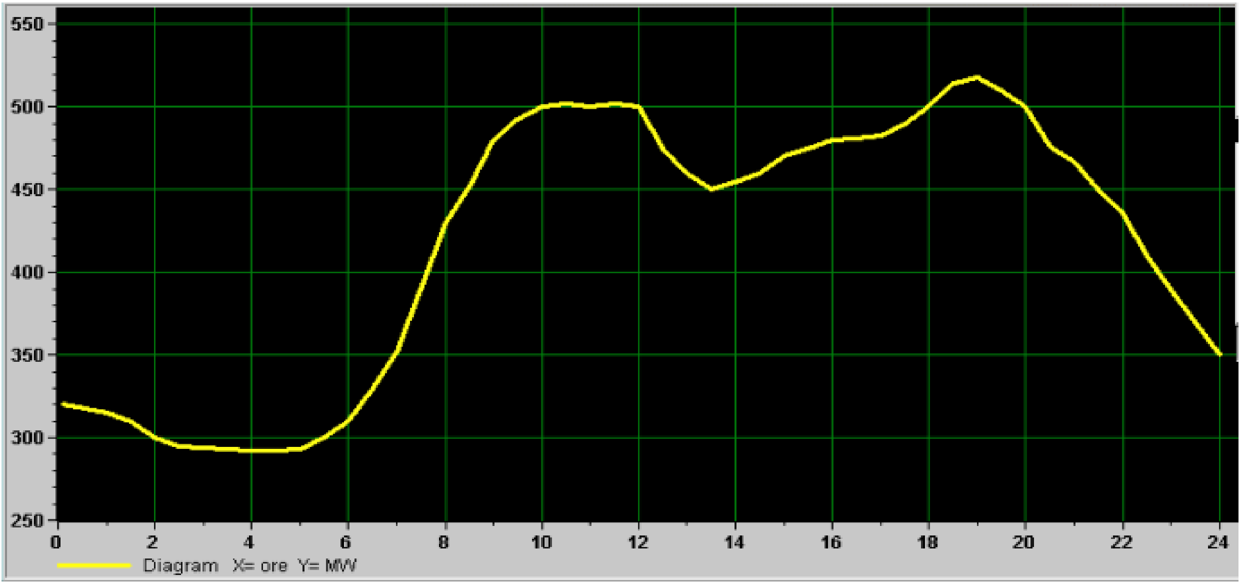


Figure (2)

Question: Describe the operation of the system in this case.

………………………………………………………………………………………………..……
………………………………………………………………………………………………..……
………………………………………………………………………………………………..……
………………………………………………………………………………………………..……
………………………………………………………………………………………………..……
………………………………………………………………………………………………..……
………………………………………………………………………………………………..……

Part II: Supervision of the Simulator

This part concerning the control and supervision of the simulator will enable a correct operation of the System.

This program enables to use all the controls of digital instruments and the potentiometers P and Q of the simulator so that the various electric quantities can be displayed and the values of active power (W) and of reactive power (Var) can be set.

Question: Describe the operation of the system in this case.

………………………………………………………………………………………………..……
………………………………………………………………………………………………..……
………………………………………………………………………………………………..……
………………………………………………………………………………………………..……
………………………………………………………………………………………………..……
………………………………………………………………………………………………..……
………………………………………………………………………………………………..……

Part III: Line Resistance and Phasing

This part will analyze the effects of ohmic and inductive resistances on the lines 3 and 5 when they are crossed by current.

Question: Describe the effect of resistance and inductance on losses, voltage drop along lines and power output by the generators, and discuss the way that used to decrease the inductive effect.

……………………………………………………………………………………………..……
……………………………………………………………………………………………..……
……………………………………………………………………………………………..……
……………………………………………………………………………………………..……
……………………………………………………………………………………………..……
……………………………………………………………………………………………..……
……………………………………………………………………………………………..……

Experiment (2)	Power System with SCADA System

Objectives:

1. To study the behavior and the operation of a power system with SCADA system.
2. Using the instrument to measure the electrical quantities like voltage, current, active power, reactive power, apparent power, power factor and frequency.
3. Showing and implementing a connection in wireless network for the supervision of the data coming from 2 multifunction instruments by PC.
4. Use of the supervision and energy management software for the monitoring and management of electrical parameters and energy consumptions of an electrical installation.

Necessary Material:

1. **SEL-1/EV:** Simulator of electric lines mod.
2. **PRMCE-1/EV**: Panel of Supervision Networks of Electrical Parameters.
3. **P14A/EV:** Three-phase transformer mod.
4. **AMT-3/EV:** Variable three-phase power supply mod.
5. **RL-2/EV:** Variable resistive load mod.
6. **IL-2/EV:** Variable inductive load mod.
7. **Contactor** with On-Off control

Experimental Procedures:

1. Consider and set the LINE 2 with the following constants: R= 18Ω; L= 72mH; C_{ES}= 0.1 and C_{ER}= 0.1µF; Length= 50km.
2. Connect with the variable three-phase power supply by inserting the three-phase insulation transformer.
3. Connect the capacitors at the sending end point of the LINE 2 in Δ-connection.
4. Connect the capacitors at the receiving end point of the LINE 2 in Y-connection.
5. Connect the instruments with the Switch/Access Point via 2 cables (of the equipment) with RJ45 connectors as shown in Figure 1.
6. Connect the circuit as shown in Figure 2.

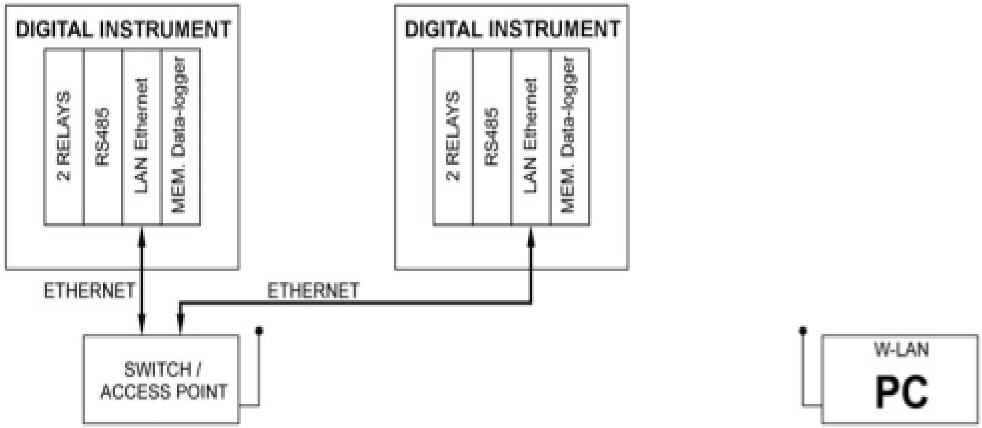


Figure (1)

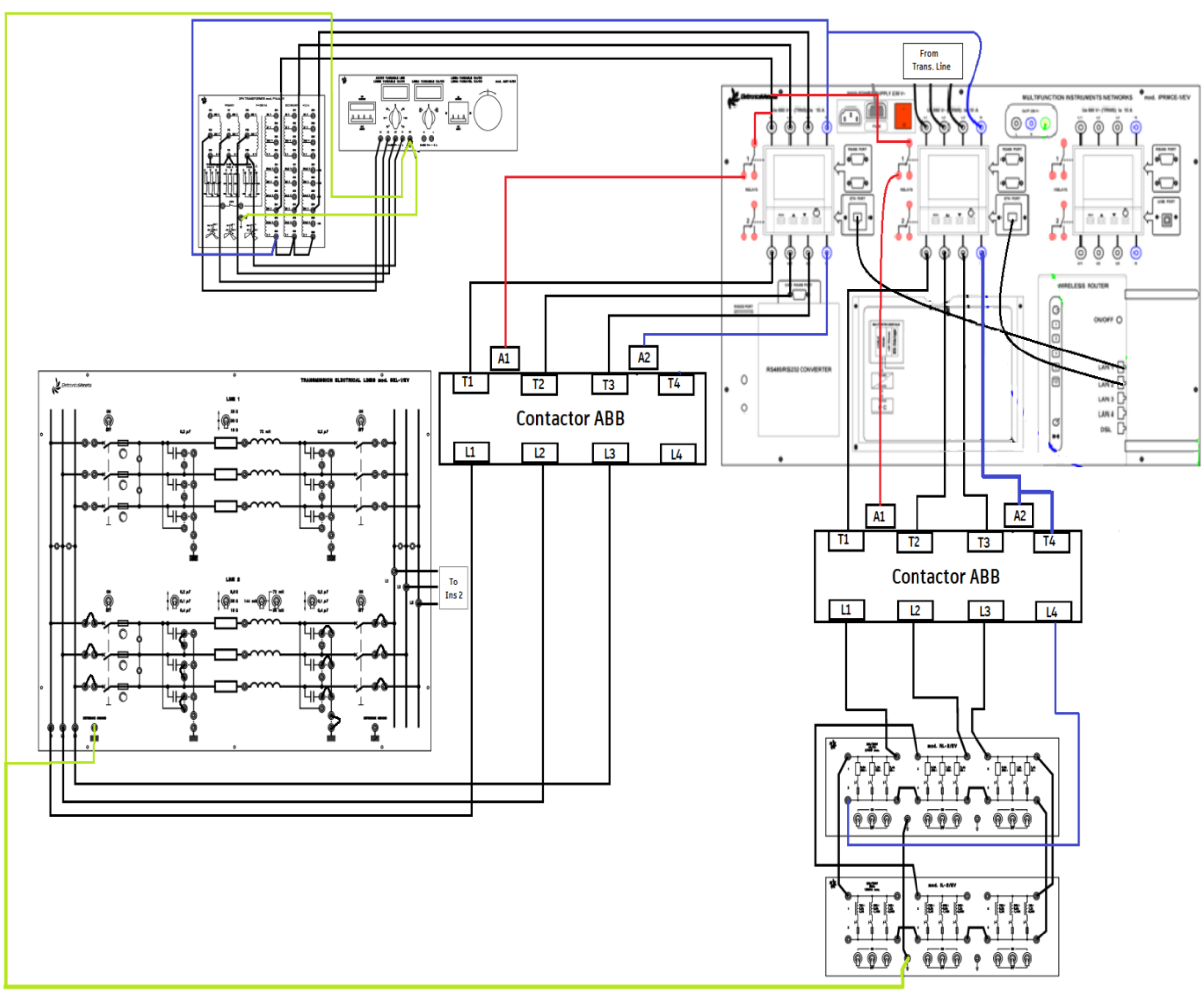


Figure (2)

7. Set the parameters of the first instrument (Left) as follows using DMK remote control software:
   - **LIM 1:**
     Max voltage = 400; Delay = 5 sec;
     Min Voltage = 250; Delay = 5 sec.
   - **LIM 2, 3 and 4 (Line current 1, 2 and 3):**
     Max current = 0.7A; Delay = 5 sec;
     Min Voltage = 0.7A; Delay = 5 sec.
   - **Configure Boolean function to Combines the 4 Limits (OR operator).**
   - **Set the Output OUT1 used to energize the relay (ALARM 1)** (This relay will depend on BOO1 which includes the OR operator of the LIM1 and LIM2, 3 and 4).
8. Set the parameters of the Second instrument (Centre) as follows using DMK remote control software:
   - **LIM 1:**
     Max voltage = 400; Delay = 2 sec;
     Min Voltage = 250; Delay = 2 sec.
   - **LIM 2, 3 and 4 (Line current 1, 2 and 3):**
     Max current = 0.7A; Delay = 2 sec;
     Min Voltage = 0.7A; Delay = 2 sec.
   - **Configure Boolean function to Combines the 4 Limits (OR operator).**
   - **Set the Output OUT1 used to energize the relay (ALARM 1)** (This relay will depend on BOO1 which includes the OR operator of the LIM1 and LIM2, 3 and 4).
9. Enable and adjust the voltage of the power supply at **350 V**.
10. Turn the breaker at the origin and at the end of the Line 2 to ON in sequence.
11. Set the transmission line under load with the insertion of resistive-inductive load.
12. Read the electric quantities on the measuring instruments and write them down in the following table.

Load		**(Instrument 1)**					**(Instrument 2)**				
RL		Vs	Is	Ps	Qs	PFs	V_R	I_R	P_R	Q_R	PF_R
A	A	350									
A	B	350									

13. Change the load to (R= A, L= A || B), Explain the operation of the system?

14. Change the settings of the limits and describe the operation of the system.