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## Experiment#1

### Introduction to Siemens PLCs

#### ➤ Objectives:

1. To introduce the students to Siemens PLCs programming and to step 7 software tools.
2. To be familiar with Siemens PLCs timers and counters.
3. To learn how to program using Statement List programming.

#### ➤ Pre lab:

Study the theory behind the Siemens PLCs

#### ➤ Equipments Required:

SIMATIC C7-621, SIMATIC S5-100U, PG 605U Programmer, STEP 7 programming software.

#### ➤ Introduction

##### **Combining Hardware and Software**

Using the STEP 7 software, you can create your S7 program within a project. The S7 programmable controller consists of a power supply unit, a CPU, and input and output modules (I/O modules). The programmable logic controller (PLC) monitors and controls your machine with the S7 program. The I/O modules are addressed in the S7 program via the addresses.

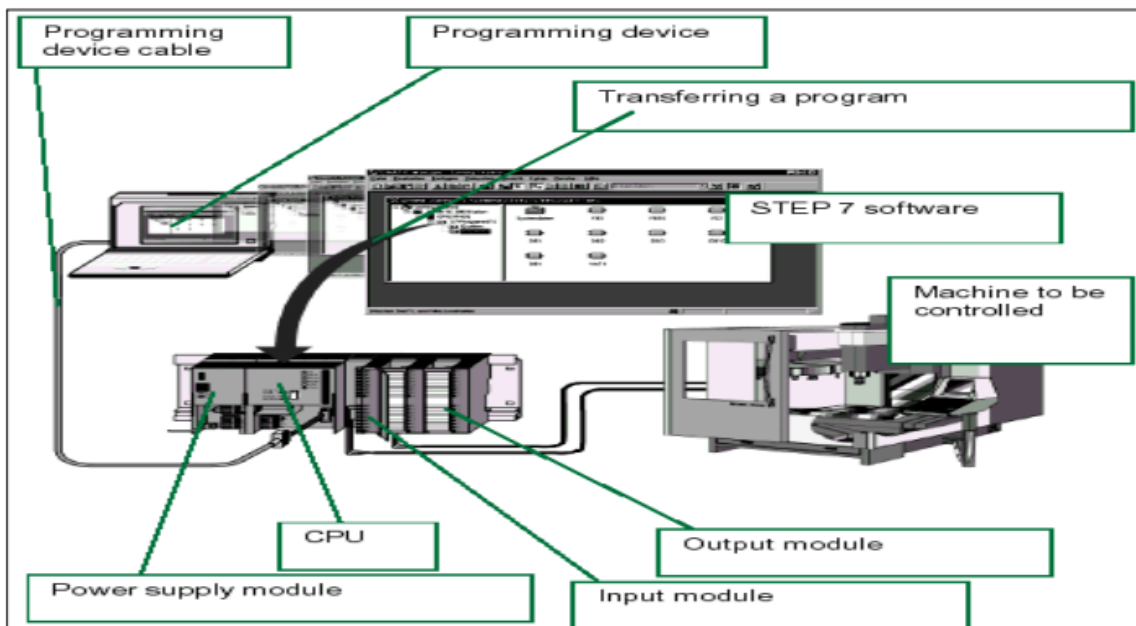


Figure (1.1)

### Choosing Ladder Logic, Statement List, or Function Block Diagram:

With STEP 7, you create S7 programs in the standard languages Ladder Logic (LAD), Statement List (STL), or Function Block Diagram (FBD). In this experiment we used ladder logic diagram with SIMATIC C7-621 Control System.

#### 1.SIMATIC C7-621 Control System:

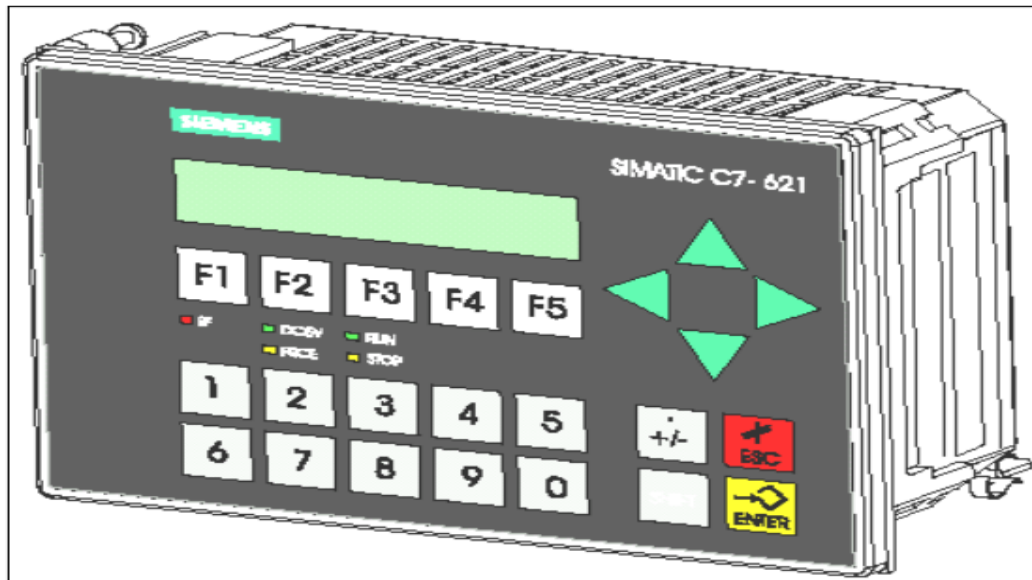


Figure (1.2)

Start up:

After connecting the power supply, the C7 perform a self-test. During this test, it checks the functionality of the most important device components and indicates the test results with the status leds and on the display.

System Functions Menu:

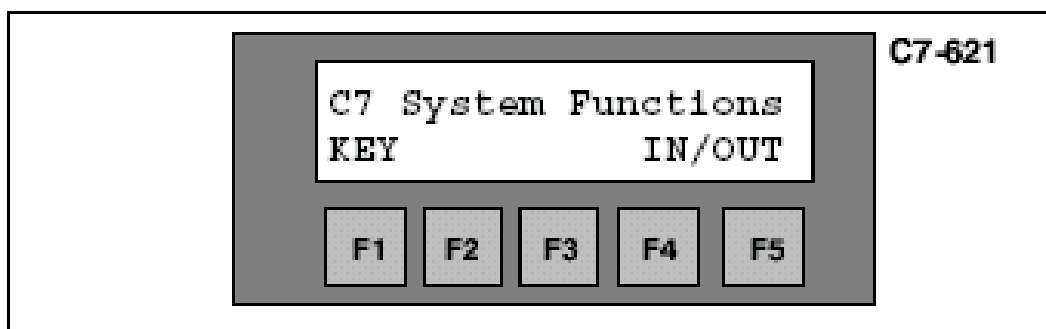
You can select the system function menu in any mode on the C7-621. When this menu is displayed, you can select the following menus or functions:

- C7 CPU mode selection **F1**
  - RUN-P
  - RUN
  - STOP
  - MRES

- DI/DO status display (C7-621) **F5**

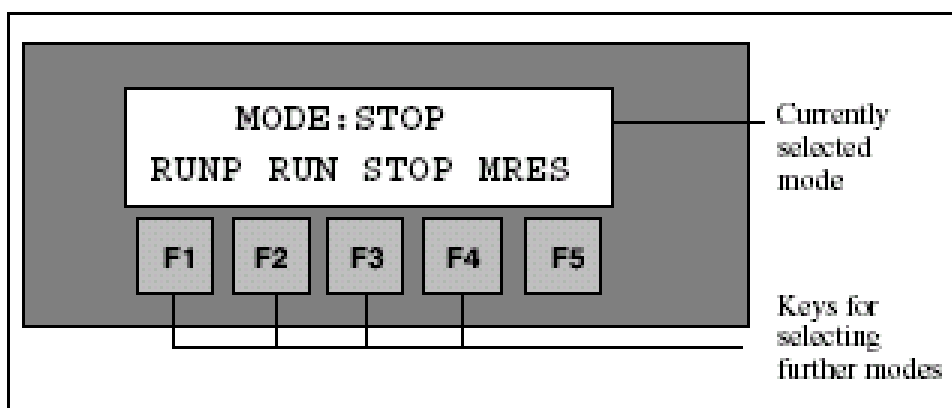
You select this menu by pressing the **SHIFT** **0** keys simultaneously.

The following menu is displayed depending on the version of the unit you are using:



You select the **C7 CPU modes** menu in the system function menu by pressing the **F1** key.

The following menu is displayed (the MODE: STOP is an example):



## 2. SIMATIC S5-100U Control system

- 1- Power supply module.
- 2- Central processing unit (CPU).

- 3- Input/output modules.
- 4- Bus units with terminal blocks.
- 5- Standard mounting rail.

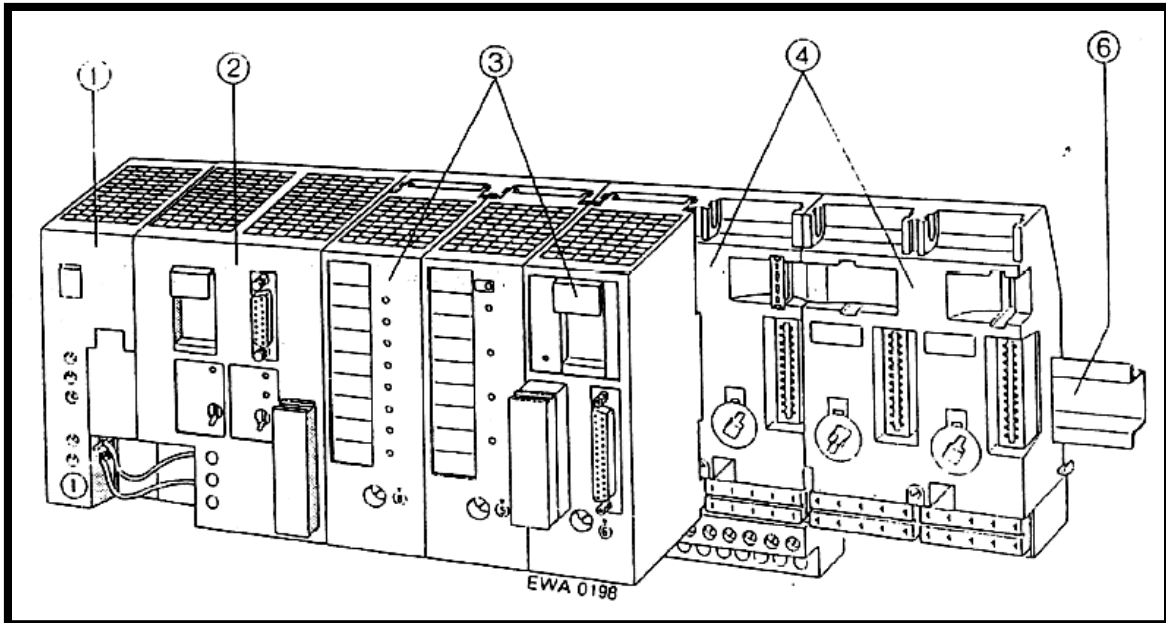


Figure (1.3)

This system differs from the previous two in that you need a hand programmer to Program it; the programming language available in the programmer is (STL) only.

**Procedure:**

1. Create new step 7 software project using SIMATIC Manager program.
2. Select the C7-621 hardware from SIMATIC 300>>C7.
3. From the Blocks folder, open the organization block OB1.

**PART A: SIMATIC C7-621 Control System:**

1. Create a project:

Select the menu item File→New. In the dialog box that appears, create a new project with any name.

Assign a hardware item to your project with the menu item Insert→Station→2 SIMATIC 300 Station. The SIMATIC 300 Station (1) folder appears. Note (Overwrite the name of this station with the new name Quickmix as shown below in figure 1.4).



Figure (1.4)

2. Define the hardware:

Open the station by double clicking .Select the Hardware folder and open it by double-clicking again.

In the Hardware Configurator call up the hardware catalog with Insert → Hardware Components. In this box, select the C7-621 from SIMATIC 300 → C7. A short description of the control system is displayed

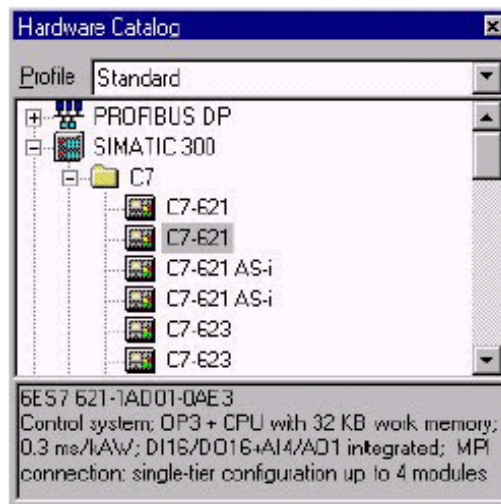


Figure (1.5)

Double-click C7-621 to insert the device in slot 2 of the Hardware Configurator. You have now defined your hardware. The window displays the MPI address of the C7 CPU (default MPI address 2) and the address allocation of the integrated digital I/O.

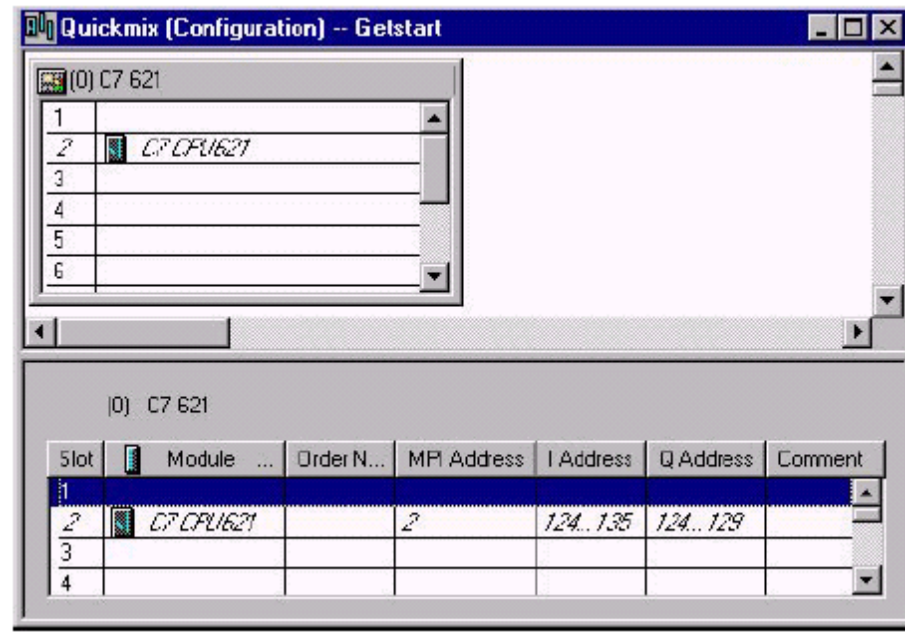


Figure (1.6)

- To save the configuration, select Station → Save and Compile.

-To quit the Hardware Configuration, select Station → Exit.

The folder C7 CPU621, which contains the S7 program, is created automatically by the SIMATIC Manager. This S7 program file contains the Blocks folder with an empty OB1 organization block.

Open the folder by double-clicking.

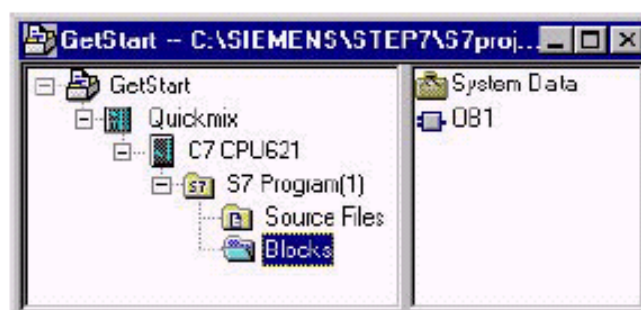


Figure (1.7)

## **PART B: Programming with Symbols:**

### **Absolute Addresses:**



Every input and output has an absolute address predefined by the hardware configuration. This address is specified directly; that is, absolutely. The absolute address can be replaced by any symbolic name you choose.

### Symbolic Programming:

In the symbol table, you assign a symbolic name and the data type to all the absolute addresses which you will address later on in your program; for example, for input I 0.1 the symbolic name Key 1. These names apply to all parts of the program and are known as global variables.

- Open the symbol table by selecting (**Options >> Symbol table**) from the menu bar, or by pressing (**Ctrl+Alt+T**) on the keyboard.
- Fill the symbol table as follows:

Table 1.1

	Symbol	Address	Data Type	Comment
1	key1	I 124.0	BOOL	
2	key2	I 124.1	BOOL	
3	key3	I 124.2	BOOL	
4	key4	I 124.3	BOOL	
5	output1	Q 124.0	BOOL	
6	output2	Q 124.1	BOOL	
7				

- Save the symbol table and Exit from the symbol editor.
- To change from absolute addressing to symbolic addressing, select the menu item (**View>>Display>>Symbolic Representation**) or press (**Ctrl + Q**) on the keyboard.

#### Note:

We refer to the “result of logic operation” By **RLO**.

### ➤ **PART C :Set & Reset Coil:**

The **Set Coil** instruction is executed only if the RLO = 1. If the RLO = 1, this instruction sets its specified address to 1. If the RLO = 0, the instruction has no effect on the specified address. The address remains unchanged. The **Reset Coil** instruction is executed only if the RLO = 1. If the RLO = 1, this instruction resets its specified address to 0. If the RLO = 0, the instruction has no effect on its specified address. The address remains unchanged.

#### **Q1) What is the difference between output coil and set coil instructions?**

1. Create the following ladder diagram in your project, and download it to the PLC SIMATIC C7-621, then test its operation.

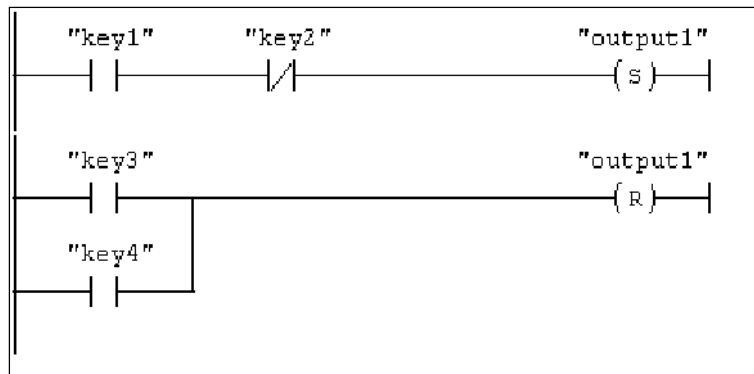


Figure (1.8)

2. Create the same program on SIMATIC S5-100U PLC using statement list programming as follows. Then test its operation.

A I 0.0

AN I 0.1

S Q 1.0

O. I 0.2

O. I 0.3

R Q 1.0

➤ **PART D: PLC Timers:**

Timers have an area reserved for them in the memory of your CPU. This memory area reserves one 16-bit word for each timer address. The ladder logic instruction set supports 256 timers.

**On Delay Timer Coil SD** starts the specified timer with the <time value> if there is a positive edge on the RLO state. The signal state of the timer is "1" when the <time value> has elapsed without error and the RLO is still "1". When the RLO changes from "1" to "0" while the timer is running, the timer is reset. In this case, a scan for "1" always produces the result "0."

Open the timer's folder in the program elements, and check out the different types of timers. Mark each timer and press F1 to display the help to that timer.

**Q2) from the help, explain the operation of the SP timer?**

1. Create the ladder diagram in figure 1.2, and then test its operation using PLC SIMATIC C7-621.

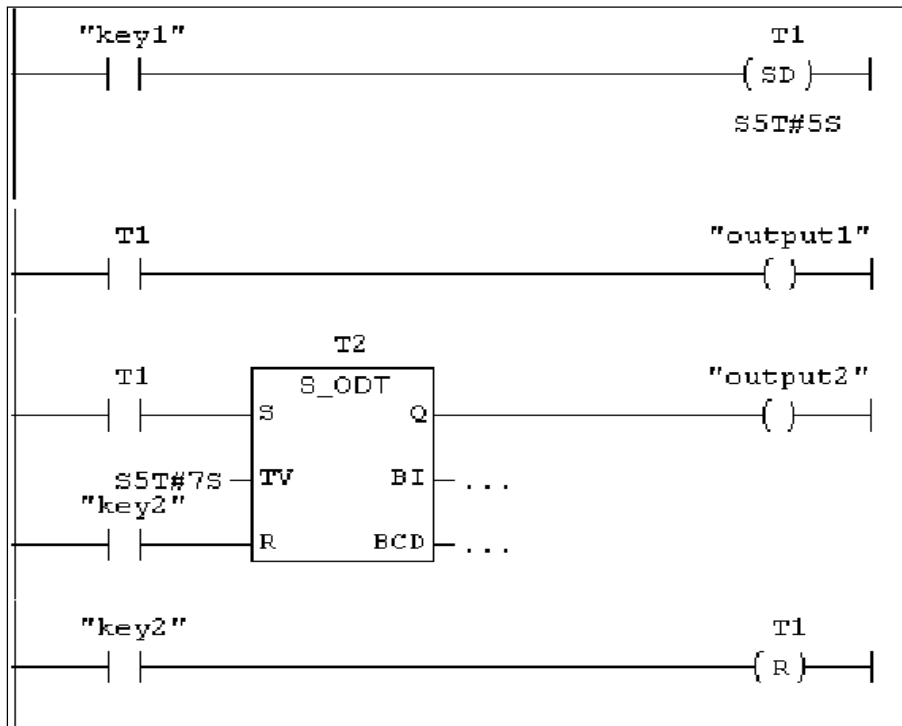


Figure (1.9)

2. Create the same program on SIMATIC S5-100U PLC using statement list programming as follows. Then test its operation.

```

A    I    0.0
L    KT   5.2
SR   T    1
A    T    1
=    Q    1.0
A    T    1
L    KT   7.2
SR   T    2
A    I    0.1
R    T    2
A    T    2

```

= Q 1.1  
 A I 0.1  
 R T 1

➤ **PART E: PLC Counters:**

Counters have an area reserved for them in the memory of your CPU. This memory area reserves one 16-bit word for each counter address. Bits 0 through 11 of the counter word contain the count value in BCD format.

**Q3) what is the range of the count value of each counter?**

1. Create the following ladder diagram, then test its operation using PLC SIMATIC C7-621.

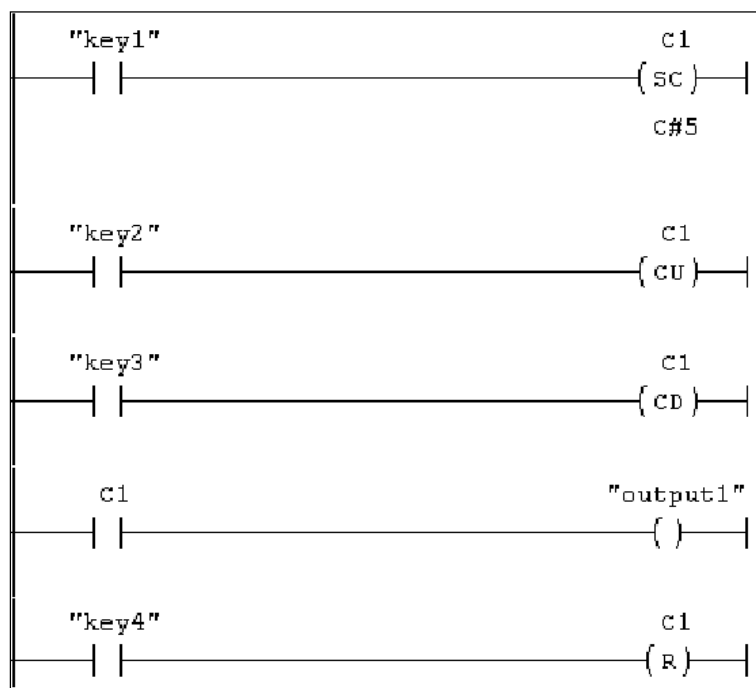


Figure (1.10)

2. Create the same program on SIMATIC S5-100U PLC using statement list programming as follows. Then test its operation.

A	I	0.0
L	KC	5
S	C	1
A	I	0.1
CU	C	1
A	I	0.2
CD	C	1
A	C	1
=	Q	1.0
A	I	0.3
R	C	1

➤ **PART F: Comparison Instructions:**

1. Create the ladder diagram in figure 1.4, and then test its operation using PLC SIMATIC C7-621.

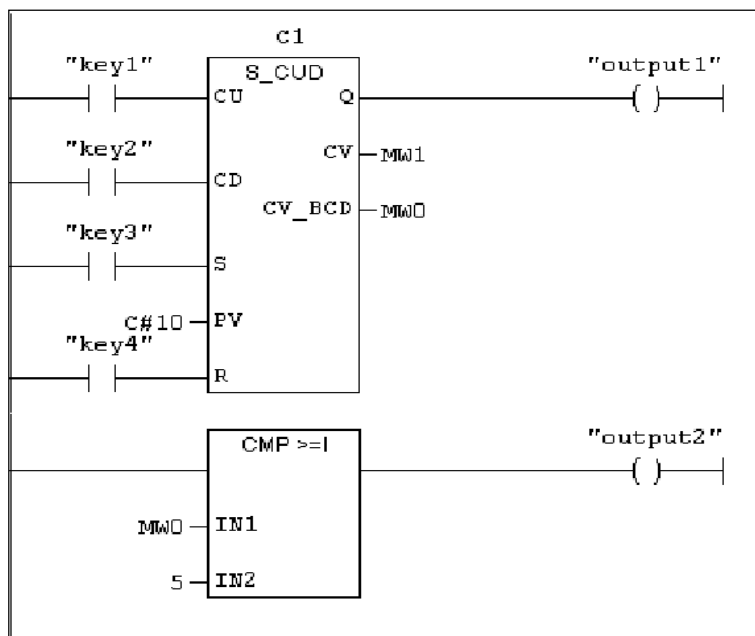


Figure (1.11)

2. Create the same program on SIMATIC S5-100U PLC using statement list programming as follows. Then test its operation.

A	I	0.0
CU	C	1
A	I	0.1

```
CD  C   1
A   I   0.2
L   KC  10
S   C   1
A   I   0.3
R   C   1
A   C   1
=   Q   1.0
L   C   1
L   KC  5
>=F
=   Q   1.1
```

➤ **Exercise:**

1. Using simatic S5-100U and PG 605U Programmer, write a program that set an on delay timer to count for 10 seconds, and display the time value (as a progress bar) on the output port with at least five steps.

➤ **Hints:**

1. Timers count down from set value to zero.
2. Use comparison instructions in your program.
3. In your program, the comparison must occur only if the timer is set.
4. You can use KC or KF to load your comparison value to the accumulator.

## Experiment#2

### Protection Relays

#### Part 1

##### ➤ Objectives:

1. To Connect and study the behavior of a fixed time maximum current relay and of a three-phase line short-circuit one with different current values and check the intervention time.
2. To Connect and study the behavior of a relay for single-phase current, minimum or maximum current, alternated or continuous current and check the intervention time.
3. To Connect and study the behavior of a maximum and minimum voltage relay in a three phase line with neutral and check the intervention time for maximum and minimum voltage.
4. To Connect and study the behavior of relay for single phase voltage, minimum or maximum voltage, alternated or continuous voltage and check the intervention time.

##### ➤ Equipments Required:

1. Modules SR1, SR2, SR3, SR4 and SR11.
2. Variable three-phase power supply source with range of 5 A current.
3. Three phase energy analyzer AZ-VIP.
4. Three phase table kind rheostat  $3 \times 500$  W,  $3 \times 50$   $\Omega$ , for current regulation.
5. Digital chronometer with resolution to the tenth of second (normal clock with chronometer), Ohmmeter.

##### ➤ Theory:

###### **Maximum current three phase relay:**

The three phase amperometric relay set to maximum current (overload) protection function enables to fix the limit of the current provided by an alternator (its nominal power) or the current that a power line can usually stand. The values of the currents are adjustable and so is the intervention time delay.

The three phase amperometric relay set to protection function against short-circuit intervenes instantly when the controlled current overcomes the set value. The current values are adjustable, but the time delay is not as it is instantaneous.

Usually the relay acts on the main switch to set the controlled object out of service (alternator or line).

The current values (over load, short circuit) as well as the delay time, must be adjusted and checked during the test phase and next in the periodical testing to be sure the protection device operates. The current values and the delay times are designed data and must be available for the tests.

### **Maximum or Minimum Single Phase Current Relay:**

The single phase relay enables the control of the over current or under current absorbed or provided by an electrical machine. If the machine is three phase, three phase relays are used that are the set of three single phase relays, one for each current, contained in the same envelope.

The over/under current to be checked can be alternated or continuous, so it follows that there are amperometric relays for alternated currents and those for continuous currents. When an amperometric relay is for alternated current, its range extends with amperometric transformers (CT) while, when it is for continuous current the shunts must be used (the CT are not good).

Most amperometric relays are in alternated current as most of the plants are in alternated current. The continuous current field is limited to a few applications, e.g. we can mention the excitation and armature current control in d.c. current motors and the excitation control in the alternators.

If the amperometric is for alternated as well as for continuous current, it is sufficient to make it checked at start and periodically only with the application electrical variable of application.

### **Maximum or Minimum Three Phase Voltage Relay:**

The three phase voltage relay detects the limit of the triad of voltage generated in ordinary services of the alternator or distributed by the transmission line. Usually, the relay acts on the main switch to set the controlled object out of service (alternator or user connected to the line) when a rise or drop of voltage can cause malfunctions or damages. To achieve this purpose, the maximum and



minimum voltage values as well as the related delay times can be adjusted. The set values must be checked in the test phase and then in the periodical tests to be sure of the protection device operation. The tolerated maximum, minimum voltage values and the delay times are designed data and must be available for the tests.

### **Maximum or Minimum Single Phase Voltage Relay:**

The single phase volmetric relay enables to check the minimum or maximum voltage in a line or devise for electrical power production. If the line is three phase, three phase relay are used that are the set of three single phase relays, one for each voltage, delta (without neutral) or star (with neutral) connected and contained in the same envelope.

The over/under voltage to be checked can be alternated or continuous, so it follows that there are volumetric relays for alternated and direct voltages. When a volumetric relay is for alternated current, its range extends with volmetric transformer (VT) while, when it is for continuous current, resistive divider s must be used.

If the volmetric is for alternated as well as for continuous voltage, it is sufficient to make it checked at start and periodically only with the application electrical variable of application.

#### ➤ **Procedure:**

#### ➤ **Part A: Maximum Current Three Phase Relay:**

1. Follow the electrical diagram in Figure 8-1 to check the intervention against overload and the diagram of Figure 8-2 to test the intervention against short-circuit.
2. Connect the 230-Vac auxiliary power supply line to the relay but do not power.
3. Use the three phase power analyzer to measure the three phase current.
4. Suppose and adjust the device with the following design data:
  - Overload threshold = 2A.
  - Intervention delay = 10 s.
  - Short circuit threshold = 3 A.
5. Connect the multimeter in Ohm to the NC contact of the output relay.
6. Adjust the voltage of the variable power supply line and the load rheostat to a current lower than 2 A. In this condition the amperometric relay does not enter alarm state.

7. Increase the test current over 2 A, record the time between the “over current” moment and the output current relay tripping one (signaled by the interruption of the multimeter continuity). If the delay time and the intervention current values, are not those supposed, adjust with the related controls in the device.
8. Repeat the test with other values (design data).
9. The overload load is signaled in the front panel of the device when the related ALARM led lights on. The output relay tripping, at the end of the given delay, is signaled with the switching off the green and this condition remain in the memory no matter if the current returns under the fixed value.
10. The short circuit is signaled in the front of the device when the related ALARM led lights on. The instant output relay tripping is signaled with the switching off of the green led and this condition remains in the memory no matter if current returns under the fixed value.
11. To reset the device and cancel the memorized information press the preset pushbutton.

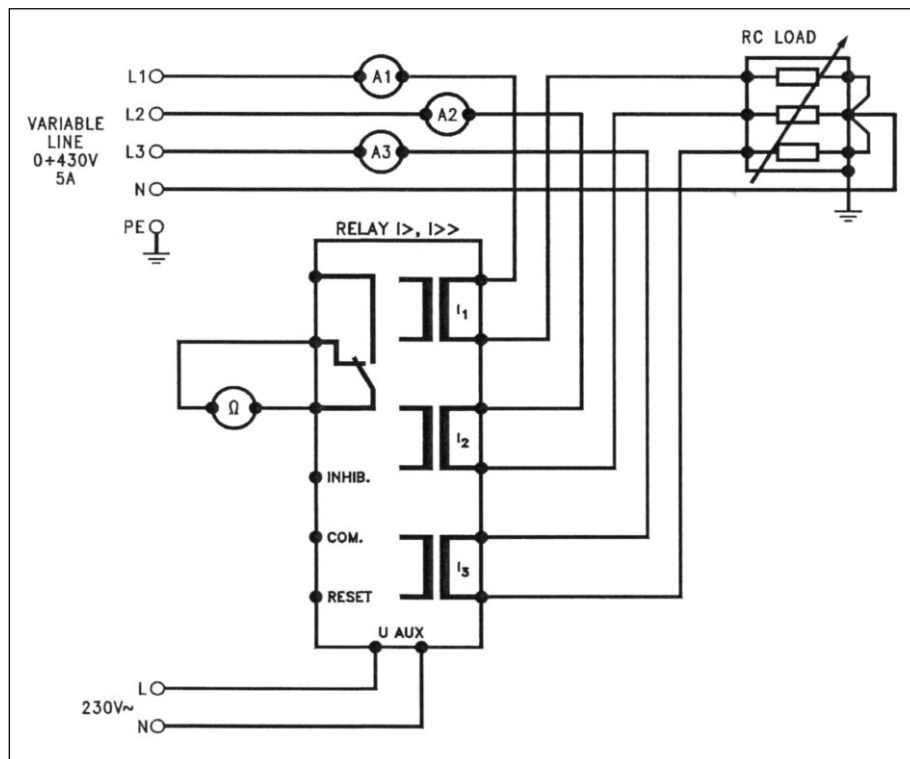


Figure 2-1: Connection Diagram a Maximum Current Relay with Fixed Time in a Three Phase line

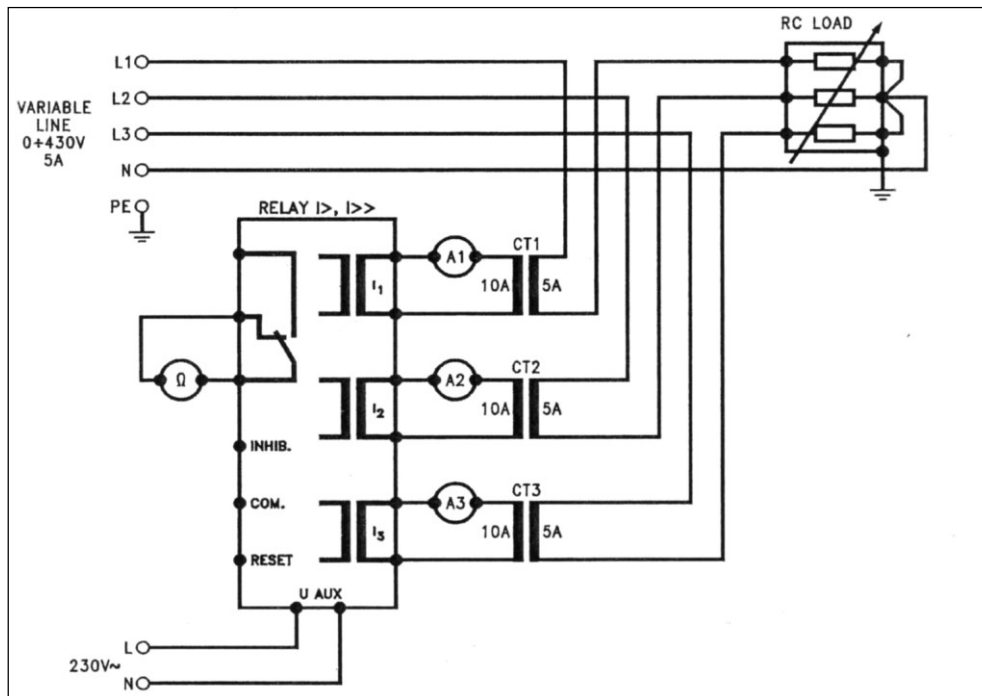


Figure 2-2: Connection Diagram for Checking a Protection Relay Against Short-Circuit Current in a Three-Phase Line

### ➤ **Part B: Single Phase Minimum or Maximum Current Relay:**

#### **Checking a Maximum Single-Phase Alternated Current Relay:**

1. Follow the electrical diagram in Figure 2-3.
2. Connect the 230-Vac auxiliary power supply line to the relay but do not power.
3. Use the three phase power analyzer to measure the phase current.
4. Configure the device as follows:
  - SW1 off, SW2 on = range 5 A.
  - SW3 off = normally excited output relay.
  - SW4 off = delay at start equal to 6s.
  - SW5 off = inhibit input enable.
  - SW6 off = maximum current function.
  - Threshold current (LEVEL) = 20% (20% of 5 A = 1 A).
  - Intervention delay (DELAY) = 5 s.
  - Intervention hysteresis (HYS) = zero.

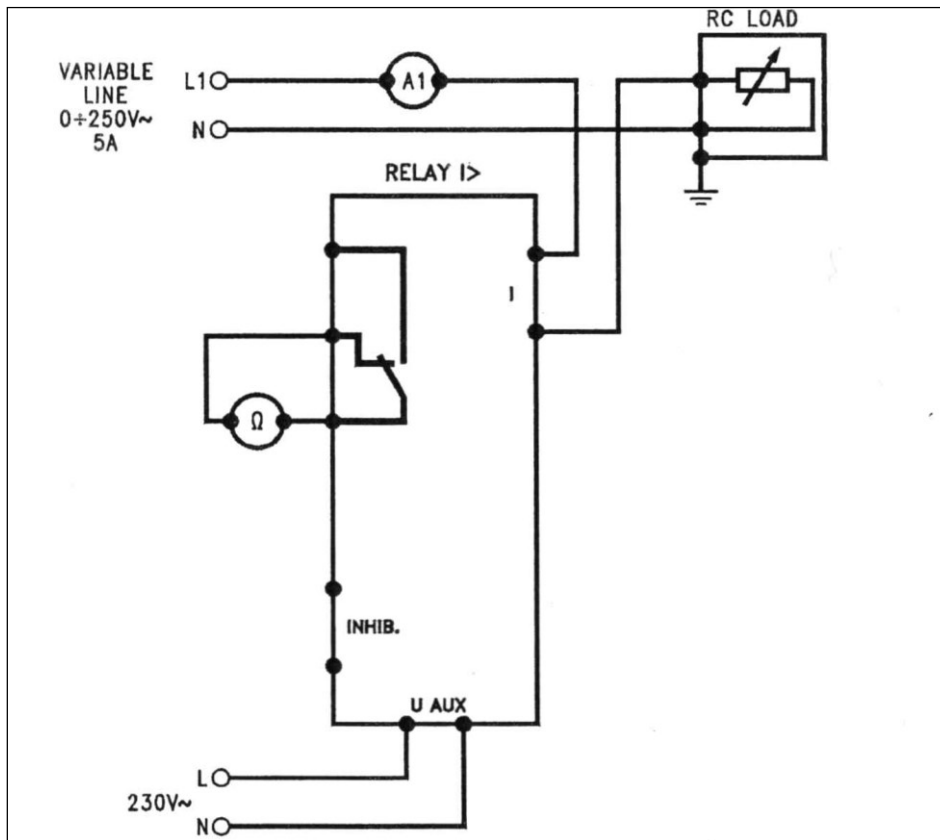


Figure 2-3: Connection Diagram for Checking a Fixed Time Maximum-Minimum, Alternated-Continuous Current Relay

5. Connect the multimeter in Ohm to the NC contact of the output relay.
6. Adjust the voltage of the variable power supply line and the load rheostat to a current lower than 1 A. In this condition the maximum current relay does not enter alarm state.
7. Slowly increase the test current over 1 A, record the time between the ‘maximum current’ moment and the output current relay tripping one (signaled by the interruption of the multimeter continuity). If the delay time and the intervention current values, are not those supposed, adjust with the related controls in the device.
8. Slowly reduce the current under 1 A and check the output relay is reset.
9. The overload is signaled in the front panel of the device by the flashing light of AL led. The output relay tripping at the end of the given delay, is signaled with permanent lighting on of the green led and even with the switching off of the led with contact symbol. The reset is automatic when the current goes under the fixed value (consider the possible hysteresis value).
10. Change the hysteresis value and repeat the test. The relay reset occurs when the current becomes lower than the one fixed plus the value set in the hysteresis.

11.If SW3 is turned ON, the output relay becomes normally de-energized. The stat of the NO-NC contacts is inverted.

### **Checking a Minimum Single-Phase Alternated Current Relay:**

1. Leave the equipments setup as in the previous test.
2. Configure the device as follows:
  - SW1 off, SW2 on = range 5 A.
  - SW3 off = normally excited output relay.
  - SW4 off = delay at start equal to 6s.
  - SW5 off = inhibit input enable.
  - SW6 off = minimum current function.
  - Threshold current (LEVEL) = 20% (20% of 5 A = 1 A).
  - Intervention delay (DELAY) = 5 s.
  - Intervention hysteresis (HYS) = zero.
3. Connect the multimeter in Ohm to the NC contact of the output relay.
4. Adjust the voltage of the variable power supply line and the load rheostat to a current over 1 A. In this condition the minimum current relay does not enter alarm state.
5. Slowly drop the test current under 1 A, record the time between the “maximum current” moment and the output current relay tripping one (signaled by the interruption of the multimeter continuity). If the delay time and the intervention current values, are not those supposed, adjust with the related controls in the device.
6. Slowly increase the current over 1 A and check the output relay is reset.
7. The under current is signaled in the front panel of the device by the flashing light of AL led. The output relay tripping at the end of the given delay, is signaled with permanent lighting on of the green led and even with the switching off of the led with contact symbol. The reset is automatic when the current goes under the fixed value (consider the possible hysteresis value).
8. Change the hysteresis value and repeat the test. The relay reset occurs when the current becomes lower than the one fixed plus the value set in the hysteresis.

➤ **Part C: Three Phase Maximum and Minimum Voltage Relay:**

1. Follow the electrical diagram of Figure 2-4.

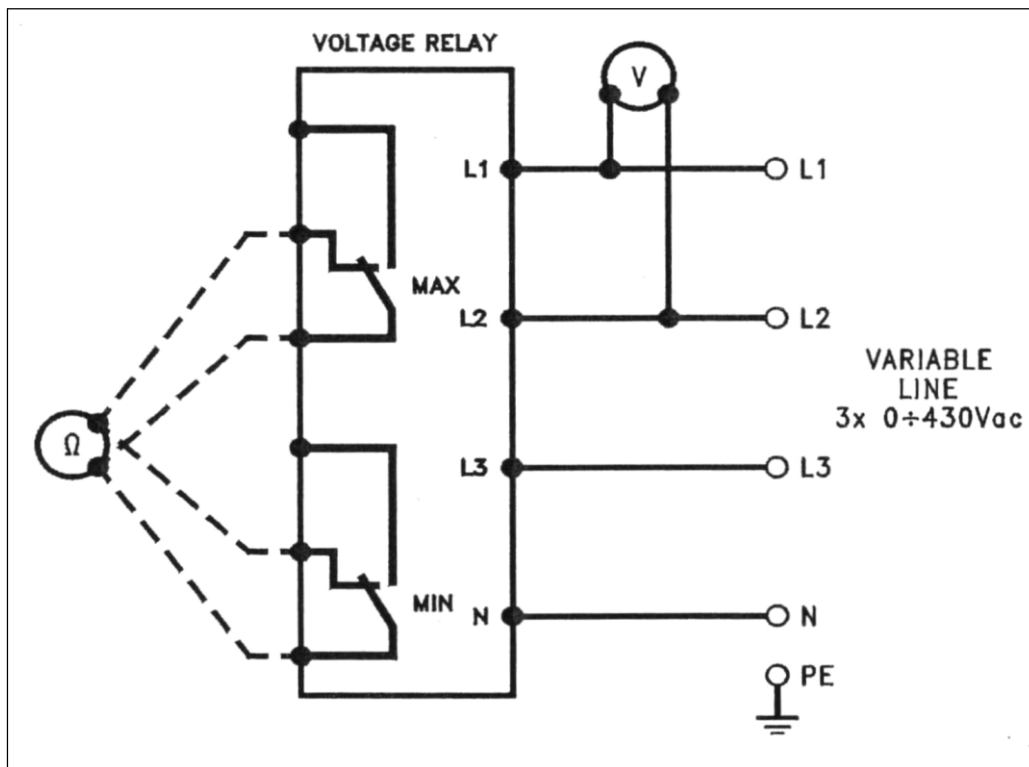


Figure 2-4: Connection Diagram for Testing a Maximum and Minimum Voltage Relay with Fixed Time in Three Phase Line

2. Connect the relay to a variable three-phase power supply line 0-430 Vac with neutral. If the relay is powered with the measurement voltage, as in this case, the auxiliary power supply is not necessary.
3. Use the three phase energy analyzer to measure the three phase voltages.
4. Adjust the device with the following designed data:
  - Line nominal voltage  $U_e = 400 \text{ V}$ .
  - Maximum voltage threshold (MAX VOLTAGE) = 105%.
  - Intervention delay for maximum voltage (DELAY MAX) = 5 s.
  - Minimum voltage threshold (MIN VOLTAGE) = -90%.
  - Intervention delay for minimum voltage (DELAY MIN) = 5 s.
5. Adjust the voltage of the variable power supply line up to 400 V (nominal voltage of the supposed distribution system). In this condition, the volumetric relay is properly powered and does not show any alarm.

6. Connect the multimeter to Ohm alternatively on the NC contacts of the maximum and minimum voltage output relays and check the correspondence of the contacts (they correspond to the diagram shown on the panel in ordinary conditions, voltage in the limit).
7. Increase the test voltage over 420 V, record the time elapsed from the “overvoltage” moment and the tripping one of the same output relay (signaled by the interruption of continuity in the multimeter). If the delay time and the maximum intervention voltage value, are not those supposed, adjust with the related controls in the device.
8. Take back the voltage to the nominal value (400 V) and check that the alarm reenters (the maximum voltage output relay resets). Consider that the relay has a hysteresis of 3% in respect to the set point. This mean the relay resets occurs at  $\approx$  410 V.
9. Drop the test voltage over 360 V, record the time elapsed from the “undervoltage” moment and the tripping one of the same output relay (signaled by the interruption of continuity in the multimeter). ). If the delay time and the minimum intervention voltage value, are not those supposed, adjust with the related controls in the device.
10. Take back the voltage to the nominal value (400 V) and check that the alarm reenters (the maximum voltage output relay resets).
11. Repeat the intervention tests for maximum and minimum voltage with other values (design data).
12. The tripping of the relay for maximum voltage alarm, at the end of the given delay, is signaled by the lighting on of the MAX led and when the voltage goes under the fixed value, it resets.
13. The tripping of the relay for minimum voltage alarm, at the end of the given delay, is signaled by the lighting on of the MIN led and when the voltage goes over the fixed value, it resets.

➤ **Part D: Single Phase Minimum or Maximum Voltage Relay.**

- **Testing the Relay for Maximum Alternated Single-Phase Voltage.**

1. Follow the electrical diagram of Figure 2-5

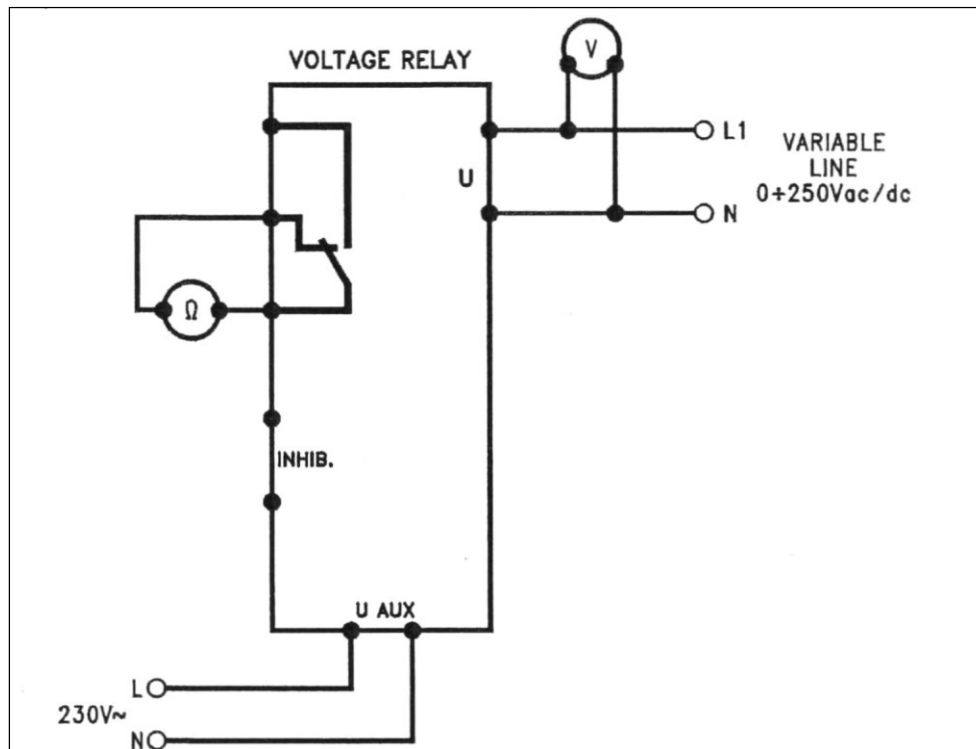


Figure 2-5: Connection Diagram for Testing a Relay for Fixed Time Maximum-Minimum Voltage, Alternated-Continuous

2. Connect the 230-Vac auxiliary power supply line to the relay but do not power it.
3. Connect the relay to the variable power supply line of 0-250 Vac.
4. Connect the three phase energy analyzer for voltage measurements.
5. Configure the device as follows:
  - SW1 off, SW2 on = range 500 V.
  - SW3 off = normally energized input relay.
  - SW4 off = delay at start up equal to 6 s.
  - SW5 off = Inhibit input enabling.
  - SW6 on = maximum voltage function.
  - Voltage threshold level (LEVEL) = 50% (50% of 500 V = 250 V).
  - Intervention delay (DELAY) = 5 s.
  - Intervention hysteresis (HYS) = zero.
6. Connect the multimeter in Ohm to the NC contact of the output relay.
7. Adjust the voltage of the variable power supply line to about 230 V. In this condition the maximum voltage relay does not enter alarm state.
8. Slowly increase the test voltage over 250 V, record the time between the "maximum voltage" moment and the output voltage relay tripping one (signaled by the interruption of the multimeter continuity). If the delay time and the



intervention voltage values, are not those supposed, adjust with the related controls in the device.

9. drop the voltage to 230 V and check the output relay is reset.
10. The over voltage is signaled in the front panel of the device by the flashing light of AL led. The output relay tripping at the end of the given delay, is signaled with permanent lighting on of the green led and even with the switching off of the led with contact symbol. The reset is automatic when the voltage goes under the fixed value (consider the possible hysteresis value).
11. Change the hysteresis value and repeat the test. The relay reset occurs when the voltage becomes lower than the one fixed plus the value set in the hysteresis.
12. If SW3 is turned ON, the output relay becomes normally de-energized. The state of the NO-NC contacts is inverted.

- **Testing the Relay for Maximum Continuous Voltage:**

Repeat the above exposed procedure but with the variable power supply line in d.c.

- **Testing the Relay for Minimum Alternated Voltage:**

1. Leaving the equipments setup as in the previous parts configure the device as follows:
  - SW1 off, SW2 on = range 500 V.
  - SW3 off = normally energized input relay.
  - SW4 off = delay at start up equal to 6 s.
  - SW5 off = Inhibit input enabling.
  - SW6 off = maximum voltage function.
  - Voltage threshold level (LEVEL) = 40% (40% of 500 V = 200 V).
  - Intervention delay (DELAY) = 5 s.
  - Intervention hysteresis (HYS) = zero.
2. Connect the multimeter in Ohm to the NC contact of the output relay.
3. Adjust the voltage of the variable power supply line to about 230 V. In this condition the maximum voltage relay does not enter alarm state.
4. Drop test voltage under 200 V, record the time between the "maximum voltage" moment and the output voltage relay tripping one (signaled by the interruption of the multimeter continuity). If the delay time and the intervention voltage values, are not those supposed, adjust with the related controls in the device.
5. Increase the voltage to 230 V and check the output relay is reset.

6. The under voltage is signaled in the front panel of the device by the flashing light of AL led. The output relay tripping at the end of the given delay, is signaled with permanent lighting on of the green led and even with the switching off of the led with contact symbol. The reset is automatic when the voltage goes under the fixed value (consider the possible hysteresis value).
  7. Change the hysteresis value and repeat the test. The relay reset occurs when the voltage becomes higher than the one fixed plus the value set in the hysteresis.
  8. If SW3 is turned ON, the output relay becomes normally de-energized. The stat of the NO-NC contacts is inverted.
- **Testing the Relay for Maximum Continuous Voltage:**  
Repeat the above described procedure but with the variable power supply line in d.c.

## Part 2

### ➤ Objectives:

1. Connect and study the behavior of phase sequence and three-phase voltage relay, check the intervention time with wrong sequence and non symmetrical conditions or with phase lack.
2. To Connect and study the behavior of a maximum current directional relay for maximum current and check the intervention time with inverse current flow.
3. To use an auxiliary relay as interface to control large power flows.
4. To use an auxiliary relay as interface for remote optical-acoustic signaling of the protection relays operation.
5. To use a timer with different time functions to extend the protection relays operation.

### ➤ Equipments Required:

1. Modules SR6, SR7, SR8,SR9 and SR10.
2. Variable three-phase power supply source with range of 5 A current.
3. Three phase energy analyzer AZ-VIP.
4. Three phase table kind rheostat  $3 \times 500$  W,  $3 \times 50$   $\Omega$ , for current regulation.
5. Digital chronometer with resolution to the tenth of second (normal clock with chronometer).
6. Ohmmeter.
7. Fixed power supply source 24Vdc,  $I_n > 1$  A.

### ➤ Theory:

Phase Sequence Relay used to ensure the sequence is correct when connecting 3 phase loads. With an incorrect phase sequence the relay will de-energize preventing the starting of incorrectly connected machinery.

Directional relays are a very large family of equipment sharing the capacity to control the power direction. The concept of direction comes from the angular relations between phase voltages and current where, by convention, + is considered the direction of a vector resulting from the composition of a reference vector with another set within 90 from the first, -the one resulting from the composition with a superior angle. The timer relays delayed in closing, delayed in opening, intermittence, enable to extend the functions of a protection relay.

➤ **Procedure:**

➤ **Part A: Phase sequence and three-phase voltage asymmetry relay:**

1. Follow the electrical diagram of figure 2.6.

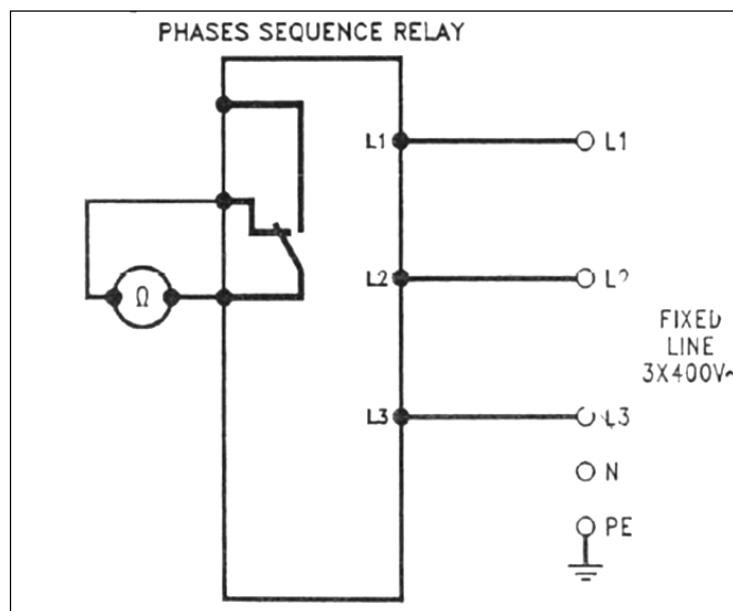


Figure 2.6 Connection diagram for testing a sequence relay, instant time phase lack in a three-phase line.

2. Connect the relay to a 400 –Vac fixed 3-phase power supply line.
3. Connect at least a voltmeter to measure a.c voltage at relay input.
4. Adjust the device at module SR6 with the following design data:
  - asymmetry (ASMMETRY)=10%.
  - Intervention delay in asymmetry (DELAY)=5s.

5. Connect to 3x400-V power supply .If the phase sequence is correct, beside the ON led, he the relay led must light on too. If not the power supply conductor must be inverted.
  - ☑ Note:  
When the relay led is on, the phase sequence and the 3-phase voltage asymmetry powered and shows no alarm.
6. With a multimeter in ohm, check the state of the relay , by connect it to the NC contact of the output relay
7. Invert two phases on themselves and check the instant intervention of the output relay.
8. Interrupt a phase of the triad under control and check the output relay instant operation.
9. Change the test circuit as in figure 2.7 ,with the VT ,so the value of one of the 3-phase of the triad under control is changed ,record the time elapsed from the “ asymmetry” time and the tripping one of the output relay .If the delay time and the intervention asymmetry value are not those supposed adjust with the related regulations in the device .

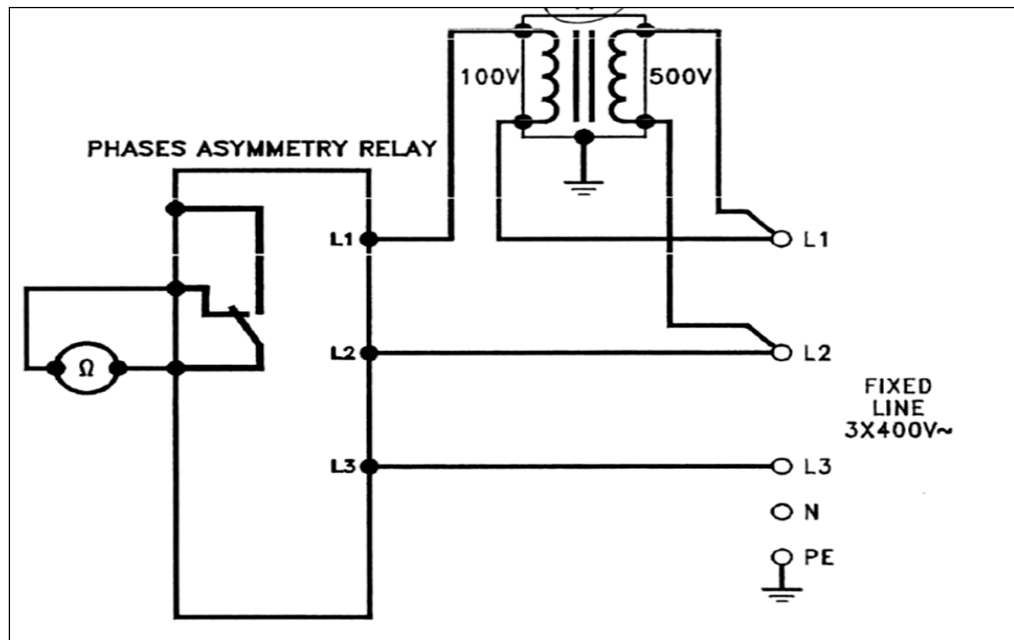


Figure 2.7 Connection diagram for testing a fixed time phase asymmetry relay in a three-phase line.

10. Repeat the intervention tests for maximum asymmetry and minimum voltage with other values.

➤ **Part B: Maximum current directional relay:**

1. Follow the electrical diagram of figure 2.8

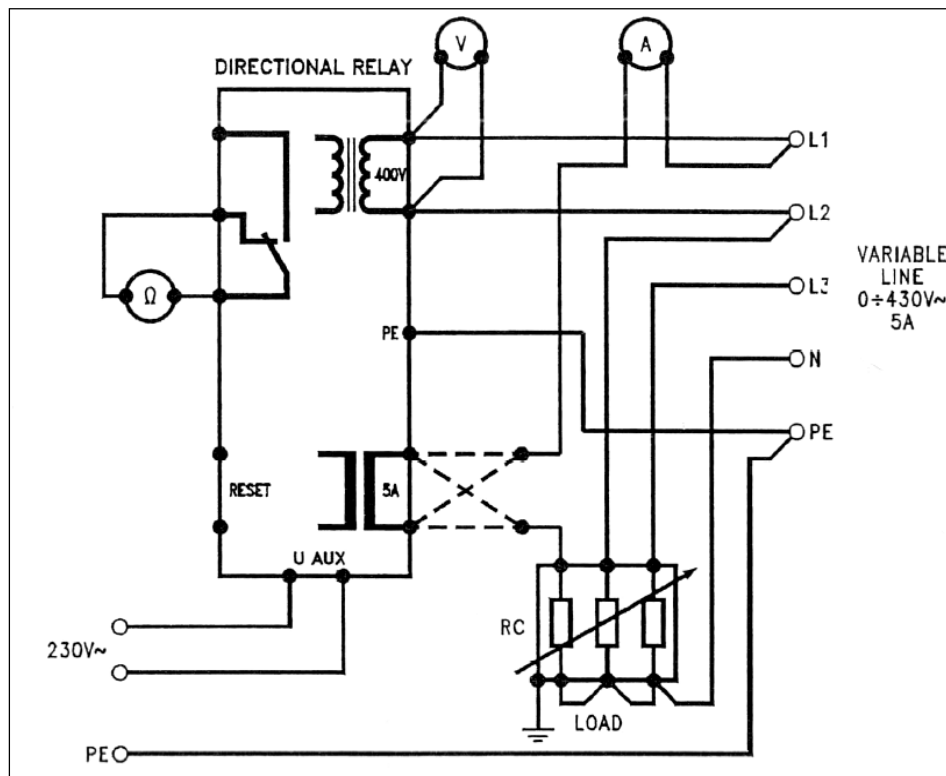


Figure 2.8 Connection diagram for testing a measurement relay of the active components of the current – power return (maximum current directional relay).

2. Connect the terminals (power supply) to 230-Vac auxiliary power supply line , but do not connect the voltage , connect the terminal PE to the protection conductor , too.
3. Connect the Terminals (voltage Input) respectively to L1 and L2 of the variable 3-phase power supply source. Connect a voltmeter to measure the relay input alternated voltage .
4. From the same 3-phase power supply source by-pass the 3-phase load consisting in the RC rheostat, the current  $I_1$  must reach the terminals (current input). Connect ammeter to measure the relay input alternated current (load current). In practice, it sufficient to insert the load only on the conductor L1-Neutral.
5. Suppose and adjust the device with the following designed data :
  - Dip- switch angle  $\alpha = 30^\circ$  :
  - Delayed intervention dip-switch =ON:
  - Inverse current threshold ( $I_s$ )= 0.7A (dip-switch a2+4 ON):

- Intervention time ( $T_s$ ) = 5s (dip- switch t 0.1 + 0.8 + 4).
6. As set, it is a directional relay that, with the current direction ( $I_n=5A$ ) to the input (input in the higher terminal) does not enter alarm state.
  7. Connect the auxiliary voltage and with 0-430V variable line adjust the load current to about 1A, check the led is lighted ON (NORMAL) on the relay front panel.
  8. Check the correspondence of the output relay contacts (powered device not in alarm state).
  9. Invert the CT input current direction and check that with a current a little over the set threshold in  $I_s$  (0.7A), after the time  $T_s$  (5s), the output relay changes state and the trip led turns on. Besides, check that the memory led lights on and it keeps lighted, even dropping the current under the  $I_s$ .
  10. The relay reset is manual, it can be done only after the current goes back under the threshold, with the pushbutton on the front panel or with the insertion of a jumper in to RESET terminals.

➤ **Part C: Auxiliary relay as interface to control large power flows:**

1. Follow the electrical diagram of figure 2.9

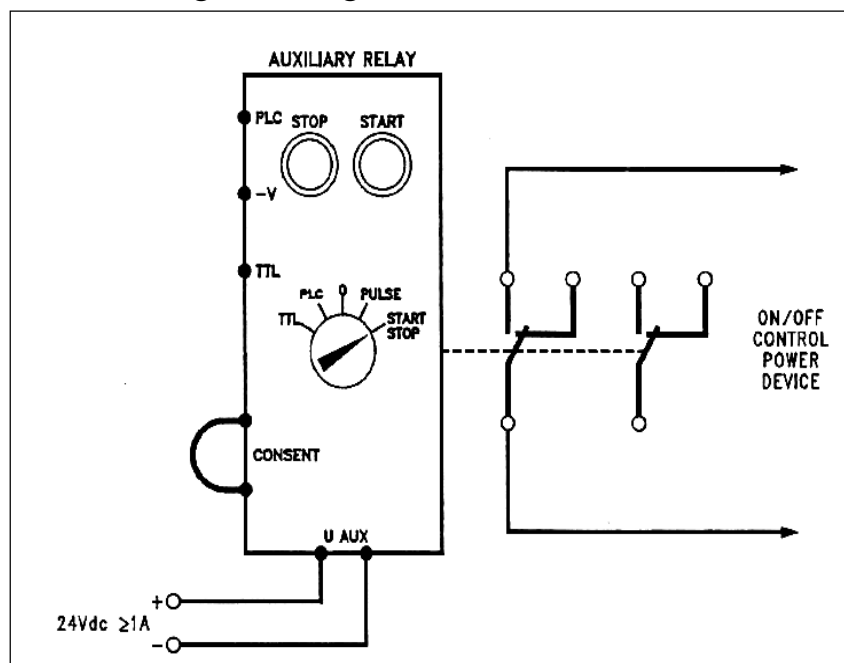


Figure 2.9 Connection diagram to use an auxiliary relay with run-stop function.

2. Turn the rotary switch to START STOP or PULSE.
3. Connect the Terminals (POWER SUPPLY) to the 24-VDC auxiliary power supply line.
4. Connect the CONSENT terminals.

5. Push the START pushbutton and check that the light on the START pushbutton lights ON to confirm the relay activated, check the corresponding of the output relay contacts.
6. Push the STOP pushbutton to check that the relay not active.
7. Further “STOP” devices can be included connecting their NC contacts to the CONSENT terminals.

➤ **Part D: Auxiliary relay as interface to control large power flows:**

1. Follow the electrical diagram of figure 2.10 or figure 2.11

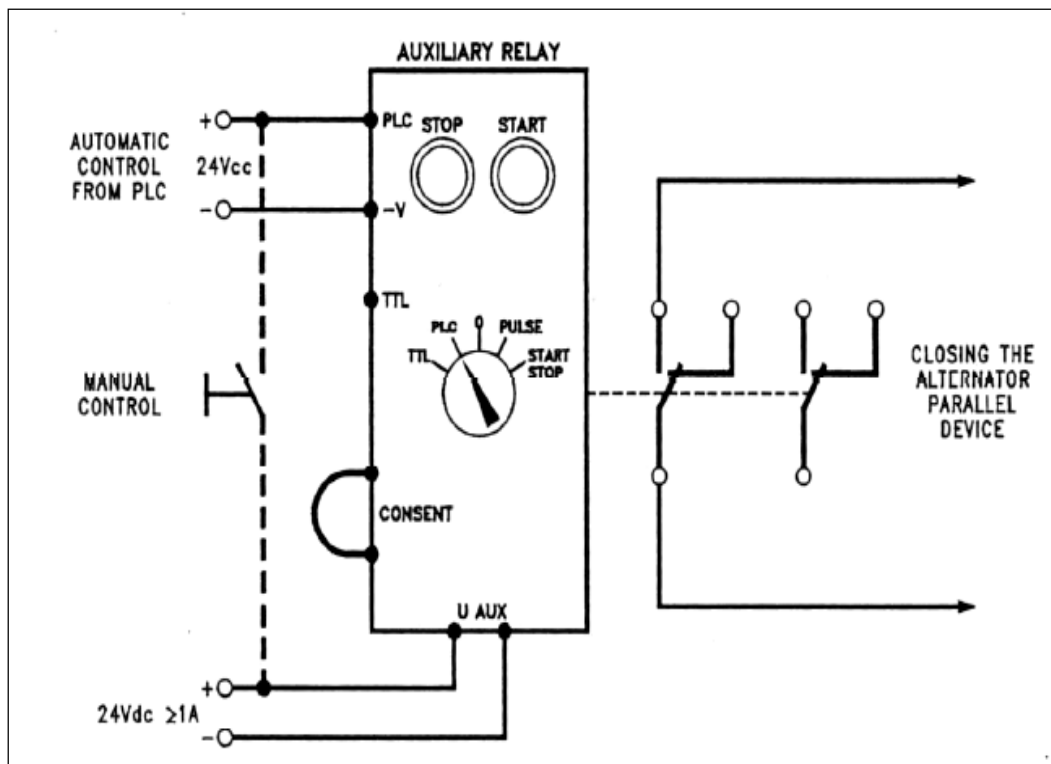


Figure 2.10 Connection diagram to use an a relay as interface for PLC.

2. Turn the rotary switch to PLC or TTL.
3. Connect the Terminals (POWER SUPPLY) to the 24-VDC auxiliary power supply line.
4. Connect the auxiliary voltage and check the stop pushbutton is lighted on.
5. Make a connection on the CONSENT terminal.
6. Inject the control voltage and check that the light on the START pushbutton lights ON to confirm the relay activated, check the corresponding of the output relay contacts.
7. Disconnect the control voltage and check the relay is not active .

8. Further “INHIBIT” device can be included connecting some NC contacts in the CONSENT terminals.

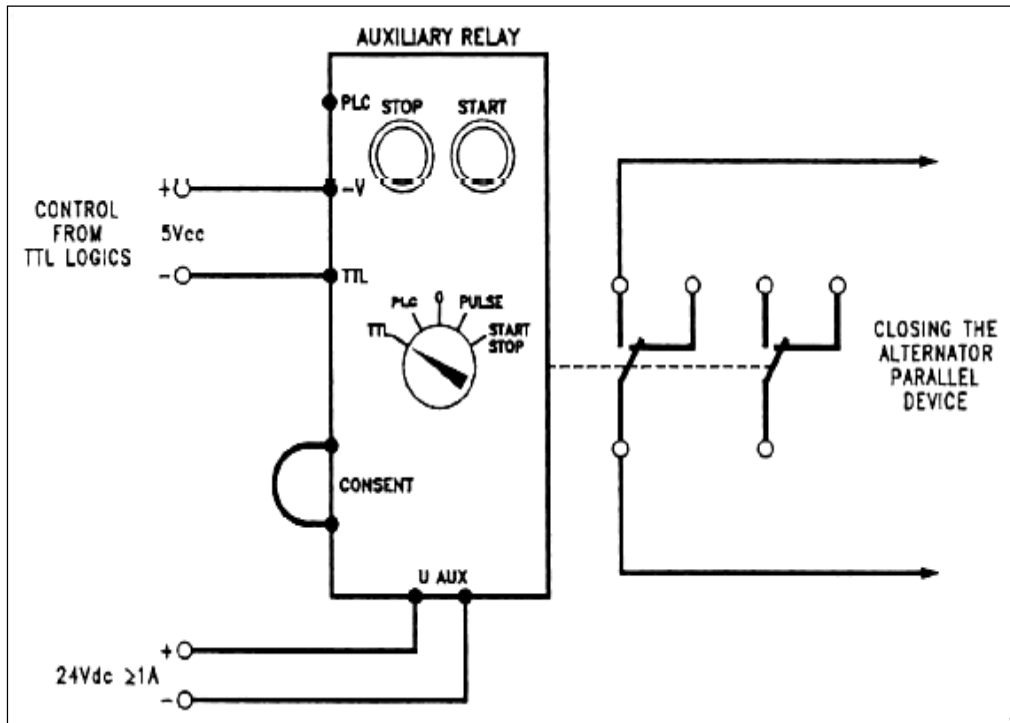


Figure 2.11 Connection diagram to use a relay with TTL logics.

➤ **PART E: Relay as interface for remote optical-acoustic signaling of the protection relays operation:**

**A. Relay used to activate an alarm ( negative safety):**

1. Follow the electrical diagram of figure 2.12

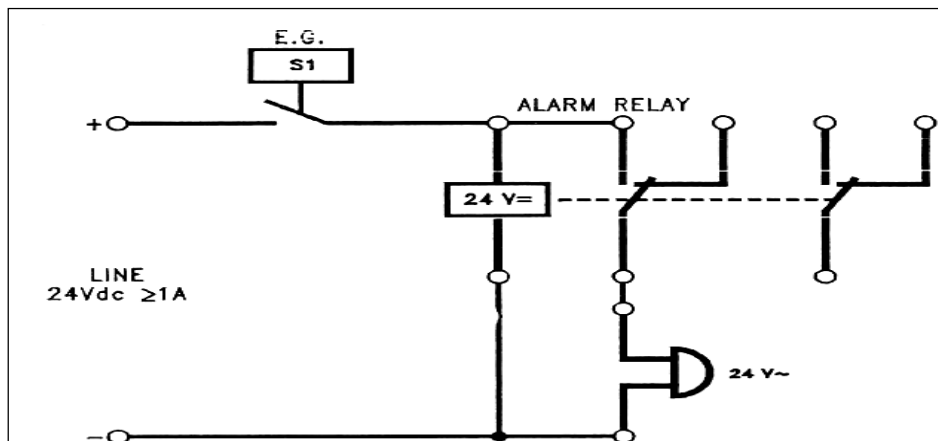


Figure 2.12 Usage diagram of an alarm relay connected to a protection relay with output on NO contact .IT is negative safety because if the alarm relay breaks signaling activates.

2. Connect the auxiliary voltage and simulate the closing of the NO contact of the maximum current relay.
3. Check the acoustic signal activation.



**B. Relay used to activate different alarm signalers (positive safety):**

1. Follow the electrical diagram of figure 2.13

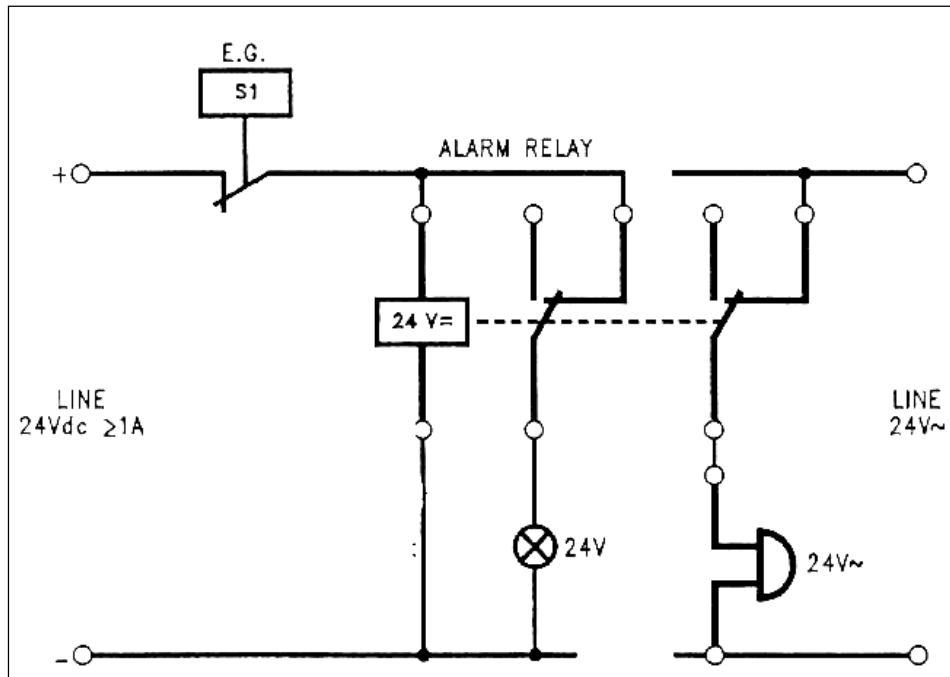


Figure 2.13 Usage diagram of an alarm relay connected to a protection relay with output on NC contact .

2. Connect the auxiliary voltage and simulate the closing of the NC contact of the maximum current relay.
3. Check the acoustic signal activation.

➤ **Part E: On delay time relay and OFF delay time relay:**

**A. On delay – time relay:**

1. Follow the electrical diagram of figure 2.14

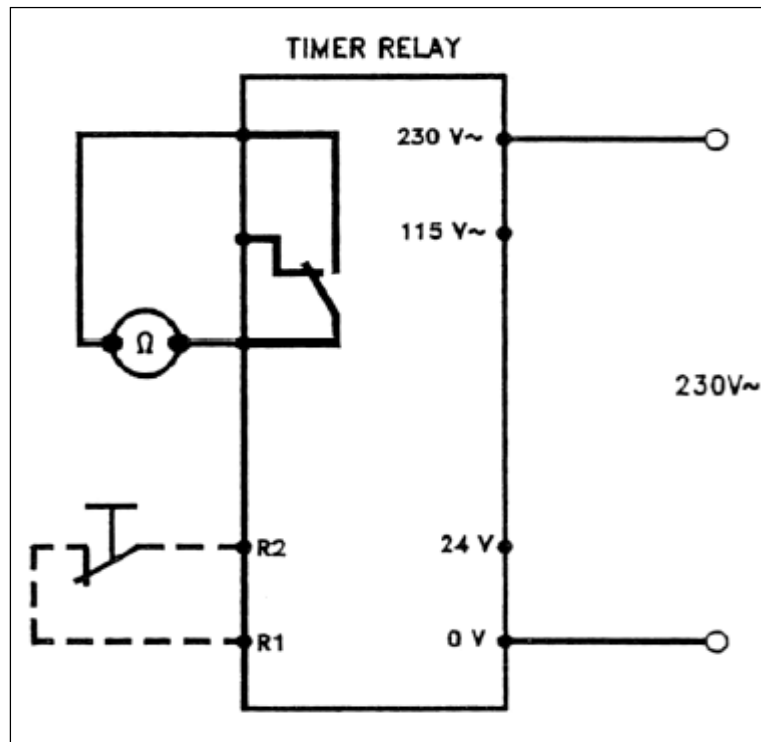


Figure 2.14 Usage diagram of a timer relay in different configurations 230-Vac power supply

2. Configure the timer as follows:

- SW3 = OFF Normal state of the output relay:
- SW4 = OFF delay function inclosing :
- SW6,7 = OFF and SW5,8 = ON(time range from 1.2 to 12s);
- Trimmer for timer regulation at half range = about 6s.

3. Connect the timer to the power supply voltage.

4. Check the state of the timer output relay after the fixed time.

**B. OFF delay –time relay:**

5. Configure the timer as follows:

- SW3 = ON Inverted state of the output relay:
- SW4 = OFF delay function inclosing :
- SW6,7 = OFF and SW5,8 = ON(time range from 1.2 to 12s);
- Trimmer for timer regulation at half range = about 6s.

6. Connect the timer to the power supply voltage, the output relay immediately activates and after the given time de-activates.

7. Check the state of the timer output relay after the fixed time.

8. Repeat part A, B for the Flowing the electrical diagram of figure 2.15

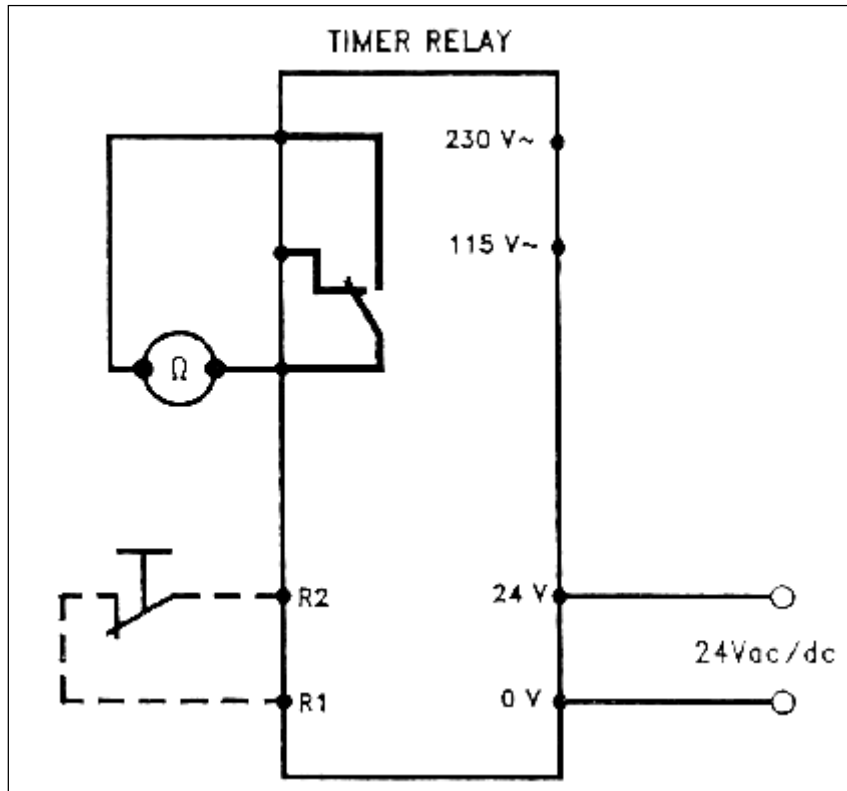


Figure 2.15 Usage diagram of a timer relay in different configurations 24-Vac/dc power supply.

## Experiment # 3

### Power-Factor Improvement

➤ **Objectives:**

To study and examine ways of improving the power-factor of single and 3-phase induction motors, using capacitors.

➤ **Equipment Required:**

1. FH80, FH90.
2. Voltmeter, Ammeter, Wattmeter.
3. Capacitors.

➤ **Theory:**

**Power-factor fundamentals:**

The usual definition of power factor based on the fact that there are two types of current in an AC circuit is particularly helpful in understanding the effect of power factor on system operation and understanding capacitor applications.

Although the following discussion on fundamentals is written around the use of capacitors because they generally are the most practical and economical means for improving the PF, these fundamentals also apply to other methods, such as synchronous motors and condensers.

The current required by induction motors, transformers, fluorescent lights, induction heating furnaces, resistance welders, etc., may be considered to be made up of two separate kinds of current: **magnetizing current** and **power-producing current**.

Some loads, such as incandescent lights, require only power-producing current. Power-producing current (or working current) is that current which is converted by the equipment into useful work such as turning a lathe, making a weld, or pumping water. The unit of measurement of power produced is the kilowatt (kW).

Magnetizing current (also known as wattles, reactive, or nonworking current) is that current which is required to produce the flux necessary to the operation of induction devices. Without magnetizing current, energy could not flow through

the core of a transformer or across the air gap of an induction motor. The unit of measurement of magnetizing volt-amperes is the kilovar (kVAR).

Total current is the current that is read on an ammeter in the circuit. It is generally made up of both magnetizing and power-producing currents. The unit of measurement of total volt-amperes or "apparent power" is the kilovolt-ampere (kVA).

Most AC power systems require both kilowatts and kilovars.

The following useful formulas apply when kW, kVAR, and kVA are substituted for their respective currents:

$$(Kva)^2 = (Kw)^2 + (Kvar)^2$$

$$(Kw)^2 = (Kva)^2 - (Kvar)^2$$

$$(Kvar)^2 = (Kva)^2 - (Kw)^2$$

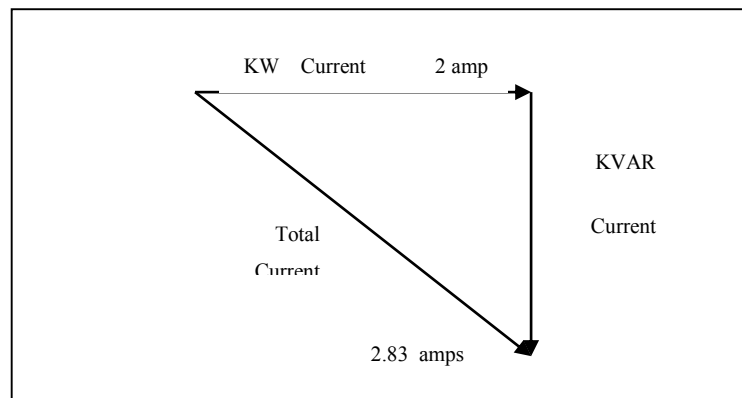


Figure 3.1: Diagram showing component current in AC circuit.

What is power-factor:

Power factor may be expressed as the ratio of power-producing current in a circuit to the total current in that circuit. Another definition of power factor, which is generally more useful, is the ratio of kW or working power to the total kVA or apparent power. Thus,

$$PF = kW/kVA$$

$$kW = kVA * PF$$

$$kVA = kW/PF$$

Stated another way, the power factor is that factor by which the apparent power must be multiplied in order to obtain the working power.

### How to improve power factor

When the kilovar current in a circuit is reduced, the total current is reduced. If the kilowatt current does not change, as is usually true, the power factor will improve as kilovar current is reduced. When the kilovar current becomes zero, all the current is kilowatt current and therefore the power factor will be 1.0 (unity) or 100%. This could be done by installing capacitors to supply the load kilovar requirements.

➤ **Procedure:**

➤ **PARTA :Single-phase induction motor:**

1. Using FH80, connect the circuit as in Figure3.2.

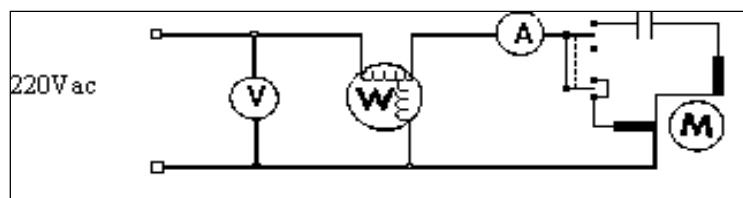


Figure 3.2: Capacitor start motor

2. Adjust the voltage to 220V, and progressively increase the torque on the motor (in steps of 0.2N.m up to 0.8N.m) taking readings of torque, speed, input power, voltage, and current. Tabulate your results and complete table 3.1. Plot these data [speed and power factor against torque].
3. Now connect the capacitor bank across the terminals of the motor as in Figure 3.3.

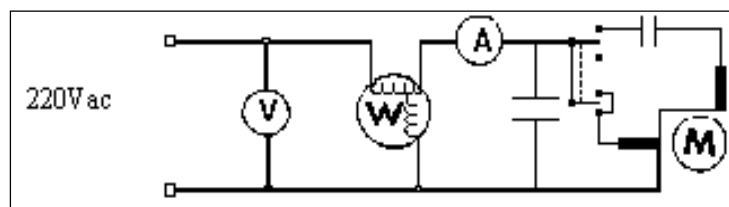


Figure 3.3: Capacitor start motor with shunt capacitor

4. Repeat step (2) for a capacitor values 3, 5, and 10uF.

Torque	Speed	$I_{in}$	V	$P_{in}$	$V \cdot I$	PF	Q
0.0							
0.2							
0.4							
0.6							
0.8							

Table 3.1

➤ **PARTB :Three-phase induction motor:**

1. Using FH90, connect the circuit as in Figure 3.4.

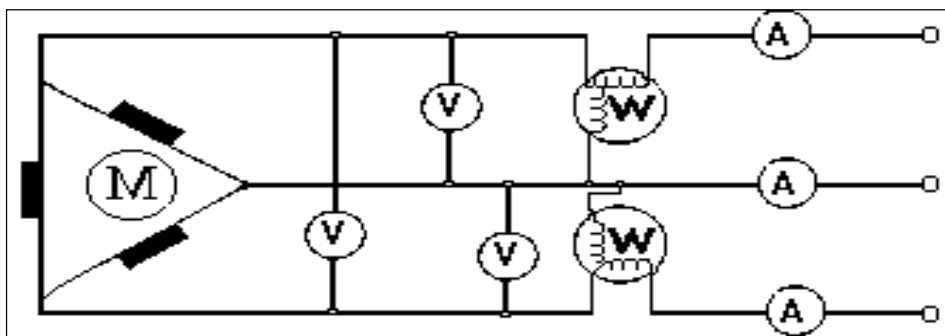


Figure 3.4: phase induction motor  $\Delta$ -connected

2. Adjust the voltage to 220V, and progressively increase the torque on the motor (in steps of 0.2N.m up to 0.8N.m) taking readings of torque, speed, input power, voltage, and current. Tabulate your results and complete table 3.2. Plot these data [speed and power factor against torque].

Torque	Speed	$I_{in}$	V	$P_{in}$	$(3)^{0.5} V \cdot I$	$P_{out}$	PF	Q	$\eta$
0.0									
0.2									

0.4									
0.6									
0.8									

Table 3.2

- Now connect the capacitor bank ( $2\mu\text{F}$   $\Delta$ -connected) across the terminals of the motor as in figure 3.5.

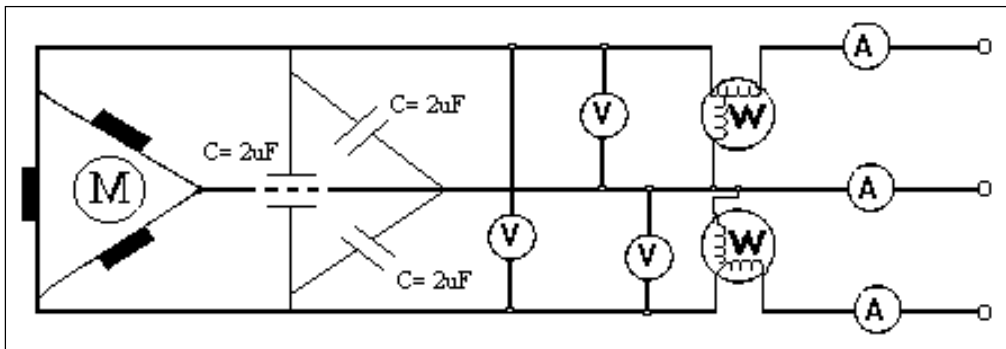


Figure 3.5: 3-phase induction motor  $\Delta$ -connected with capacitors  $\Delta$ -connected.

- Repeat step (2).
- Now connect the capacitor bank ( $6\mu\text{F}$  Y-connected) across the terminals of the motor as in figure 3.6.

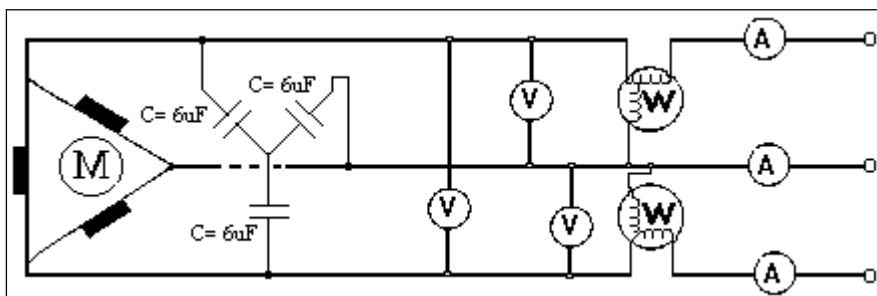


Figure 3.6: 3-phase induction motor  $\Delta$ -connected with capacitors Y-connected.

- Repeat step (2).

➤ **Questions:**

➤ **Single-phase induction motor :**

- Complete the VI and PF columns in table(1), and plot on the same graph the PF against torque for each value of correction capacitor, including zero capacitance.
- complete the Q column in table(1), using the values calculated in the previous question as follows:



$$Q^2 = (VI)^2 - (P_{in})^2$$

$$Q_c = - V^2 (2\pi f c)$$

Add the appropriate negative value to the uncorrected average Q reading calculated earlier. The results should agree fairly closely with the average Q found experimentally with the used corrective capacitor.

**A. Three-phase induction motor:**

1. Compute the efficiency with capacitors and without and discuss the results?
2. Complete the table to find Q in case without and with capacitors?
3. Discuss the results of compensation of reactive power when we are using Y-connection and delta-connection?
4. Compute Q and compare it at the same PF in Y and delta?

## Experiment #4

# Measurement of Irradiance and PV Module I-V and P-V Characteristics

## ➤ Objective

This experiment aims to get student acquainted to solar irradiance and factors affecting it. It also aims to demonstrate PV module main performance characteristics including open circuit voltage ( $V_{oc}$ ), short circuit current ( $I_{sc}$ ) and measure their I-V and P-V characteristics with varying irradiance and different connections of modules in series and in parallel.

The annual irradiance will also be measured by taking one day of each month to represent the average irradiance of that month.

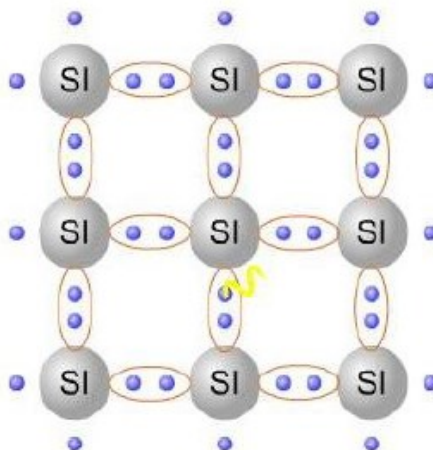
## ➤ Theory

### 1.1. Principle of a solar cell

Solar cells are usually made of silicon which is the second most frequently found element in the earth's crust. A silicon atom has four valence electrons. In a silicon crystal, two electrons of neighboring atoms form a pair in each case. In this state, the silicon crystal is not conductive, because no free electrons are available for transporting charge.

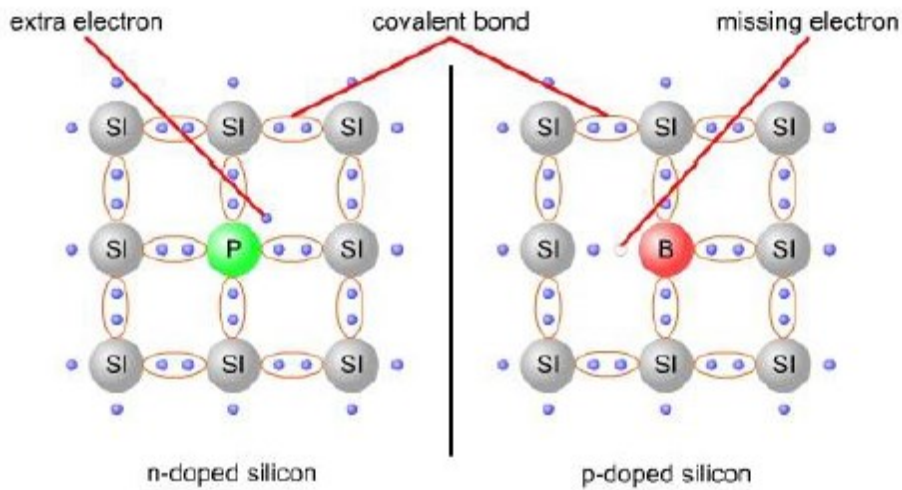
When a silicon crystal receives energy in the form of light or heat, for instance, the energy is also absorbed by the electrons. Once an electron pair has absorbed enough energy, it breaks up so that the electrons are free to move inside the silicon crystal. Each electron which has drifted in this manner leaves a "hole" at its original location in the crystal lattice.

The silicon becomes conductive, this property being known as the intrinsic conductivity of a semiconductor. When the energy supply is interrupted, each drifting electron releases the energy it previously absorbed and returns to a free electron hole.



An electrical field can be used to separate the electrons from the electron holes. Impurity atoms permit an electrical field to be generated inside a semiconductor. For this purpose, atoms with five electrons each are integrated into one section, known as n-semiconductor or n-doped. This section bears a slightly negative charge with respect to the pure silicon

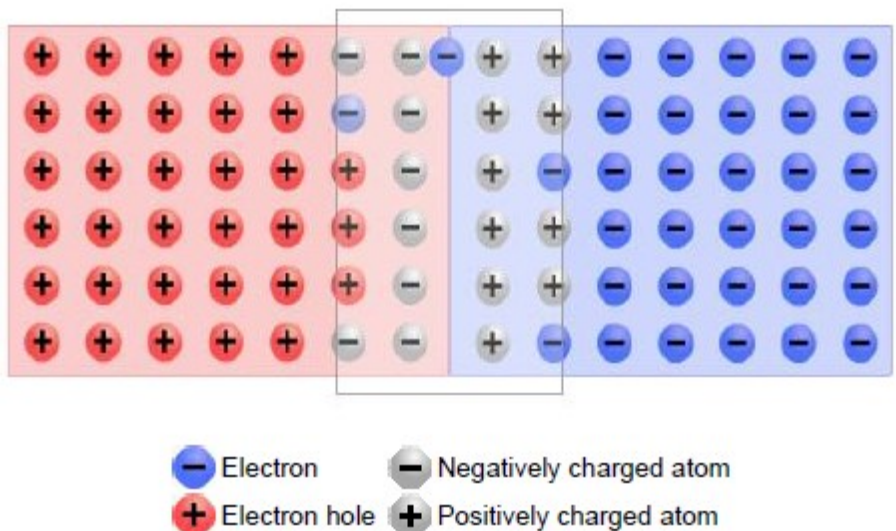
crystal lattice.



Atoms with three electrons each are integrated into another section, known as semiconductor or p-doped. This section bears a slightly positive charge with respect to the pure silicon crystal lattice. If the n- and p-semiconductors are brought right next to each other, an electric field forms in the p-n junction arising between the two semiconductors.

### 1.2. p-n junction

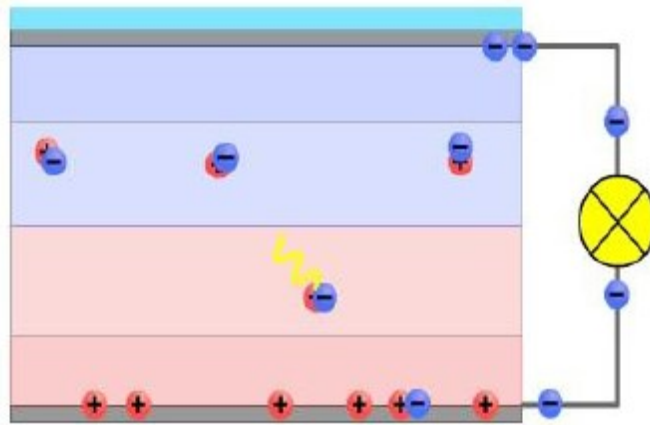
A p-n junction is formed by joining p- and n-semiconductor layers. Electrons from the n-layer drift across this junction to the p-layer, where they combine with the holes.



When electrons leave the n-layer, the atoms remaining there result in a slightly positive charge in that region. Conversely, the p-layer where the incoming electrons combine with the holes accumulates a slightly negative charge as a result. This charge separation creates an electric field across the semiconductor junction, also termed space-charge region.

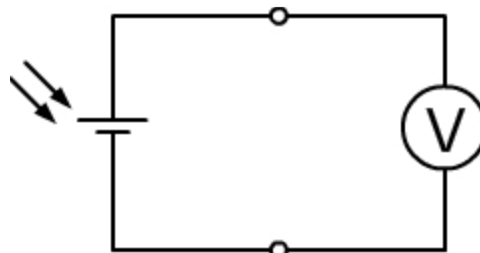
### 1.3. Photovoltaic effect

When light impinges on the PV cell's crystal lattice, the light energy is transferred to the lattice, where the atoms are excited to form electron-hole pairs. If this happens outside the p-n junction, the electron-hole pairs re-combine very quickly. Electron-hole pairs inside the p-n junction are separated by the local electric field. The resultant electrons drift to the n-layer while the holes drift to the p-layer, causing the PV cell's voltage to build up. If a consumer is then connected to the cell, a current begins to flow.



#### 1.4. Open-circuit voltage of a PV cell

As the largest voltage occurring across the terminals of a PV cell, the open-circuit voltage  $V_{OC}$  is important in dimensioning subsequent circuits (e.g. inverters). This voltage is measured without any load being connected to the PV cell.



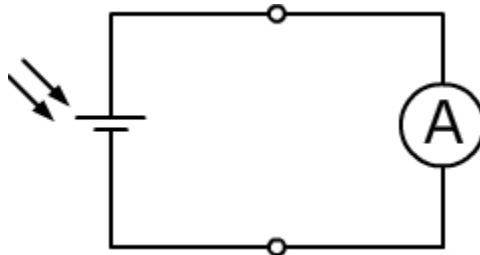
The semiconductor material making up the PV cell decisively determines the voltage produced by the cell.

The factors mentioned next influence the open-circuit voltage.

- Irradiance :  $V_{oc}$  is not a linear function of the irradiance. The voltage approaches its maximum level already at low irradiances.
- Angle of incidence:  $V_{oc}$  is maximized when the light impinges perpendicularly.
- Temperature:  $V_{oc}$  has a negative temperature coefficient, i.e. as a PV cell or module warms up (e.g. on exposure to light), its open-circuit voltage drops.

#### 1.5. Short-circuit current of a PV cell

The short-circuit current  $I_K$  is the largest possible current a PV cell can supply. This current is measured using an ammeter with a very low internal resistance connected directly to the PV cell's terminals.



PV cells are short circuit proof, i.e. they do not get damaged if their terminals are short circuited. Because the short-circuit current is only slightly higher than the rated current, the module lines need not be protected by fuses against short circuit. However, the lines must be dimensioned to handle short-circuit current.

A short circuit resulting from a fault (e.g. defective insulation) can result in hazardous arcs.

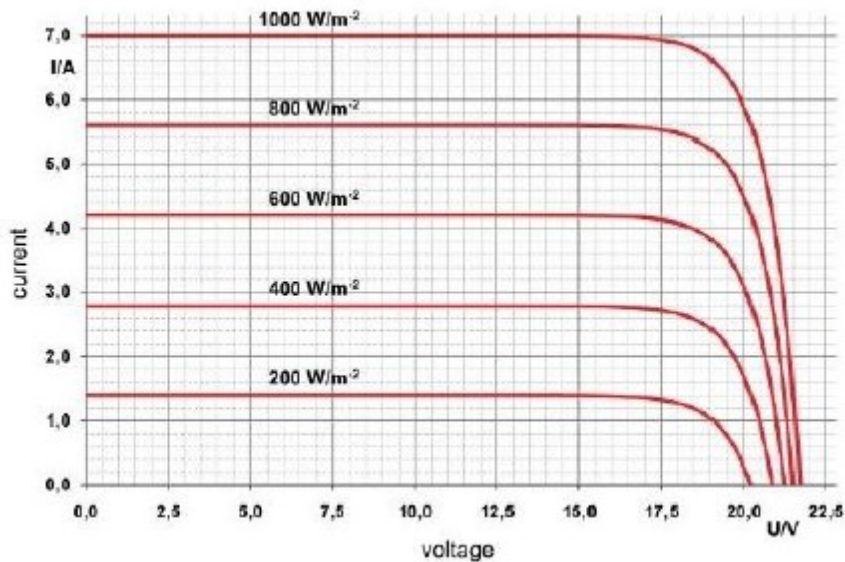
The short-circuit current depends on:

- **Irradiance:** higher irradiance yields higher short circuit current.
- **Angle of light incidence:** the short-circuit current attains its maximum value when the light impinges perpendicularly on the PV cell.
- **Temperature : short circuit current have** a positive temperature coefficient, i.e. as the PV cell warms up, its short-circuit current rises.

## 1.6. Characteristic of a PV cell

Between the two operating points representing no-load and short-circuit respectively, it is possible to measure further operating points at different currents. All measurement points together result in the cell's characteristic. This characteristic is determined by the various currents and their corresponding voltages.

The characteristic of a cell / module serves as an important assessment criterion in solar technology. The diagram below shows the typical V/I characteristic of a PV cell at various irradiance levels.

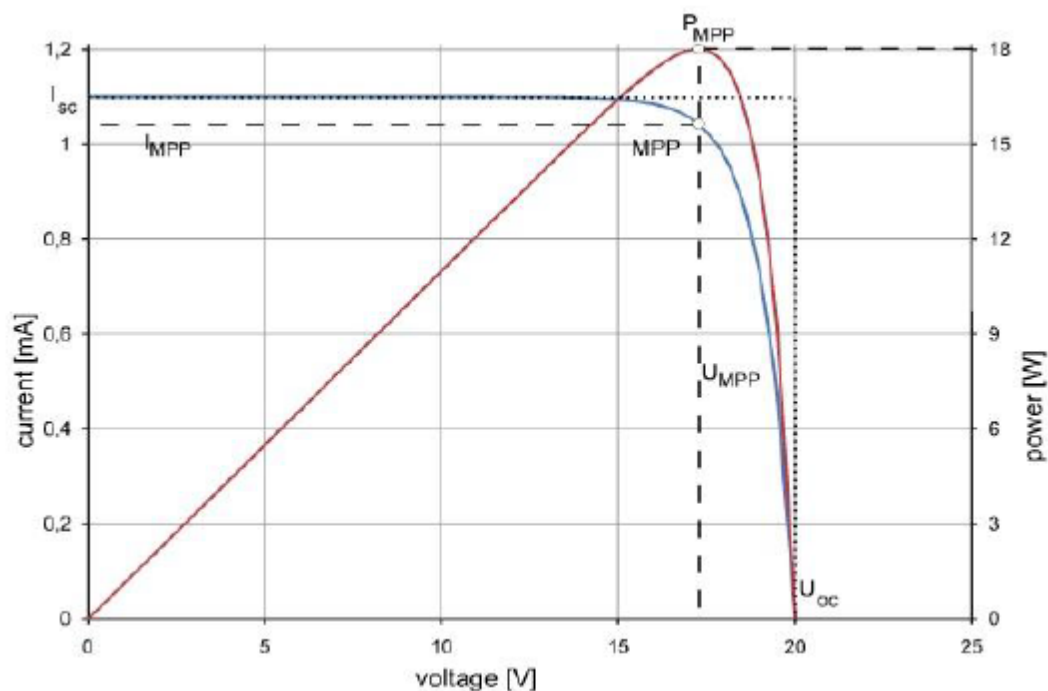


### 1.7. Efficiency of a solar cell

The power which can be supplied by a PV cell or module depends not only on the irradiance, but also how well the consumers are matched. The no-load operating point with  $I = 0$  mA and the short-circuit operating point with  $V = 0$  V, yield the output power  $P = 0$  W in accordance with the formula  $P = V \cdot I$ .

Between these two operating points, the product  $P = V \cdot I$  must therefore attain a maximum value. This operating point is termed the **Maximum Power Point (MPP)**.

The maximum power  $P_{Max}$  a PV cell can deliver to a connected consumer is always smaller than the product of the short-circuit current and open-circuit voltage



#### 2.7.1. The fill factor

The fill factor is a quality criterion of a solar cell and states to what extent the I-V characteristic approaches the rectangle made up of the no-load voltage (VOC) and short circuit current (ISC) shown below. The fill factor is calculated using the following equation:

$$FF = \frac{P_{MPP}}{V_{OC} \cdot I_{SC}}$$

$$= \frac{V_{MPP} \cdot I_{MPP}}{V_L \cdot I_{SC}}$$

### 2.7.2. The efficiency

To determine the efficiency  $\eta$  of a solar cell you need to know the maximum power point (MPP), the irradiance E and the surface area A of the solar cell. The efficiency is then computed from the following expression:

$$\eta = \frac{P_{MPP}}{E \cdot A}$$

## 1.8. Connecting PV Modules

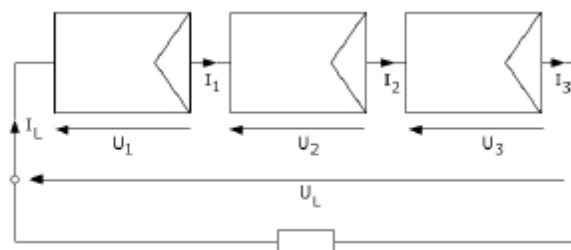
### 1.8.1. Series connection

Different voltages and amperages can be achieved by wiring PV cells in correspondingly different ways, e.g.

- series connections
- parallel connections
- hybrid connections

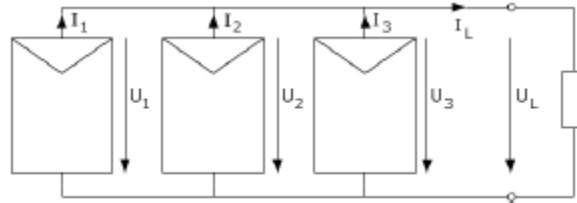
#### Series connection of PV cells

Because individual cells fail to produce a sufficiently high voltage for most applications, several cells can be connected in series so that their individual voltages are added to form the required voltage



Series-connected modules are often termed **string**. Because cells / modules are not perfectly identical, the total current flowing through a string depends on the lowest-quality cell / module. This effect is known as **mismatching**.

Needless to say, a module's no-load and short-circuit points are also interspersed by further operating points forming the module's characteristic.



Only cells / modules of the same type must be connected in parallel, as differences in type would cause compensation currents to flow, thus invalidating the addition of the individual currents.

The described connections of solar cells also apply to solar modules.

### 1.8.2. Parallel Connection

Connecting cells / modules in parallel adds their individual currents to result in a higher total current.

## 2. Procedure

### 2.1. Open-circuit voltage of a PV cell

In this experiment, we will use an analog/digital multimeter to examine the Dependency of a solar module's open-circuit voltage **VOC** on irradiance. On the sun position emulator, set the sun and panel angles to  $0^\circ$ , and the elevation angle to  $90^\circ$ . The halogen lamp should then be positioned perpendicularly over the solar module. Connect the analog/digital multimeter to the mains power supply; turn on the multimeter and select the voltage display mode.



To set irradiance values for the subsequent measurements, move the dimmer's slide control in quarterly steps. This results in five different positions for the control, the lowest irradiance corresponding to position 0/4, the highest to 4/4. Set the irradiances as indicated in the table below, measure the solar module's corresponding open-circuit voltages and enter their values in the table.





Position of dimmer	Irradiance [ $\text{W}/\text{m}^2$ ]	Voc [V]
0	100	
1	170	
2	240	
3	310	
4	380	

**Q1. What can be said about the obtained characteristic?**

The open-circuit voltage VOC...

What is the value of the solar module's VOC at the halogen lamp's maximum irradiance?

... remains constant.

... is not a linear function of irradiance.

... rises linearly with the irradiance.

... reaches nearly its maximum value already at a low irradiance (about  $100 \text{ W}/\text{m}^2$ ).

**2.2. Short-circuit current of a PV cell**

In this experiment, we will use an analog/digital multimeter to examine the dependency of a solar module's short-circuit current ISC on irradiance. On the sun position emulator, set the sun and panel angles to  $0^\circ$ , and the elevation angle to  $90^\circ$ . The halogen lamp should then be positioned perpendicularly over the solar module.



Set the analog/digital multimeter to current display by pressing the *I* selector switch. To set irradiance values for the subsequent measurements, move the dimmer's slide control in quarterly steps. This results in five different positions for the control, the lowest irradiance corresponding to position 0/4, the highest to 4/4. Set the irradiances as indicated in the table below, measure the solar module's corresponding short-circuit currents and enter their values in the table.

Position of dimmer	Irradiance [ $\text{W}/\text{m}^2$ ]	Isc [A]
0	100	
1	170	
2	240	
3	310	
4	380	

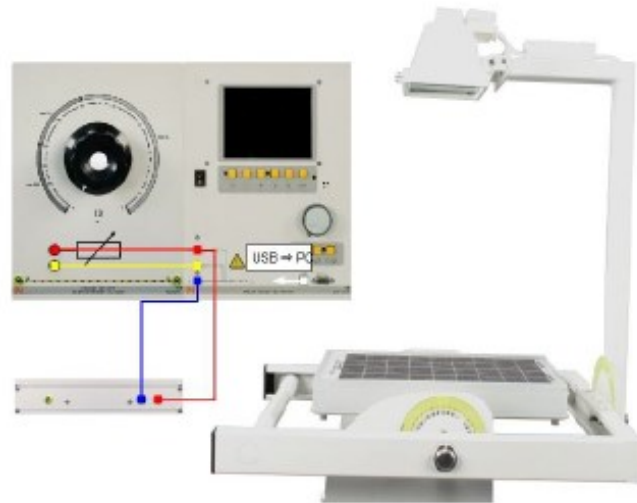
## Q2. The short-circuit current $I_{sc}$ ...

- ... is almost linearly proportional to the irradiance.
- ... does not depend on the irradiance.
- ... decreases as the irradiance increases.


## 2.3. Recording Characteristic of a PV cell

Between the two operating points representing open-circuit and short-circuit respectively, it is possible to measure further operating points at different currents. All measurement points together result in the  $V/I$  characteristic. This characteristic is determined by measuring the solar module's currents and corresponding voltages. A variable load resistor (potentiometer) is

connected in order to set various measurement points. The Figure below shows how to set up the experiment.

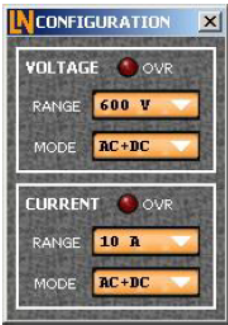


Open the analog/digital multimeter's *X/Y recorder* virtual instrument via the menu path *Instruments | X/Y recorder*. Click the right-hand mouse button in the plotter area and select *Properties* from the context menu which appears. On the scaling tab, perform the settings shown below.



<b>X/Y recorder settings</b>			
<b>Axis</b>	<b>Parameter</b>	<b>Maximum</b>	<b>Division</b>
X	$V_{rms}$	20V	2V
Y	$I_{rms}$	0.2A	0.02A

Use the *X/Y recorder's* "Config" button to set the measurement ranges shown below.



<b>Measurement ranges</b>		
<b>Parameter</b>	<b>Range</b>	<b>Mode</b>
Voltage	30V	AC+DC
Current	1A	AC+DC

Record the characteristic using the procedure described next.

1. Set the irradiance to 0/4.

2. Set the potentiometer to  $0 \Omega$  (short circuit).
3. Press the **REC** button to start recording the V/I characteristic.
4. Slowly turn the potentiometer to its maximum resistance value.
5. Press the **REC** button again to stop recording the characteristic.

To ensure that a proper characteristic is recorded, turn the potentiometer slowly and evenly. Otherwise sudden jumps might occur especially at the characteristic's inflection points.

**Using this procedure, record the solar module's characteristics at the halogen lamp's 5 different settings for irradiance variation.**

Copy the obtained results to the placeholder below. For this purpose, click the **right-hand** mouse button in the X/Y recorder's plotter area and select **Copy** from the context menu which appears. To insert the graphic into the placeholder, click the right-hand mouse button inside the placeholder and select **Paste** from the context menu.

**Q3. Compare between the I-V curves in the above cases ?**

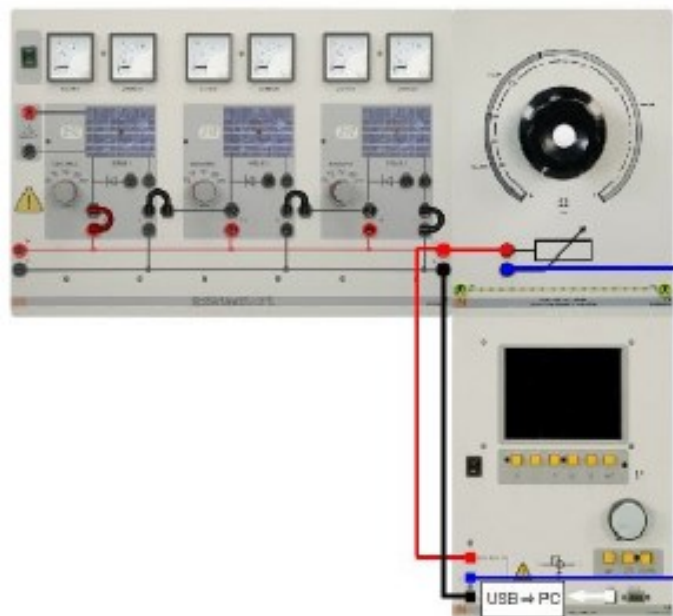
**Q4.a. Calculate the FF at  $E=1000 \text{ W/m}^2$  ?**

**(Assume the Halogen lamp maximum irradiance  $=370 \text{ W/m}^2$  in the measured characteristics)**


**Q4.b. Calculate the efficiency of the cell at  $E=1000 \text{ W/m}^2$  ? Use the real area A of the panel under test?**

## 2.4. Series connection of Modules

In this experiment, we will investigate series connections of solar modules by recording the V/I characteristics of a number of series-connected arrays. These characteristics will serve to determine the series-connections' current and voltage properties. The Figure below shows how to set up the experiment for three cells in series

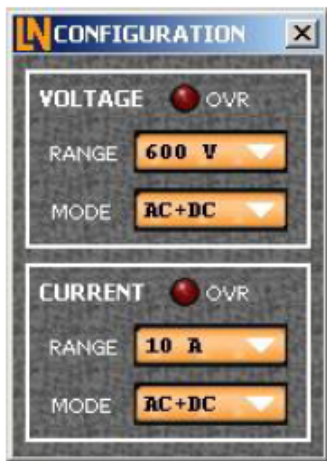


Open the analog/digital multimeter's *X/Y recorder* virtual instrument via the menu path *Instruments | X/Y recorder*. Click the right-hand mouse button in the plotter area and select *Properties* from the context menu which appears. On the scaling tab, perform the settings shown below.





X/Y recorder settings			
Axis	Parameter	Maximum	Division
X	$V_{rms}$	80V	10V
Y	$I_{rms}$	2.5A	0.5A

Use the *X/Y recorder's* "Config" button to set the measurement ranges shown below



Measurement ranges		
Parameter	Range	Mode
Voltage	300V	AC+DC
Current	10A	AC+DC

Set the irradiance to  $1000\text{W}/\text{m}^2$  on all solar module simulations. First record a single module's V/I characteristic using the procedure described next.

1. Set the potentiometer to  $0\Omega$  (short circuit).
2. Start recording by pressing the  button.
3. Slowly increase the potentiometer's resistance to its maximum value.
4. Stop recording by pressing the  button.
5. Label the obtained characteristic with the number of employed solar modules.

➔ To ensure that a proper characteristic is recorded, turn the potentiometer slowly and evenly. Otherwise sudden jumps might occur especially at the characteristic's inflection points.

➔ **Record the V/I characteristic again for a series-connection of two and three solar modules respectively. (Make sure all modules have irradiance set to the same value)**

⇒ Copy the obtained results. For this purpose, click the **right-hand** mouse button in the X/Y recorder's plotter area and select **Copy** from the context menu which appears.

➔ Repeat the measurement for  $G=600 \text{ W/m}^2$  and  $200 \text{ W/m}^2$  and Copy the obtained results

#### Q5. Which of the following statements are correct?

In the case of series-connected solar modules ...

... the amperages through the individual solar modules are added together.

... the solar module conducting the lowest current determines the amperage through the series-connected array.

... the voltages across the individual solar modules are added together.

... the voltage does not depend on the number of connected solar modules.

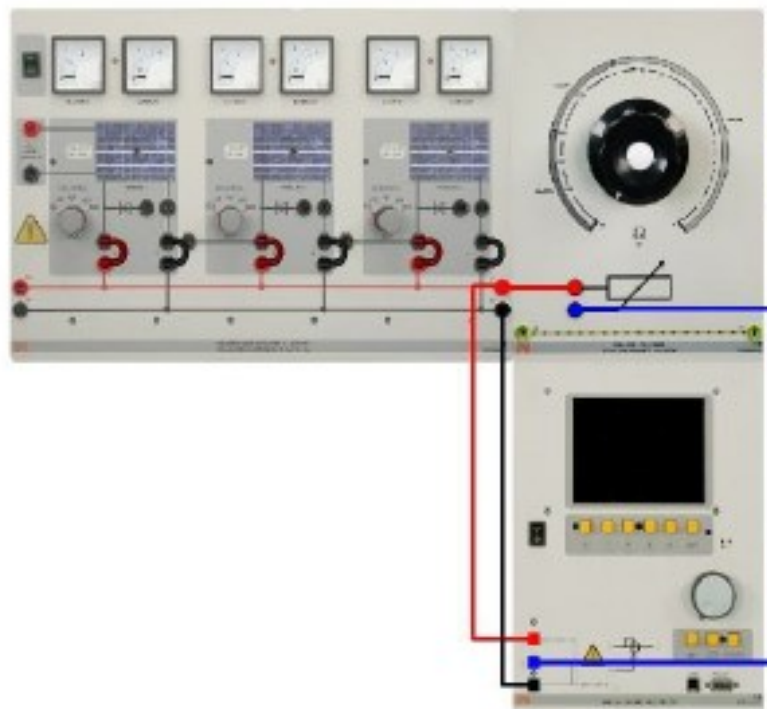
**Note: More than one statement might be correct**

### 2.5. Parallel connection of Modules

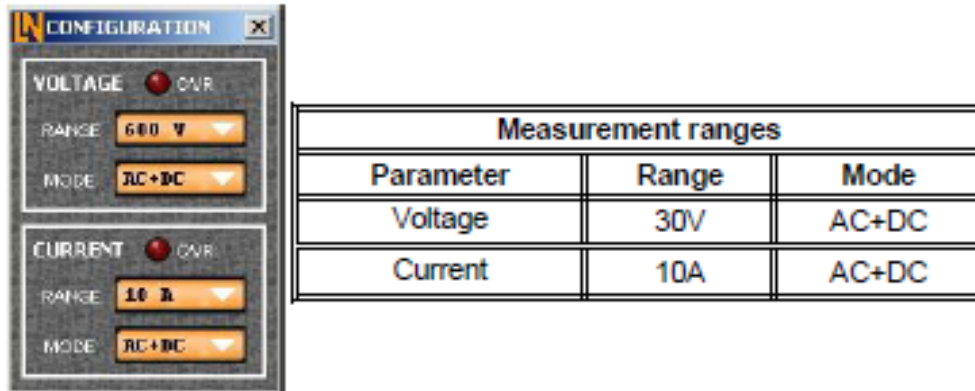
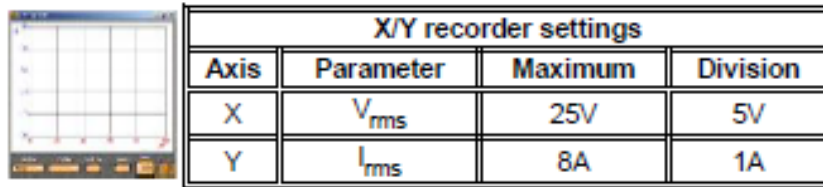
In this experiment, we will investigate parallel connections of solar modules by recording the V/I characteristics of several parallel-connected arrays. These characteristics will serve to determine the parallel-connections' current and voltage properties.

The Figure below shows how to set up the experiment for 3 modules connected in parallel



(Note: **make sure all panels have the same irradiance level at any given time**)



Equipment setting:



Set the irradiance to  $1000\text{W/m}^2$  on all solar module simulations. First record a single module's V/I characteristic using the procedure described next.

1. Set the potentiometer to  $0\Omega$  (short circuit).
2. Start recording by pressing the  button.
3. Slowly increase the potentiometer's resistance to its maximum value.
4. Stop recording by pressing the  button.
5. Label the characteristic with the number of employed solar modules.

➔ To ensure that a proper characteristic is recorded, turn the potentiometer slowly and evenly. Otherwise sudden jumps might occur especially at the characteristic's inflection points.

➔ Record the V/I characteristic again for a parallel-connection of two and three solar modules respectively.

➔ Repeat the measurement for  $600\text{W/m}^2$  and  $200\text{W/m}^2$  and copy the obtained results.

**Q6: Which of the following statements are correct?**

In the case of parallel-connected solar modules ...

... the amperages through the individual solar modules are added together.

... the voltage drops progressively as each further solar module is connected in parallel.

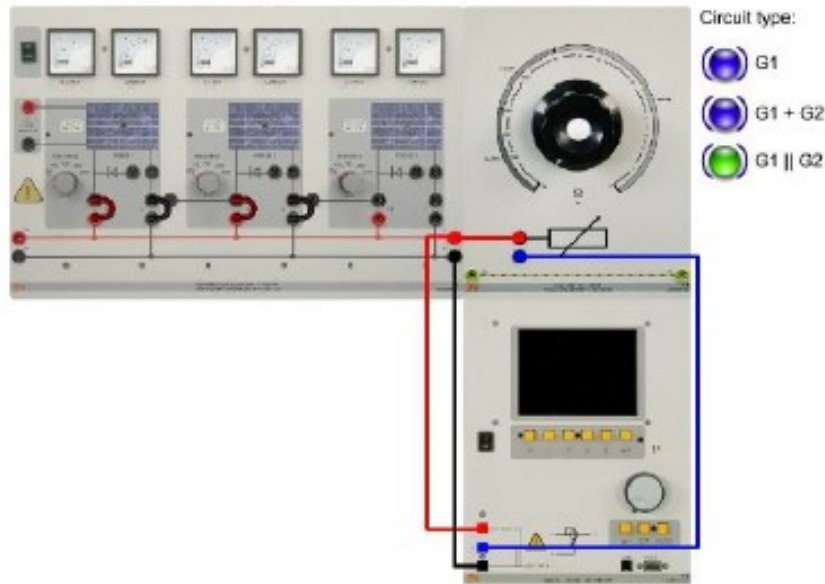
... the solar module conducting the lowest current determines the amperage through the parallel-connected array.

... the voltage remains constant.

**Note: Several answers may be correct.**


## 2.6. Power Levels

In this experiment, we will investigate the power levels output by solar modules connected in series and parallel at different irradiance levels. Connect the equipment as shown



To investigate the power output by solar modules connected in series and parallel, we will first record the characteristic of solar module G1.

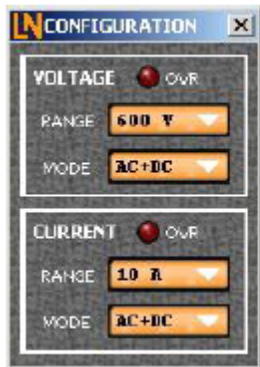
Open the analog/digital multimeter's *X/Y recorder* virtual instrument via the menu path *Instruments | X/Y recorder*. Click the right-hand mouse button in the plotter area and select *Properties* from the context menu which appears. On the scaling tab, perform the settings shown below.



X/Y recorder settings			
Axis	Parameter	Maximum	Division
X	$V_{rms}$	60V	10V
Y	$I_{rms}$	6A	1A
Y	P	100W	10W

Use the *X/Y recorder's* “Config” button to set the measurement ranges shown below.





Measurement ranges		
Parameter	Range	Mode
Voltage	300V	AC+DC
Current	10A	AC+DC

Set the irradiance to 1000W/m<sup>2</sup> on all solar module simulations, and record the characteristics using the procedure described next.

1. Set the potentiometer to 0Ω (short circuit).
2. Start recording by pressing the button.
3. Slowly increase the potentiometer's resistance to its maximum value.
4. Stop recording by pressing the button.
5. Label the characteristic with the number of employed solar modules.

To ensure that a proper characteristic is recorded, turn the potentiometer slowly and evenly. Otherwise sudden jumps might occur especially at the characteristics inflection points.

#### **Recording the power characteristic of two and three series-connected solar modules**

Connect solar module G1 in series to solar module G2.

Record the series-connection's characteristic.

Repeat the measurement for 3 modules in series and record the results.

#### **Recording the power characteristic of two and three parallel-connected solar modules**

Now rearrange the circuit by connecting solar modules G1 and G2 in parallel.

Record the parallel connection's characteristic.

Repeat the measurement for 3 modules in parallel and record the results.

To Copy the obtained results, click the **right-hand** mouse button in the X/Y recorder's plotter area and select **Copy** from the context menu which appears.

#### **Q7: What do the characteristics indicate?**

A comparison of two solar modules connected in series and parallel reveals that ...

- ... their maximum power points are identical.
- ... their maximum power points differ.
- ... the values at the maximum power points are equal.

**Note: Several answers may be correct.**

## 2.7. Recording annual irradiance

Set up the experiment as shown below



The irradiance will be measured at 12.00 hours solar time on the 22nd of every month, this value representing the entire month. Not really good practice, this technique is simply intended to facilitate recording of the characteristic. Compute the sun's position using the calculator and perform the settings shown further below.

**(table below provides these angles for a location at 33° latitude on October 22<sup>nd</sup> of each month)**

**It is possible to perform calculations for any other location at any given day using specialized calculators which are available online)**

Month	1	2	3	4	5	6	7	8	9	10	11	12
<b>Azimuth angle</b>	180	180	180	180	180	180	180	180	180	180	180	180
<b>Elevation angle</b>	35	45	60	70	75	80	75	70	60	45	35	30
<b>I [mA]</b>												

⇒ **Fill in the above table and plot the results**

**Note that this measurement results do not accurately reflect real conditions but only indicate a trend instead.**

**Q8: In which month(s) is the short-circuit current highest?**

**Q9: What causes the variations in irradiance in the course of the year?**

.....The earth's declination.

.....The earth's rotation.

.....The earth's elliptical orbit about the sun.

.....Variations in solar radiation during the year.

**Note: Several answers may be correct**

Experiment #5  
Power Transmission Line

### **Objectives**

1. To operate single and dual transmission lines at no load while changing the connection of transmission line equivalent capacitance.
2. To notice the changes on the receiving voltage, charging current, active power, reactive power and power factor.
3. To study the behavior of T.L under different load conditions (voltage drop, currents and efficiency of T.L) .
4. To notice the flow of real and reactive power under different types of loads at T.L.

### **Equipments required:**

1. Simulator of electric lines mod. SEL-1/EV.
2. Variable three-phase power supply mod. AMT-3/EV, in option three phase line generated by the generator control board mod. GCB-1/EV, or a fixed three-phase line 3 x 380 V.
3. Three-phase transformer mod. P 14A/EV.
4. Set of leads/jumpers for electrical connections.
5. 2 electromagnetic voltmeters with range of 250 - 500 Vac.
6. 1 electromagnetic ammeter with range of 100 mAac.
7. 1 electromagnetic wattmeter with low power factor 1-2 A / 240-480 V.
8. The instruments of the generator control boards mod. GCB-1/EV or two digital instruments for measuring the parameters of electric energy in three-phase systems mod. AZ-VIP, can be used as alternative.

### **Theory**

Power transmission lines are designed to transmit large volumes of power between even far points (hundreds and sometimes thousands of kilometers). Generally power plants are constructed where an energy source is available, then these plants will serve all the users located in urban and industrial areas. The operating voltage is chosen according to the power in order to minimize the average-power losses ( $R I^2$ ). It can immediately be realized that losses will be reduced when current is reduced, However, when huge volumes of power have to be sent, energy will exclusively be transmitted with high voltages (of some hundreds of kV). All that will lead to consider also the accessories that are step-up transformers at the origin and the respective step-down transformers at the destination of the lines.

In the first part of this experiment we will study the operation of power system transmission line in no load condition, and study the effect of this case at different value

like, sending end voltage receiving end voltage, power factor, and the amount of reactive and active power at the sending end of the transmission line.

A long transmission line draws a substantial quantity of charging current. If such a line is open circuited or very lightly loaded at the receiving end, the voltage at receiving end may become greater than voltage at sending end. This is known as *Ferranti Effect* and is due to the voltage drop across the line inductance (due to charging current) being in phase with the sending end voltages. Therefore both capacitance and inductance is responsible to produce this phenomenon.

The Ferranti effect can be seen clearly in medium and long transmission line, however it is negligible in short transmission line due to the small values of charging current.

If current drawn by the distributed capacitance of the transmission line itself is greater than the current associated with the load at the receiving end of the line, then the **Ferranti Effect** occurs. Therefore, the Ferranti effect tends to be a bigger problem on lightly loaded lines, and especially on underground cable circuits where the shunt capacitance is greater than with a corresponding overhead line. This effect is due to the voltage drop across the line inductance (due to charging current) being in phase with the sending end voltages. As this voltage drop affects the sending end voltage, the receiving end voltage becomes greater. The Ferranti Effect will be more pronounced the longer the line and the higher the voltage applied.

The Ferranti Effect is not a problem with lines that are loaded because line capacitive effect is constant independent of load, while inductance will vary with load. As inductive load is added, the VAR generated by the line capacitance is consumed by the load.

**Transmission line at no load:**

$$V_S = A * V_R + B * I_R$$

$$I_R = 0 \text{ (no load)}$$

$$V_R = V_S / A$$

**At this case  $A < 1$  which give that  $V_R > V_S$**

**Preparing the exercise**

1. Start this exercise considering the transmission LINE 1 with the following constants:  
Resistance = 25  $\Omega$ ; Capacitance = 0.2  $\mu\text{F}$ ; Inductance = 0.072 H; Length = 50 km.

2. If necessary, remove all the jumpers of the LINE 2 not considered.
3. Turn the breakers at the origin and at the end of the LINE 1, to OFF.
4. Connect the measuring instruments between the left busway and the terminals at the beginning of the LINE 1.
5. Connect the measuring instruments between the end terminals of the LINE 1 and the right busway.
6. Connect the jumpers with the set of left capacitors, only in the LINE 1, to reproduce the capacitance between active conductors (called  $C_L$ ). These capacitors can be connected either in star or delta configuration. The delta connection will ensure stronger capacitive currents.
7. Adjust the position of the selector Resistance LINE 1 at the value of  $25 \Omega$ .
8. Connect with the variable three-phase power supply by inserting the three-phase insulation transformer.

The transformer is used to insulate the line from the user mains to avoid that, when connected, the current unbalances of the capacitance  $C_E$  (capacitance to the ground) can provoke the untimely intervention of the differential protections of high sensitiveness. If the power supply is insulated from the main, that is it is not grounded, this three-phase transformer can be omitted.

### **Part A: Single Transmission Line**

Connect the circuit as shown in Figure 1

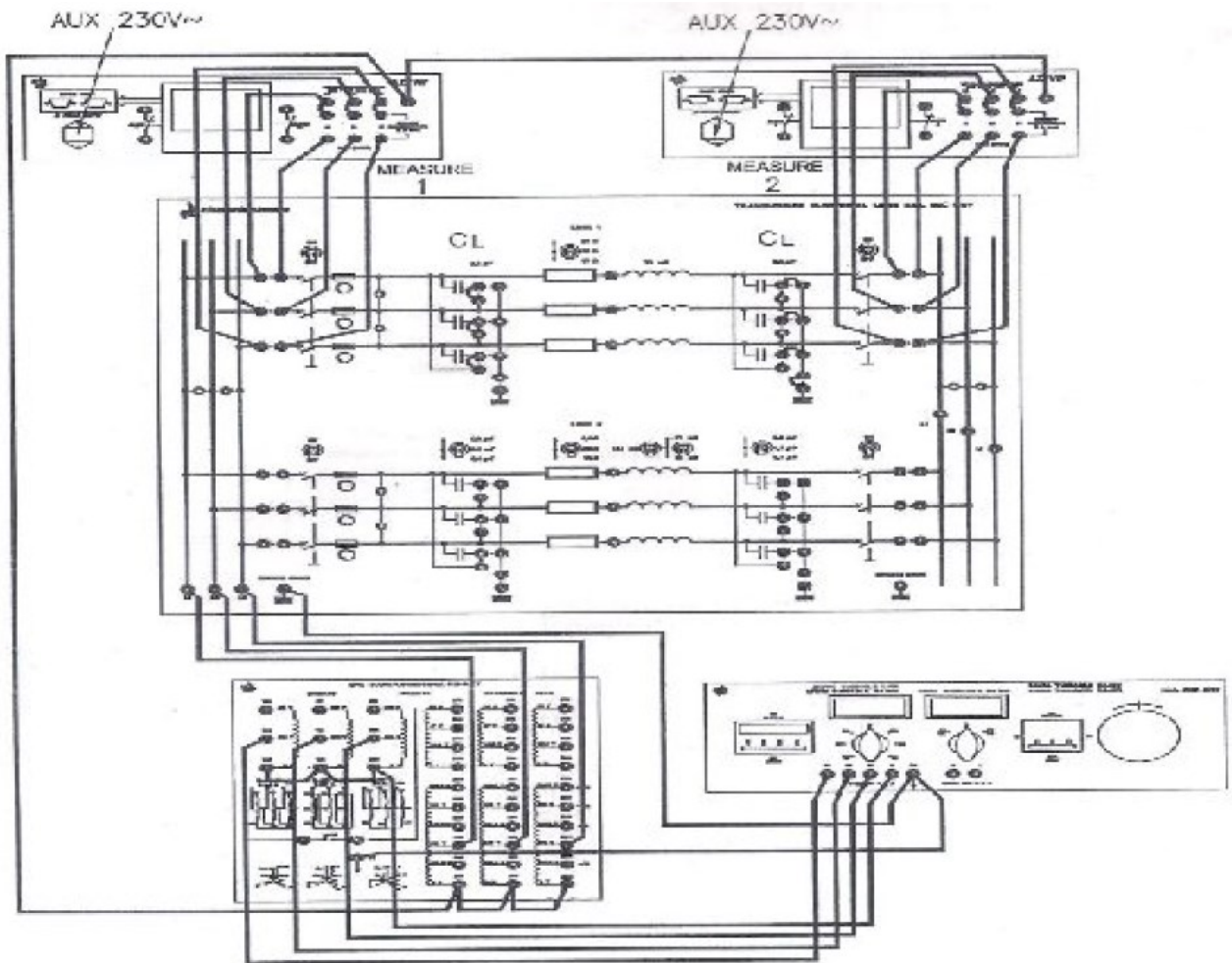


Figure 1

### Test #1

1. Connect the capacitors at the sending end of the transmission line on  $\Delta$  connection
2. Connect the capacitors at the receiving end of the transmission line on Y connection
3. The voltage  $V_s=380$  V.
4. Read the electric quantities on the measuring instruments and write them down in the following table (Table #1).

L-L voltage at sending part (V)	Line current (A)	Total active power at sending part (W)	L-L voltage at receiving part (V)	Total reactive power at sending part (VAR)

Table #1

### Question:

Calculate the reactive power generated by the capacitors in this part and compare it with the measured value on the line.

### Test #2

1. Connect the capacitors at the sending end of the transmission line on  $\Delta$  connection
2. Connect the capacitors at the receiving end of the transmission line on  $\Delta$  connection
3. The voltage  $V_s=380$  V.

4. Read the electric quantities on the measuring instruments and write them down in the following table (Table #2).

L-L voltage at sending part (V)	Line current (A)	Total active power at sending part (W)	L-L voltage at receiving part (V)	Total reactive power at sending part (VAR)

Table #2

**Question:**

Calculate the reactive power generated by the capacitors in this part and compare it with the measured value on the line.

**Part B: Series Operation of Two Transmission Lines at No load**

Connect the circuit as shown in Figure 2

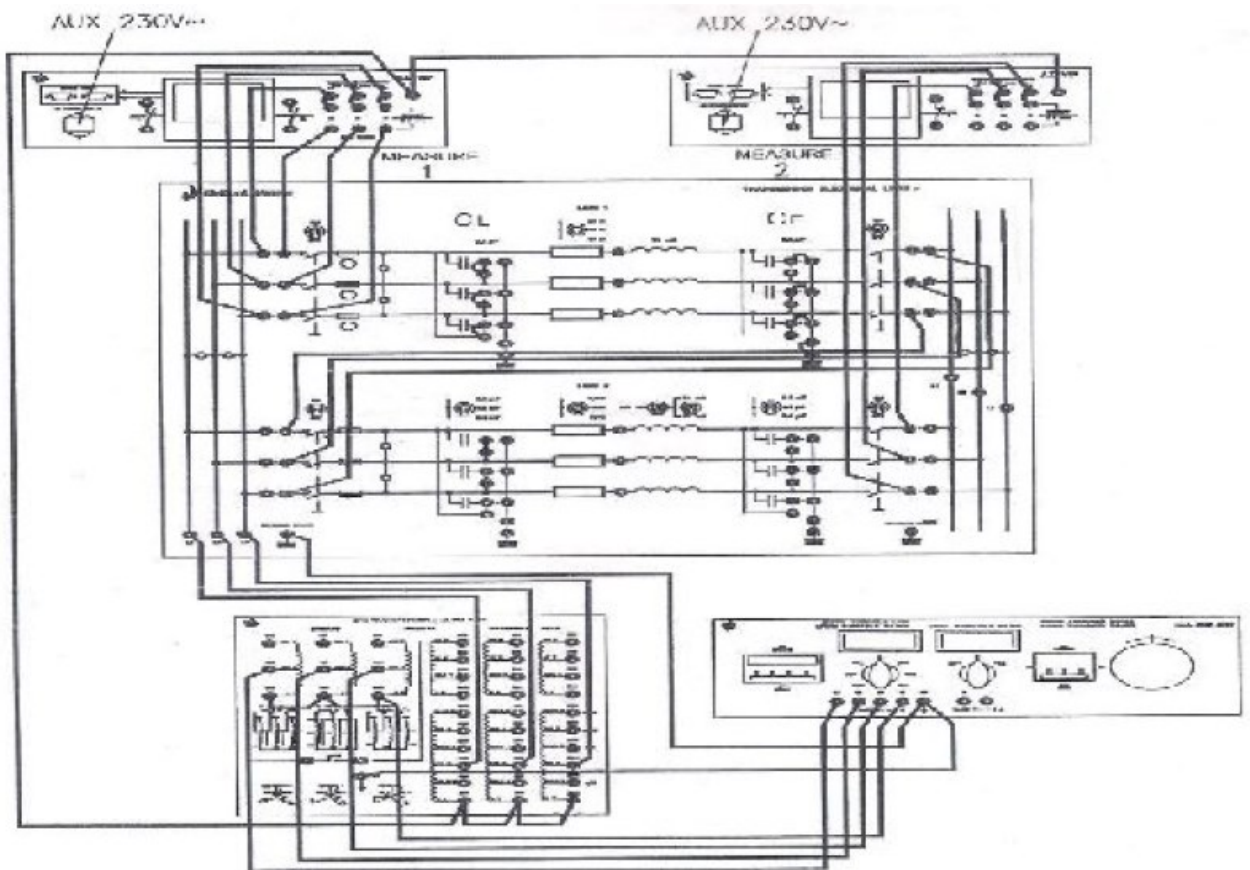


Figure .2

**Test #1**

1. Connect the capacitor at the sending end of the first transmission line to  $\Delta$  connection.
2. Connect the capacitor at the receiving end the first transmission line to Y connection.
3. Connect the capacitor at the sending end of the second transmission line to  $\Delta$  connection.
4. Connect the capacitor at the receiving end the second transmission line to  $\Delta$  connection.



5. The voltage  $V_s=380$  V.
6. Read the electric quantities on the measuring instruments and write them down in the following table (Table #3).

L-L voltage at sending part (V)	Line current (A)	Total active power at sending part (W)	L-L voltage at receiving part (V)	Total reactive power at sending part (VAR)

Table #3

**Question:**

Calculate the reactive power generated by the capacitors in this part and compare it with the measured value on the line.

**Test #2**

1. Connect the capacitor at the sending end of the first transmission line to  $\Delta$  connection
2. Connect the capacitor at the receiving end the first transmission line to  $\Delta$  connection
3. Connect the capacitor at the sending end of the second transmission line to  $\Delta$  connection
4. Connect the capacitor at the receiving end the second transmission line to  $\Delta$  connection
5. The voltage  $V_s=380$  V.
6. Read the electric quantities on the measuring instruments and write them down in the following table (Table #4).

L-L voltage at sending part (V)	Line current (A)	Total active power at sending part (W)	L-L voltage at receiving part (V)	Total reactive power at sending part (VAR)

Table #4

**Question:**

Calculate the reactive power generated by the capacitors in this part and compare it with the measured value on the line.

**Part C: Parallel Operation of Two Transmission Lines at No load**

Connect the circuit as shown in Figure 3

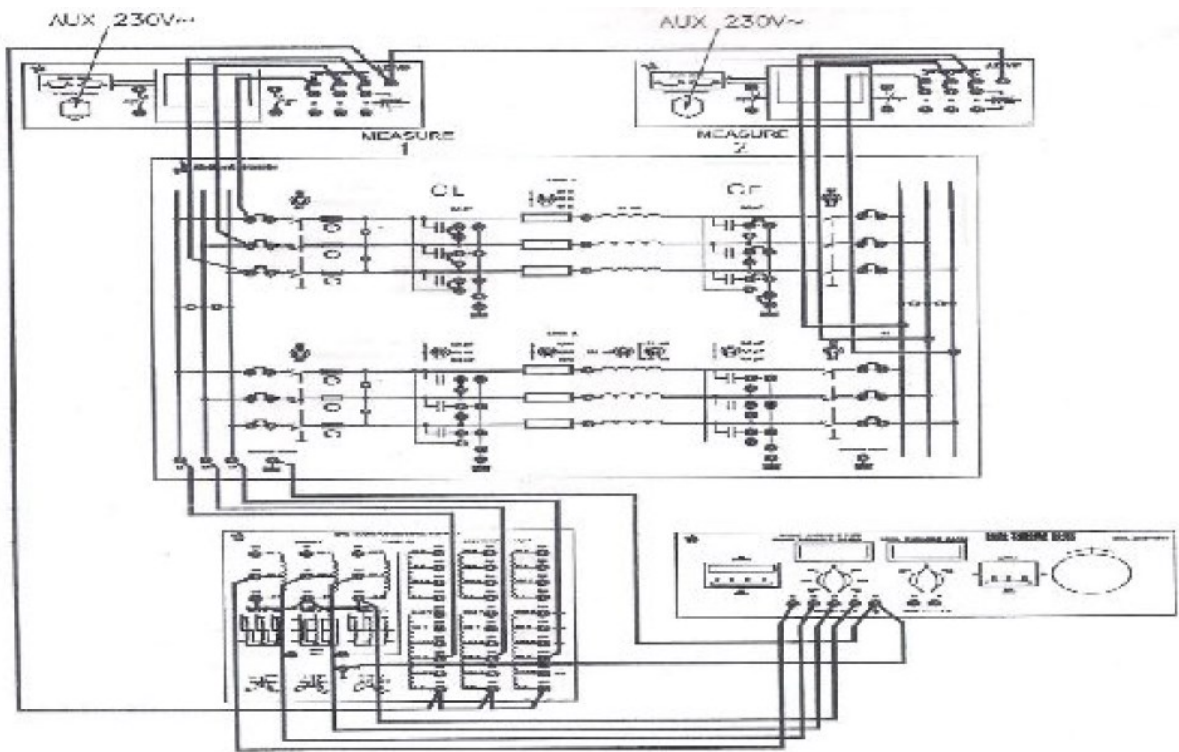


Figure .3

**Test #1**

1. Connect the capacitor at the sending end of the first transmission line to  $\Delta$  connection
2. Connect the capacitor at the receiving end the first transmission line to Y connection
3. Connect the capacitor at the sending end of the second transmission line to  $\Delta$  connection
4. Connect the capacitor at the receiving end the second transmission line to  $\Delta$  connection
5. The voltage  $V_s=380$  V.
6. Read the electric quantities on the measuring instruments and write them down in the following table. (Table #5).

L-L voltage at sending part (V)	Line current (A)	Total active power at sending part (W)	L-L voltage at receiving part (V)	Total reactive power at sending part (VAR)

Table #5

**Question:**

Calculate the reactive power generated by the capacitors in this part and compare it with the measured value on the line.

**Test #2**

1. Connect the capacitor at the sending end of the first transmission line to  $\Delta$  connection
2. Connect the capacitor at the receiving end the first transmission line to  $\Delta$  connection
3. Connect the capacitor at the sending end of the second transmission line to  $\Delta$  connection
4. Connect the capacitor at the receiving end the second transmission line to  $\Delta$  connection

5. Keep the voltage  $V_s=380$  V.
6. Read the electric quantities on the measuring instruments and write them down in the following table (Table #6).

L-L voltage at sending part (V)	Line current (A)	Total active power at sending part (W)	L-L voltage at receiving part (V)	Total reactive power at sending part (VAR)

Table #6

**Question:** Calculate the reactive power generated by the capacitors in this part and compare it with the measured value on the line.

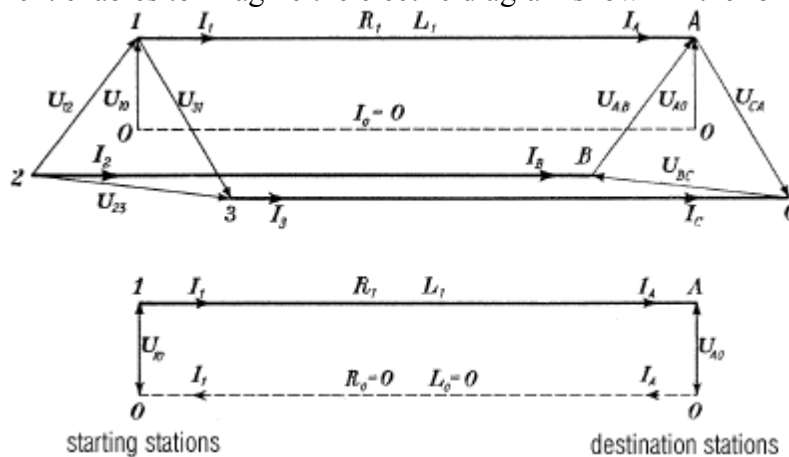
**Questions should be answered in the report:**

1. State why the reactive power displayed in these experiments has negative sign?
2. What are the problems you noticed when operating a medium or long transmission line at no load?
3. Write your overall conclusion?

**PartD: Operation of a Transmission Line in Different Load Condition**

**Theory:**

The power losses and voltage drops of a transmission line are defined under load when the root-mean-square values of the electric quantities are measured at both the starting and destination stations. The simulator will refer to lines with symmetrical conductors and balanced load. This statement enables to imagine the electric diagram shown in the following figure.



*Equivalent diagram of a three-phase line with symmetrical conductors and balanced load*

The diagram of the fig. 1 also includes a fictitious neutral conductor, equidistant from the three active conductors: this gives the possibility of leading the study of

the operating characteristics of the three-phase line to a mere single-phase circuit consisting of only one of the three line wires and of an ideal return wire without resistance nor inductance. All that is due to the fact that the neutral wire of a three-phase line with balanced load would not be crossed by any current, and consequently it could not provoke any ohmic nor inductive voltage drop.

The line defined s indicated above would show:

- The total power  $P_S = 3 \times V_S \times I_S \cdot \cos\theta$  at the origin of the line.
- The total power  $P_R = 3 \times V_R \times I_R \cdot \cos\theta$  at the end of the line.
- The total loss  $P = P_S - P_R$
- The performance in load condition  $\eta = P_R / P_S = 1 - P / P_S$
- The percent loss  $P\% = 100 \times P / P_S$
- The percent voltage drop  $\Delta V \% = 100 \times (V_S - V_R) / V_S$
- The percent current variation  $\Delta I \% = 100 \times (I_S - I_R) / I_S$

### PREPARING THE EXERCISE

- Start this exercise considering the transmission LINE 2 with the following constants: Resistance = 8.9  $\Omega$ ; Capacitance = 0.1  $\mu\text{F}$ ; Inductance = 0.035 H; Length = 25 km; Section = 50 mm<sup>2</sup> - conductor of copper.
- If necessary, remove all the jumpers of the LINE 1 not considered.
- Turn the breakers at the origin and at the end of the LINE 2, to OFF.
- Connect the measuring instruments between the left busway and the terminals at the starting of the LINE 2, and between the end terminals of the LINE 2 and the right busway.
- Connect the jumpers with the set of left capacitors, in the LINE 2, to reproduce the capacitance between active conductors (called  $C_L$ ). Carry out the delta connection ensuring stronger capacitive currents. Select the value of 0.1  $\mu\text{F}$  for  $C_L$ .
- Connect the jumpers with the set of right capacitors, still in the LINE 2, to reproduce the capacitance between the active conductors and the ground (called  $C_E$ ); connect also the jumper that grounds the star center of the capacitors. In this case the only star connection can be carried out because each line conductor generates a capacitance to the ground. Select the value of 0.1  $\mu\text{F}$  for  $C_E$  too.
- Adjust the position of the selector Resistance LINE 2 at the value of 8.9  $\Omega$  and that of inductance at the value of 0.036 H.
- Connect with the variable three-phase power supply inserting the three phase insulation transformer. This transformer is used to insulate the line from the user mains to avoid that, when connected, the current unbalances of the capacitors  $C_E$  (capacitance to the ground) can provoke the untimely intervention of the differential protections of high sensitiveness. If the power supply is insulated from the mains, that is it is not grounded, this three-phase transformer can be omitted.
- The reference electric diagram, the connections and configuration of the line are respectively shown in the figure 4.

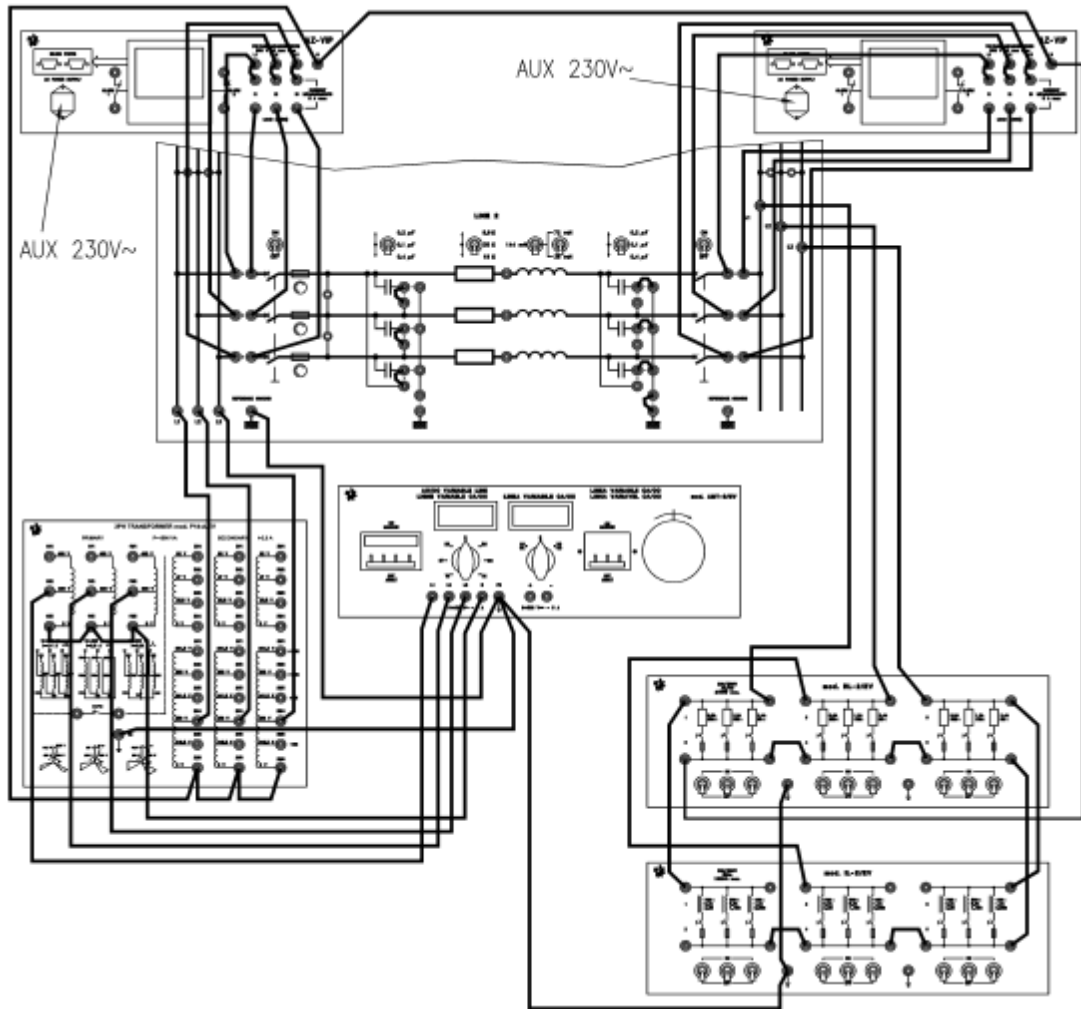


Figure 4

### OPERATIONAL MODE FOR DETECTING THE PERFORMANCE WITH RESISTIVE LOAD

- Enable and adjust the voltage of the power supply at 380 V. The warning lights of the left busway will be on. If no variable three-phase power supply is available, but only a fixed line is used, the voltage can be adjusted at the nearest rated value through the outlets of per cent variation of the transformer (+/- 5 %).
- Turn the breakers at the origin and at the end of the LINE 2, to ON.
- Connect the various steps of the resistive load (apply a balanced load using the same step for the three phases), read the electric quantities on the instruments and write them down in the table shown below.

Actual measurements carried out on the LINE 2 with:  
Resistance =  $8.9\Omega$ ; Capacitance =  $0.1\mu\text{F}$ ; Inductance =  $0.036\text{ H}$

	$U_s$	$I_s$	$P_s$	$Q_s$	$PF_s$	$U_R$	$I_R$	$P_R$	$Q_R$	$PF_R$
	(V)	(A)	(W)	(VAR)		(V)	(A)	(W)	(VAR)	

<b>No Load</b>										
<b>735 <math>\Omega</math></b>										
<b>365 <math>\Omega</math></b>										
<b>240 <math>\Omega</math></b>										

**Question:**

Chose one row of the above table to draw the phaser diagram.

**OPERATIONAL MODE FOR DETECTING THE PERFORMANCE WITH INDUCTIVE LOAD**

- Replace the resistive load with an inductive load, or add this last.
- Enable and adjust the voltage of the power supply at 380 V. The warning lights of the left busway will be on. If no variable three-phase power supply is available, but only a fixed line is used, the voltage can be adjusted at the nearest rated value through the outlets of percent variation of the transformer (+/- 5 %).
- Turn the breakers at the origin and at the end of the LINE 2, to ON.
- Connect the various steps of the inductive load (apply a balanced load using the same step for the three phases), read the electric quantities on the instruments and write them down in the table shown h below.

Actual measurements carried out on the LINE 2 with:

Resistance = 8.9 $\Omega$ ; Capacitance = 0.1 $\mu$ F; Inductance = 0.036 H

	<b>U<sub>s</sub></b> (V)	<b>I<sub>s</sub></b> (A)	<b>P<sub>s</sub></b> (W)	<b>Q<sub>s</sub></b> (VAR)	<b>PF<sub>s</sub></b>	<b>U<sub>R</sub></b> (V)	<b>I<sub>R</sub></b> (A)	<b>P<sub>R</sub></b> (W)	<b>Q<sub>R</sub></b> (VAR)	<b>PF<sub>R</sub></b>
<b>No Load</b>										
<b>2.3 H</b>										
<b>1.15 H</b>										
<b>0.77 H</b>										

**Question:**

Chose one row of the above table to draw the phaser diagram.

**OPERATIONAL MODE FOR DETECTING THE PERFORMANCE WITH CAPACITIVE LOAD**

- Replace the resistive load with a capacitive load, or add this last.

- Enable and adjust the voltage of the power supply at 380 V. The warning lights of the left busway will be on. If no variable three-phase power supply is available, but only a fixed line is used, the voltage can be adjusted at the nearest rated value through the outlets of percent variation of the transformer (+/- 5 %).
- Turn the breakers at the origin and at the end of the LINE 2, to ON.
- Connect the various steps of the capacitive load (assemble balanced loads using the same step for the three phases), read the electric quantities on the instruments and write them down in the table shown below.

Actual measurements carried out on the LINE 2 with:  
Resistance = 8.9Ω; Capacitance = 0.1μF; Inductance = 0.036 H

	<b>U<sub>s</sub></b> <b>(V)</b>	<b>I<sub>s</sub></b> <b>(A)</b>	<b>P<sub>s</sub></b> <b>(W)</b>	<b>Q<sub>s</sub></b> <b>(VAR)</b>	<b>PF<sub>s</sub></b>	<b>U<sub>R</sub></b> <b>(V)</b>	<b>I<sub>R</sub></b> <b>(A)</b>	<b>P<sub>R</sub></b> <b>(W)</b>	<b>Q<sub>R</sub></b> <b>(VAR)</b>	<b>PF<sub>R</sub></b>
<b>No Load</b>										
<b>4.5 μF</b>										
<b>9 μF</b>										
<b>13 μF</b>										

**Question:**

Chose one row of the above table to draw the phaser diagram.

**OPERATIONAL MODE FOR DETECTING THE PERFORMANCE WITH R-L, R-C LOAD**

1. Adjust the sending end voltage to be 380 V.
2. Actual measurements carried out on the LINE 2 with:  
Resistance = 8.9Ω; Capacitance = 0.1μF; Inductance = 0.036 H
3. Connect the variable loads to receiving end of T.L and vary it in steps and take your results as in the table below:

	<b>U<sub>s</sub></b> <b>(V)</b>	<b>I<sub>s</sub></b> <b>(A)</b>	<b>P<sub>s</sub></b> <b>(W)</b>	<b>Q<sub>s</sub></b> <b>(VAR)</b>	<b>PF<sub>s</sub></b>	<b>U<sub>R</sub></b> <b>(V)</b>	<b>I<sub>R</sub></b> <b>(A)</b>	<b>P<sub>R</sub></b> <b>(W)</b>	<b>Q<sub>R</sub></b> <b>(VAR)</b>	<b>PF<sub>R</sub></b>
No Load										
360Ω + L1										
360Ω + L2										
360Ω + L3										

$360\Omega + C1$										
$360\Omega + C2$										
$360\Omega + C3$										

**Question:**

Chose one row of the above table to draw the phaser diagram for R-L Load.

And one row of the above table to draw the phaser diagram for R-C Load.

**Part E: Calculate The Voltage Drop, Total Power Losses and Performance (Efficiency) of The Transmission Line**

1. Adjust the sending end voltage to be 380 V.
2. Actual measurements carried out on the LINE 2 with:  
Resistance =  $8.9\Omega$ ; Capacitance =  $0.1\mu\text{F}$ ; Inductance =  $0.036\text{ H}$
3. Connect the variable loads to receiving end of T.L and vary it in steps and take your results as in the table below:

	<b>Us</b> <b>(V)</b>	<b>Is</b> <b>(A)</b>	<b>Ps</b> <b>(W)</b>	<b>UR</b> <b>(V)</b>	<b>IR</b> <b>(A)</b>	<b>PR</b> <b>(W)</b>	<b>Us - UR</b> <b>(V)</b>	<b>Ps - PR</b> <b>(W)</b>	<b><math>\eta</math></b>
No Load									
720 $\Omega$									
360 $\Omega$									
240 $\Omega$									
2.3 H									
1.15 H									
0.77 H									
4.5 $\mu\text{F}$									
9 $\mu\text{F}$									
13 $\mu\text{F}$									



$360 \Omega + 2.3 \text{ H}$									
$360 \Omega + 1.15 \text{ H}$									
$360 \Omega + 0.77 \text{ H}$									
$360 \Omega + 4.5 \mu\text{F}$									
$360 \Omega + 9 \mu\text{F}$									
$360 \Omega + 13 \mu\text{F}$									

**Question:**

**Write your comments on the above table in detail**

### **Experiment #6**

Studying the Operation of a Power Transmission Line in Condition of  
Ground Fault

**Objectives:**

- Studying the operation of power transmission line with neutral cable insulated in condition of ground fault.
- Studying the operation of power transmission line with compensated neutral conductor (Peterson coil) in condition of ground fault.

### **Necessary Equipments:**

1. Simulator of electric lines mod. SEL-1/EV.
2. Variable three phase power supply mod. AMT-3/EV, in option three-phase line generated by the generator control board mod. GCB-1/EV, or a fixed three-phase line 3X380v.
3. Three-phase transformer mod. P14A/EV.
4. Set of loads/jumpers for electrical connection.
5. Two digital instruments for measuring the parameters of electric energy in three-phase system mod. AZ-VIP.
6. Variable resistive load mod. RL-2/EV or mod. RL-1/EV.
7. Variable inductive load mod. IL-2/EV.

### **Part A: Power transmission line with neutral cable insulated in condition of ground fault**

#### **Theory:**

The single line ground fault current of an electric system insulated from ground, closes through the ground capacitance of the phases (it is defined  $C_E$ ), and consequently its value is not very high. The overhead power lines with insulated neutral conductor offer the following advantages:

- Reduce the total ground voltage in cabins for medium-voltage and high voltage faults.
- The transient electric arc generated in ground faults will be suppressed automatically, thus the operation continuity will be improved.

On the contrary the disadvantages due to the insulated neutral conductor are:

- Difficult troubleshooting
- High operating and fault overvoltages.

The ground fault current of the system with insulated neutral conductor (Figure -1) will rise as the ground capacitance ( $C_E$ ) increases, that is as main is extended.

An alternative to the insulated neutral cable is represented by the grounding of this same cable through a coil (Peterson coil, or arc-suppression coil), this will be explained in Part B.

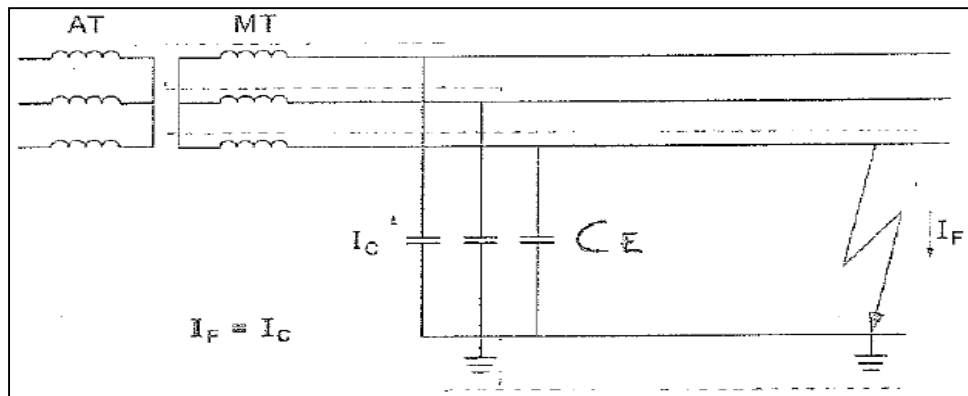


Figure -1: Ground fault current in a line with insulated neutral conductor

### Experimental procedure:

1. Connect the circuit as shown on Figure -2.

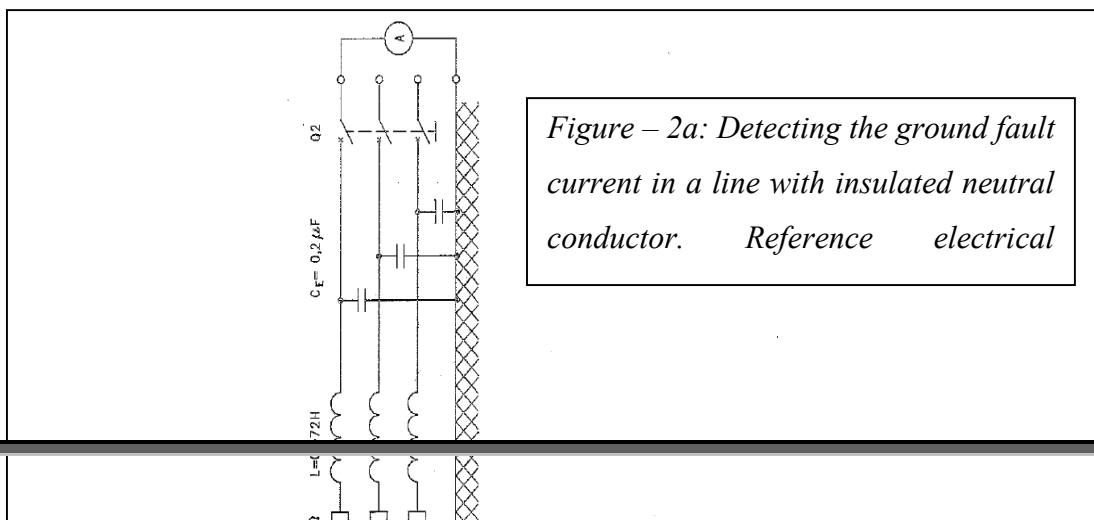


Figure - 2a: Detecting the ground fault current in a line with insulated neutral conductor. Reference electrical



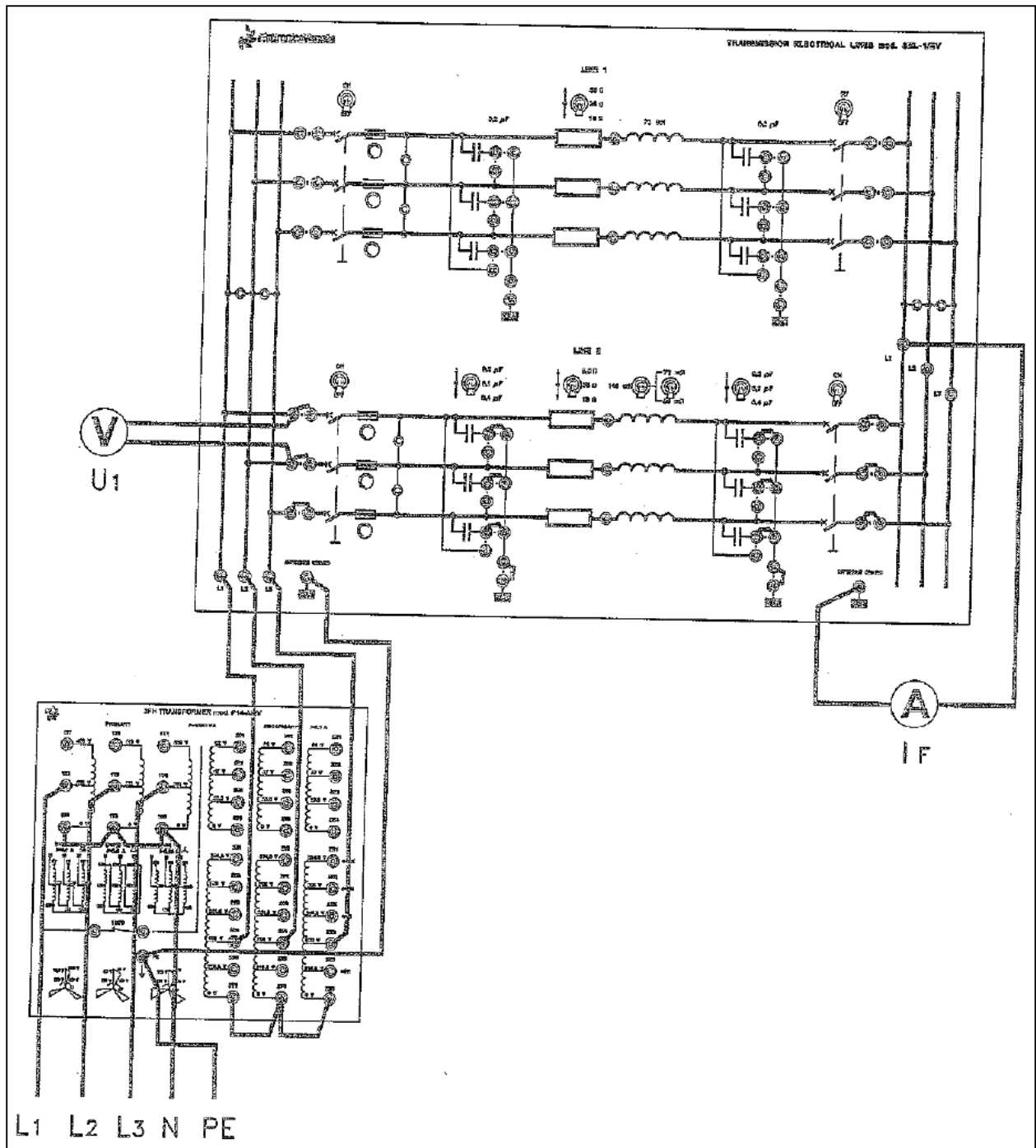


Figure – 2b: Detecting the ground fault current in a line with insulated neutral conductor

2. Consider the transmission LINE 2 with the following constants: Resistance =  $18\Omega$ , Inductance =  $0.072H$ , Capacitance =  $0.1 + 0.1 \mu F$ , Length =  $50 \text{ km}$ ; Section= $50 \text{ mm}^2$  - conductor of copper.
3. Turn the breakers at the origin and at the end of the LINE 2, to OFF.

4. Connect the measuring instruments between the left busway and the terminals at the starting of the LINE 2, and between the end terminals of the LINE 2 and the right busway.
5. Connect the jumpers of the both set of capacitors, in the LINE 2, to reproduce the capacitance between active conductors and ground equal 0.1 $\mu$ F -called  $C_E$ .
6. Connect the left busway with the variable three-phase power supply. **This exercise does not require any load in the right busway.** However, we make a short circuit on the right busway between line1 and ground as shown in Figure - 2.
7. Switch on the three – phase power supply and adjust the sending end voltage of the transmission line to 380 volt and keep it constant throughout the test.
8. Turn the breaker at the origin and at the end of the Line 2 to ON, in sequence.
9. modify the set of capacitors  $C_E$  (via the proper selectors) and check the trend of ground fault current at sending end and receiving end and tabulate you results in table-1.

$C_E$ sending, $C_E$ receiving  ( $\mu$ F)	Sending Voltage  $V_s$ (V)	Free ground fault current  $I_F$ (A)	Trend fault current at sending end  $I_{F,S}$ (A)	Trend fault current at receiving end  $I_{F,R}$ (A)
0.1 , 0.1	380			
0.1 , 0.2	380			
0.1 , 0.4	380			
0.2 , 0.2	380			
0.2 , 0.4	380			
0.4 , 0.4	380			

Table – 1

### Questions:

- Explain the effect of increasing the values of  $C_E$  sending and  $C_E$  receiving on the fault current?
- Plot the curve of  $C_{total}$  ( $C_E$  sending +  $C_E$  receiving) versus  $I_{F,R}$  and explain the effect of adding certain value of resistance in series with the faulted line?

## PART B: Power transmission line with compensated neutral conductor (Peterson coil) in condition of ground fault

### Theory:

An alternative to power transmission lines with insulated neutral conductor consists in grounding this same cable through a coil. The operating principle of Petersen coil is shown in the Figure-3. 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 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.

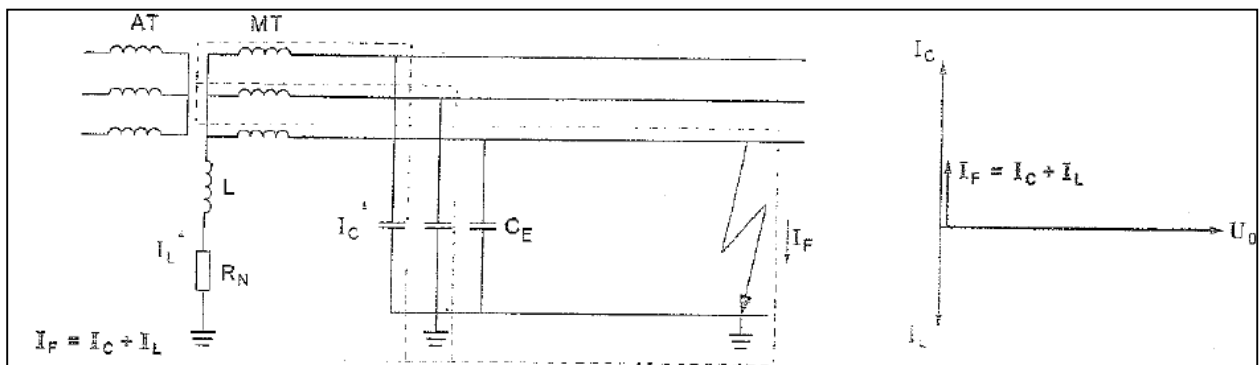


Figure -3: Ground fault current in a line with compensated neutral conductor

### Experimental procedure:

1. Connect the circuit as shown on Figure -4.

2. Consider and set the transmission LINE 2 with the following constants: Resistance =  $18\Omega$ , Capacitance =  $0.4 + 0.4 \mu\text{F}$ , Inductance =  $0.072 \text{ H}$ , Length =  $50 \text{ km}$ ; Section= $50 \text{ mm}^2$  - conductor of copper.
3. Turn the breakers at the origin and at the end of the LINE 2, to OFF.
4. Connect twomeasuring instruments between the left busway and the terminals at the starting of the LINE 2, and between the end terminal the LINE 2 and the right busway.
5. Connect the jumpers of both set of capacitors, in the LINE 2, to reproduce the capacitance between active conductors and ground (called CE).
6. Connect the left busway with the variable three-phase power supply.  
This exercise does not require any load in the right busway but here make a short circuit on the right busway between **a phase of the line** and ground as shown in Figure-4 **without any resistor connected in series with this fault line.**
7. Switch ON the three – phase power supply and adjust the sending end voltage of the transmission line to **380volt** and keep it constant throughout the test.
8. Turn the breaker at the origin and at the end of the Line 2 to ON.
9. Select the values of **CEs =  $0.4\mu\text{F}$  & CEr = $0.4\mu\text{F}$**  and then vary the values of the inductor connected in series with the neutral line and measure the values of fault current at sending end and receiving end and tabulate your results in Table - 2.

$C_E$ sending, $C_E$ receiving  ( $\mu\text{F}$ )	Sending Voltage  $V_s$ (V)	Conductance of compensation coil L  (mH)	Trend fault current at sending end  $I_{f,s}$ (A)	Trend fault current at receiving end  $I_{f,r}$ (A)
0.4 , 0.4	380	$(2.3+2.3+2.3)=6.9$		
0.4 , 0.4	380	$(2.3+2.3+1.15)=5.75$		
0.4 , 0.4	380	$(2.3+2.3+0.58)=5.18$		
0.4 , 0.4	380	$(2.3+1.15+0.58)=4.03$		
0.4 , 0.4	380	$(2.3+0.58+0.58)=3.46$		
0.4 , 0.4	380	$(1.15+0.58+0.58)=2.3$		
0.4 , 0.4	380	$(0.58+0.58+0.58)=1.74$		

Table - 2



10. Repeat the previous test by changing the values of  $C_E = 0.2\mu F$  &  $C_{Er} = 0.2\mu F$ , register your values in Table -3.

$C_E$ sending, $C_E$ receiving  ( $\mu F$ )	Sending Voltage $V_s$ (V)	Conductance of compensation coil L  (mH)	Trend fault current at sending end  $I_{F,S}$ (A)	Trend fault current at receiving end  $I_{F,R}$ (A)
0.2 , 0.2	380	(2.3 +2.3 + 2.3)=6.9		
0.2 , 0.2	380	(2.3 +2.3 +1.15)=5.75		
0.2 , 0.2	380	(2.3 +2.3 +0.58)=5.18		
0.2 , 0.2	380	(2.3 +1.15+0.58)=4.03		
0.2 , 0.2	380	(2.3 +0.58+0.58)=3.46		
0.2 , 0.2	380	(1.15+0.58+0.58)=2.3		
0.2 , 0.2	380	(0.58+0.58+0.58)=1.74		

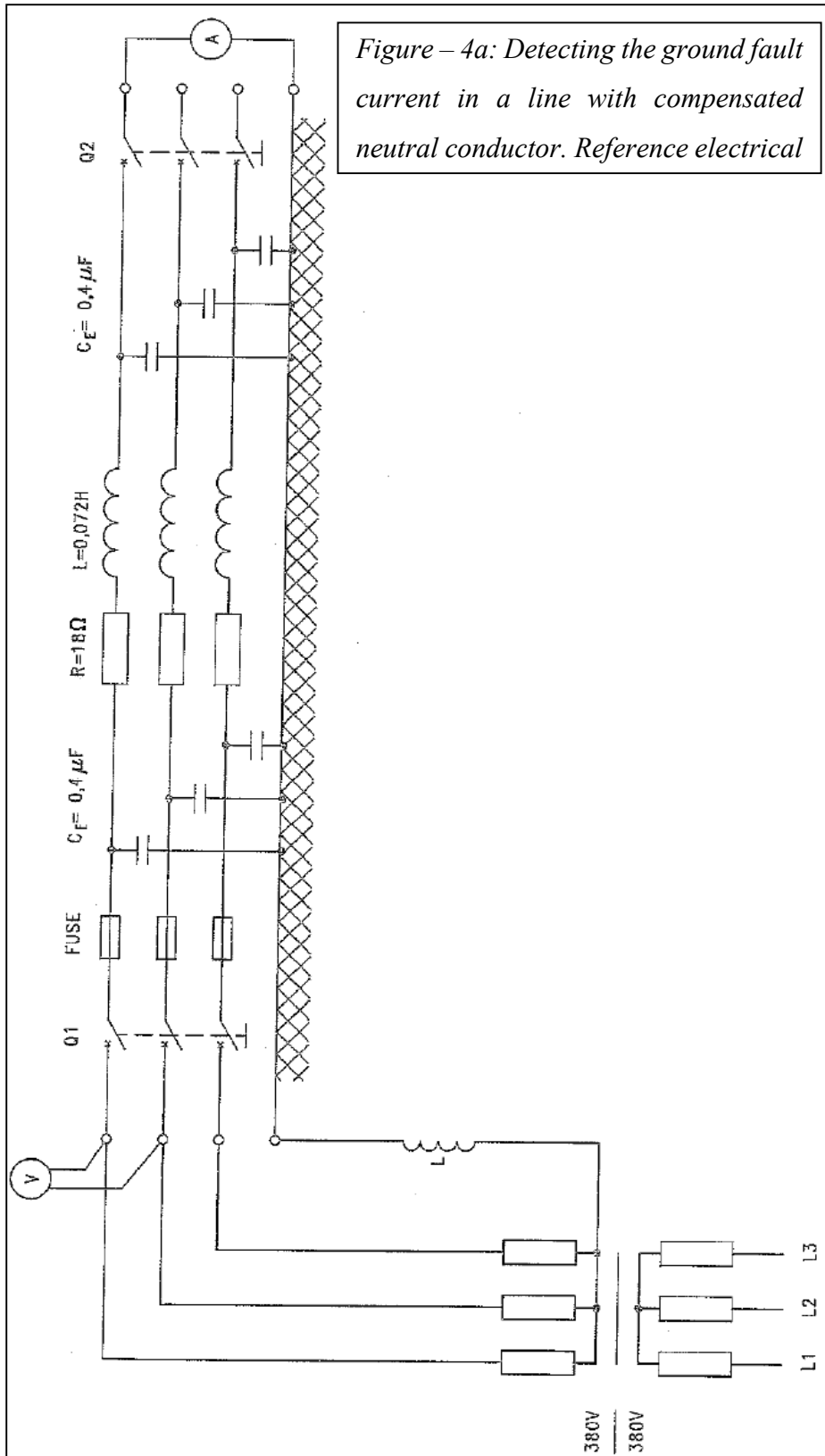


Figure – 4a: Detecting the ground fault current in a line with compensated neutral conductor. Reference electrical

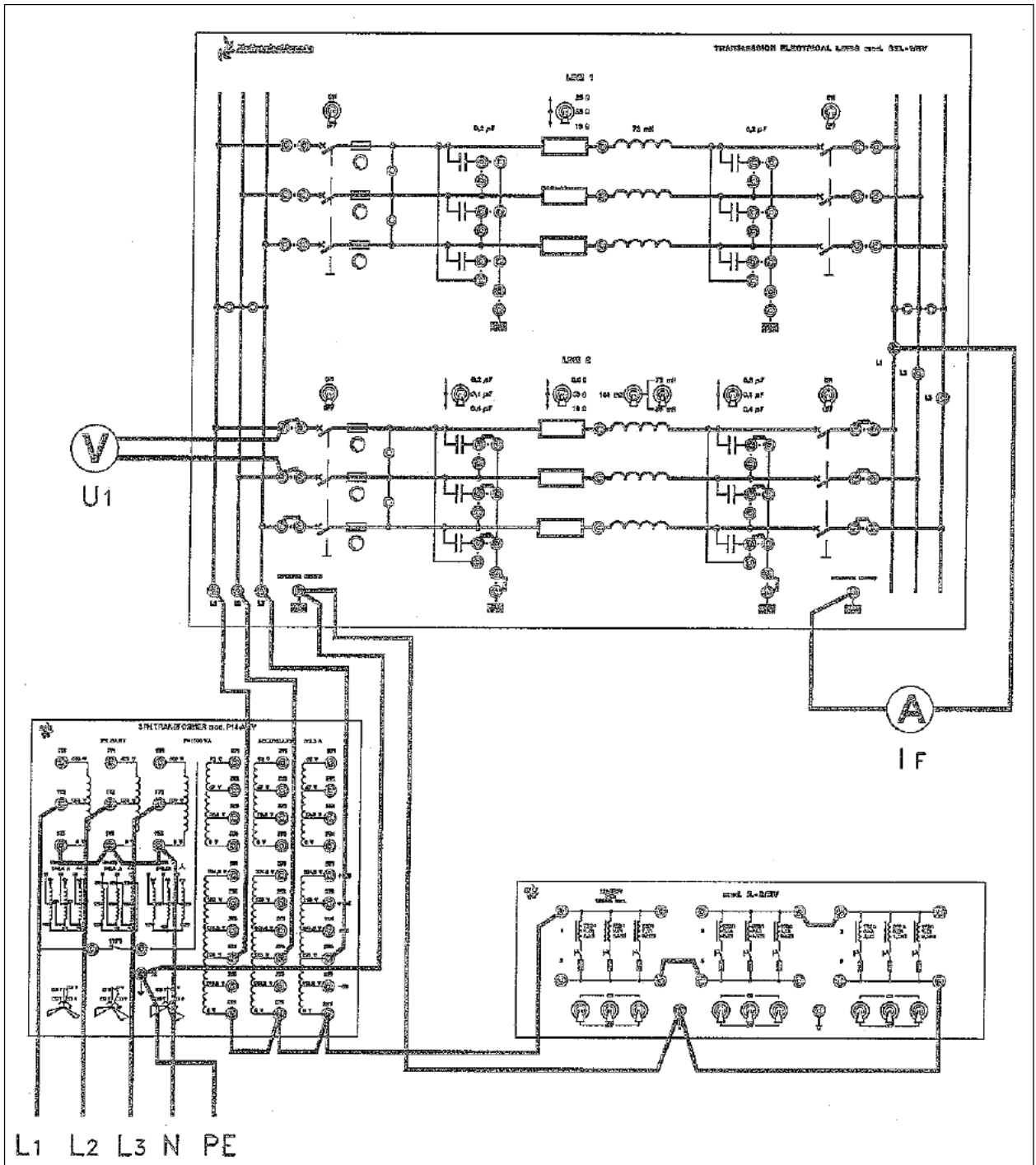


Figure – 4b: Detecting the ground fault current in a line with compensated neutral conductor

# Experiment # 7

## Induction Motor Speed Control

### Part 1

#### ➤ Objectives:

1. The object of this experiment to control the speed of an asynchronous three-phase motor by changing the supply frequency with different mode control of the drive.
2. To learn the different mode control of drive such as remote mode and local mode control .To run the motor at the jog speed, and multistep running.
3. To measure the motor torque versus the absorbed current for different frequency. To test the motor torque speed curve.

#### ➤ Equipments Required:

1. DL 2309a1 = Digital controlled inverter
2. M = Asynchronous three-phase motor with squirrel cage rotor
3. K2 = Optical transducer
4. G = Electromagnetic brake
5. K = Torque meter
6. PS = Brake power supply

#### ➤ Procedure:

#### ➤ PART A :Open Loop Speed Regulation:

##### - Remote Mode:

The object of this exercise is the control of the speed of an asynchronous three-phase motor by changing the supply frequency with remote mode control of the drive.

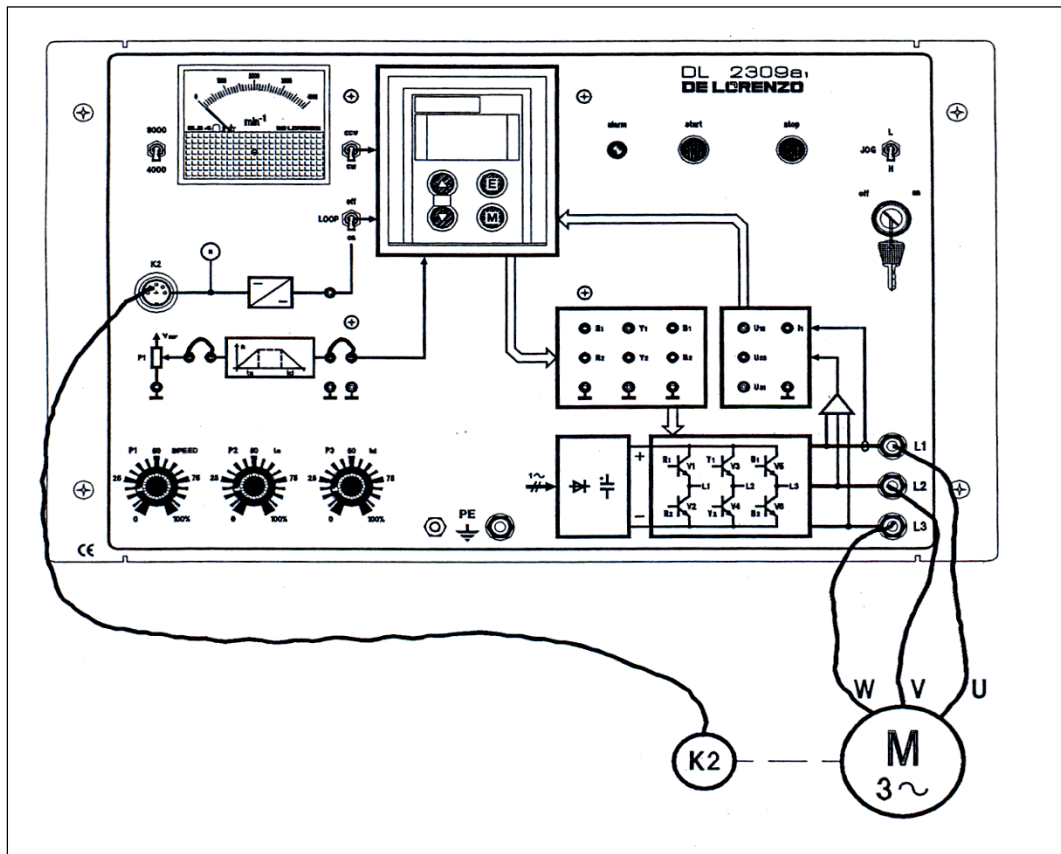


Figure 6.1

1. Connect the motor M to terminals L1 (U), L2 (V) and L3 (W).
2. Make the following basic settings of DL 2309a1:
  - Set both key and LOOP switches to "off".
  - Set JOG switch to "L".
  - Set P1=0
  - Set P2 and P3 potentiometers to desired acceleration and deceleration times
  - (Add 10s for factory default values of parameters **P3** and **P4**).
  - Set switch "cw/ccw" to "cw" (cw rotation of the motor shaft).
3. Press both (  $\Delta$  ) and (  $\nabla$  ) keys simultaneously and then switch on the main supply closing the rear switch.
  - The display shows [**rSt**]: release the two keys.
  - The parameters are reset to factory defaults.
  - Press (**M**) key: now the display shows [**rdY**].

4. Set the frequency control from potentiometer P1(Remote Mode: Parameter **P13**/ Mode 0) and the desired frequency range programming the digital control:
5. Parameter **P1** = (0Hz) minimum operation frequency
6. Parameter **P2** = (60Hz) maximum operation frequency
7. Set the inverter maximum output frequency at which maximum voltage is reached according to motor specific characteristics ( Motor 1.1kW/220V  $\Delta$ /50Hz):
8. Parameter **P7** = (50Hz) base frequency
9. Turn "on" the key switch.
10. Push "start" button and increase the SPEED signal adjusting the potentiometer P1 to desired speed value.
11. The motor has to start with the set acceleration ramp and settle to speed corresponding to the potentiometer P1 value.
12. The motor revolving speed is directly read on the tachometer, the motor speed can be changed adjusting the potentiometer P1 value.
13. Stop the motor by setting P1=0 or pressing button "stop": after the motor deceleration according to the set deceleration ramp, the inverter is inhibited and the motor stops.
14. Set the key switch to "off" and open the rear main switch.

➤ **PART B :Open Loop Speed Regulation Local Mode:**

The object of this exercise is the control of the speed of an asynchronous three-phase motor by changing the supply frequency with local mode control of the drive.

1. Modify the previous circuit by disconnecting the potentiometer P1.
2. Connect the motor M to terminals L1(U), L2(V) and L3(W).
3. make the following basic settings of DL 2309a1:
  - Set the key switch to "off".
  - Set JOG switch to "L".
4. Press both (  $\Delta$  ) and (  $\nabla$  ) keys simultaneously and then switch on the main supply closing the rear switch.
  - The display shows [**rSt**]: release the two keys.
  - The parameters are reset to factory defaults.
  - Press (**M**) key: now the display shows [**rdY**] .
5. Set the desired motor frequency range programming the digital control:

6. Parameter **P1** = (0Hz) minimum operation frequency
7. Parameter **P2** = (60Hz) maximum operation frequency
8. Set the inverter maximum output frequency at which maximum voltage is reached according to motor specific characteristics ( Motor 1.1kW/220V Δ/50Hz):
9. Parameter **P7** = (50Hz) base frequency
10. With display showing [**rdY**] enter the local mode:
11. Press ( Δ ) and ( ▽ ) simultaneously: the display will begin to spell LOC.
12. When all three letters are displayed and the word [**LOC**] is flashing release the ( Δ ) and ( ▽ ) keys.
13. The display now shows the local set point of the frequency which can be increased using the ( Δ ) or decreased using the ( ▽ ) key.
14. Set the running frequency [**50.0**]: the max running frequency depends on the Parameter **P2** value.
15. While in the stopped state pressing the (**M**) red key will show the current direction: this direction may be changed by holding down the (**M**) key while simultaneously pressing either the ( Δ ) key for forward [**Frd**] or the ( ▽ ) key for reverse [**rEU**].
16. Now the (**E**) green key can be used to start the inverter.
17. The motor revolving speed is directly read on the tachometer, the motor speed can be changed pressing either the ( Δ ) key or the ( ▽ ) key.
18. Stop the motor by pressing the (M) red key.
19. To return to Remote Mode [**rdY**] press ( Δ ) and ( ▽ ) simultaneously.
20. Open the rear switch.

➤ **PART C :Jog Speed:**

1. The object of this exercise is the motor running at Jog Speed.
2. The same previous circuit.
3. Connect the motor M to terminals L1 (U), L2 (V) and L3 (W).
4. make the following basic settings of DL 2309a1:
  - Set the key switch to "off".
  - Set JOG switch to "L".
  - Set switch "cw/ccw" to "cw"

5. Press both (  $\Delta$  ) and (  $\nabla$  ) keys simultaneously and then switch on the main supply closing the rear switch.
  - The display shows [rSt]: release the two keys.
  - The parameters are reset to factory defaults.
  - Press (M) key: now the display shows [rdY] .
6. Set the frequency control for Jog speed and for the motor running speed:
7. Parameter **P8** = (30Hz) running freq. the max running frequency depends on the Parameter **P7** value.
8. Set the inverter maximum output frequency at which maximum voltage is reached according to motor specific characteristics ( Motor 1.1kW/220V  $\Delta$ /50Hz):
9. Parameter **P7** = (50Hz) base frequency
10. Now it is possible to start the motor setting the Jog switch in "H" position: the motor has to start with the set acceleration ramp and to settle to speed corresponding to the Jog value.
11. To reverse the direction of rotation of the motor set the "cw/ccw" to "ccw" position, stop the motor by setting the Jog switch in "L" position. Then open the rear main switch.

➤ **PART D :Multistep Control:**

The object of this exercise is the motor multistep running.

1. Connect the motor M to terminals L1 (U), L2 (V) and L3 (W).
2. Make the following basic settings of DL 2309a1:
  - Set the key switch to "off".
  - Set JOG switch to "L".
  - Set switch "cw/ccw" to "cw".
3. Press both (  $\Delta$  ) and (  $\nabla$  ) keys simultaneously and then switch on the main supply closing the rear switch.



- a. The display shows [**rSt**]: release the two keys.
  - b. The parameters are reset to factory defaults.
  - c. Press (**M**) key: now the display shows [**rdY**] .
4. Set the frequency control for multispeed operation(Remote Mode: Parameter **P13**/ Mode 2) and for the motor running speeds:
    - Parameter **P1** = (0Hz)
    - Parameter **P2** = (60Hz)
    - Parameter **P8** = (25Hz)
    - Parameter **P9** = (50Hz)
  5. Set the inverter maximum output frequency at which maximum voltage is reached according to motor specific characteristics ( Motor 1.1kW/220V Δ/50Hz):
  6. Parameter **P7** = (50Hz) base frequency
  7. Turn "on" the key switch.
  8. Push the "start" button: the motor do not start because the combination "cw/ccw" =**cw** / "JOG"=**L** corresponds to speed preset by the parameter **P1**.
  9. Operating the switches "cw/ccw" and "JOG" carry out the control sequence as follows:
    - "cw/ccw"=**ccw** / "JOG"=**L**.
    - "cw/ccw"=**ccw** / "JOG"=**H**.
    - "cw/ccw"=**cw** / "JOG"=**H**.
  10. Stop the motor by setting "JOG"=**L** when "cw/ccw"=**cw** or pressing button "stop" , then open the rear main switch.

➤ **PART E :Motor Power Curve:**

The object of this exercise is the measure of the motor torque versus the absorbed current for different frequency values.

Connect the circuit in figure 6.2

1. Connect the motor M to terminals L1 (U), L2 (V) and L3 (W) with the ammeter A to measure the motor current and the voltmeter V to measure the inverter output voltage.

2. Make the following basic settings of DL 2309a1:

- Set the key switch to "off".
- Set JOG switch to "L".

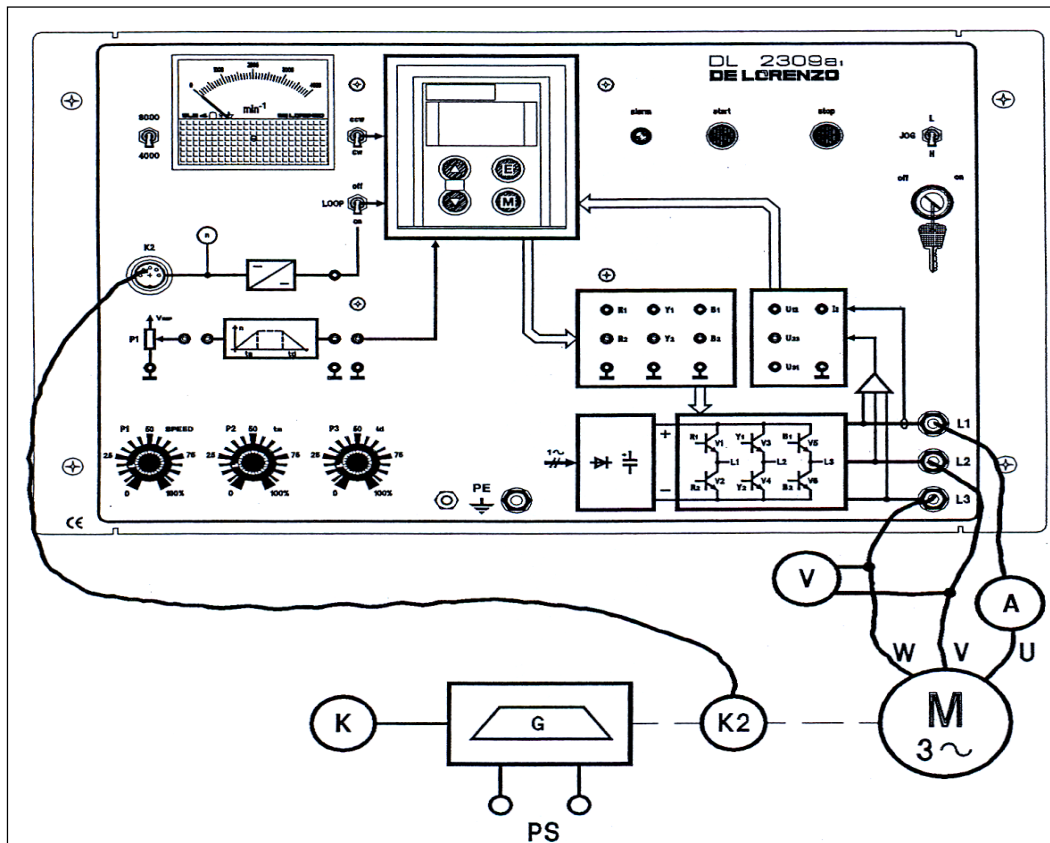


Figure 6.2

3. Press both (  $\Delta$  ) and (  $\nabla$  ) keys simultaneously and then switch on the main supply closing the rear switch.

The display shows [rSt]: release the two keys.

The parameters are reset to factory defaults.

Press (M) key: now the display shows [rdY] .

4. Set the desired frequency range programming the digital control:

- Parameter **P2** = (70Hz)

5. Set the inverter maximum output frequency at which maximum voltage is reached according to motor specific characteristics (Motor 1.1kW/220V  $\Delta$ /50Hz):

- Parameter **P7** = (50Hz) base frequency.

6 With display showing [**rdY**] enter the local mode:

Press (  $\Delta$  ) and (  $\nabla$  ) simultaneously: the display will begin to spell LOC.

When all three letters are displayed and the word [**LOC**] is flashing release the (  $\Delta$  ) and (  $\nabla$  ) keys. The display now shows the local set point of the frequency which can be increased using the (  $\Delta$  ) or decreased using the (  $\nabla$  ) key.

Set the first running frequency  $f_1=f_B$ : [**50.0**].

Now the (**E**) green key can be used to start the inverter.

8. Supply the brake and increase the brake setting by 0.5 N.m up to 4N.m, at each brake setting measure and record in a table the torque, the voltage and the absorbed current values.

9. Stop the motor pressing the (**M**) red key and de-energize the brake.

With standstill motor return to Remote Mode [**rdY**] pressing (  $\Delta$  ) and (  $\nabla$  ) simultaneously and set the second running frequency  $f_2 = (40\text{Hz})$

Change the Parameter **P7**= (40Hz).

Return to the Local Mode [**LOC**].

Set the second running frequency  $f_2$ : [**40.0**].

Start again the motor repeating step 7 and make the measurements following step 8.

Repeat for new frequency  $f_3$ : [**60.0**].

Stop the motor pressing (**M**) key, de-energize the brake and open the rear main switch.

Construct on a graph the power curves T vs I for different frequency values.

## Part 2

### ➤ Objectives:

1. The object of this experiment to control the speed of an asynchronous three-phase motor by changing the supply frequency with different mode control of the drive.
2. To learn the different mode control of drive such as remote mode and local mode control .To run the motor at the jog speed, and multistep running.
3. To measure the motor torque versus the absorbed current for different frequency. To test the motor torque speed curve.

### ➤ Equipments Required:

1. DL 2309a1 = Digital controlled inverter
2. M = Asynchronous three-phase motor with squirrel cage rotor
3. K2 = Optical transducer
4. G = Electromagnetic brake
5. K = Torque meter
6. PS = Brake power supply

### ➤ Procedure:

#### ➤ PART A :Motor Torque-Speed Curve:

The object of this exercise is the measure of the motor torque vs the speed, for different frequency values.

1. Connect the following circuit in Figure 8.1

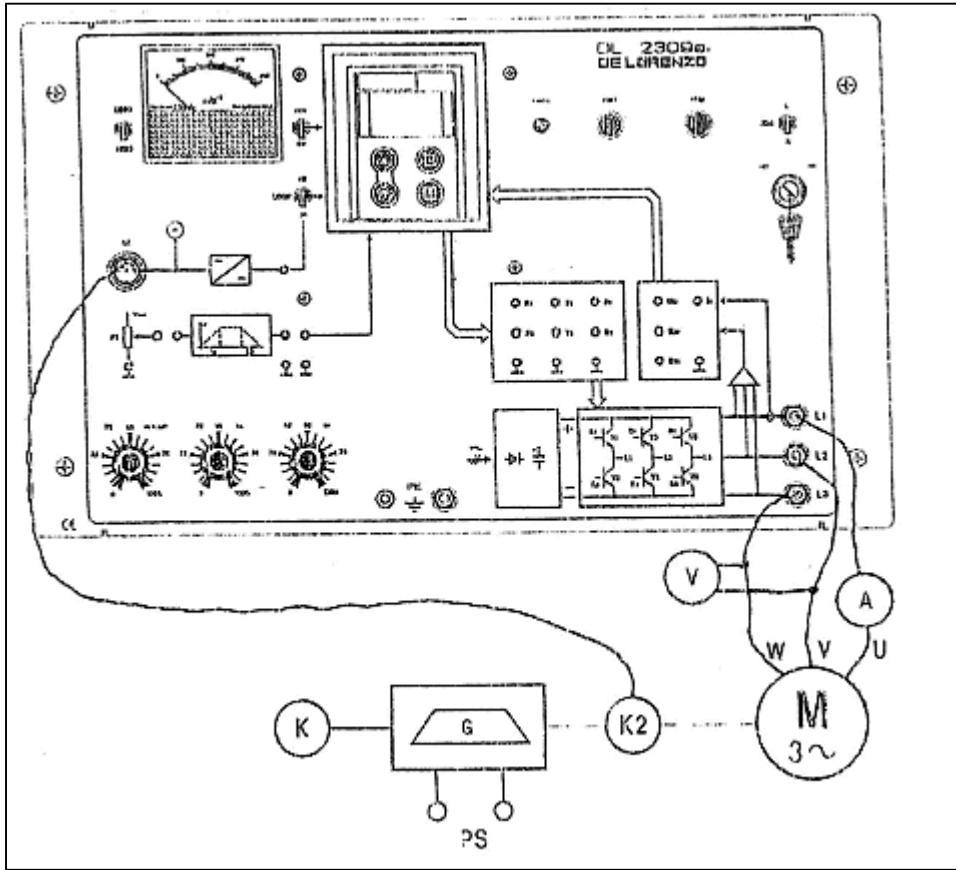


Figure 8.1

2. Connect the motor M to terminals L1(U), L2(V) and L3(W) with the ammeter A to measure the motor current and the voltmeter V to measure the inverter output voltage.

3. Make the following basic settings of DL 2309a1:

Set the key switch to "off".

Set JOG switch to "L".

4. Press both (  $\Delta$  ) and (  $\nabla$  ) keys simultaneously and then switch on the main supply closing the rear switch.

The display shows [rSt]: release the two keys.

The parameters are reset to factory defaults.

Press (M) key: now the display shows [rdY] .

5. Set the desired frequency range programming the digital control:

- Parameter **P2** = (60Hz)

6. Set the inverter maximum output frequency at which maximum voltage is reached according to motor specific characteristics ( Motor 1.1kW/220V  $\Delta$ /50Hz):

- Parameter **P7** = (50Hz) base frequency.

7. With display showing [**rdY**] enter the local mode:

Press (  $\Delta$  ) and (  $\nabla$  ) simultaneously: the display will begin to spell LOC.

When all three letters are displayed and the word [**LOC**] is flashing release the (  $\Delta$  ) and (  $\nabla$  ) keys.

The display now shows the local setpoint of the frequency which can be increased using the (  $\Delta$  ) or decreased using the (  $\nabla$  ) key.

Set the first running frequency  $f_1=f_B$ : [**50.0**].

8. Now the (**E**) green key can be used to start the inverter.

9. Supply the brake and increase the brake setting by 0.5 N.m up to 4N.m, at each brake setting measure and record in a table the torque , the voltage and the speed values.

10. De-energise the brake and change the motor speed for a frequency  $f_2 = [25.0]$  by pressing the (  $\nabla$  ) key.

11. Repeat the measurements following step 8.

12. Stop the motor pressing the (M) key, de-energise the brake and open the rear switch.

13. Construct on a graph the torque T vs n the speed for the two frequency values.

### ➤ **PART B :Variable Frequency Speed Control:**

The object of this exercise is the measure of the torque-speed curve of the motor-inverter system.,Connect the same circuit of the previous part.

1. Connect the motor M to terminals L1(U), L2(V) and L3(W) with the ammeter A to measure the motor current and the voltmeter V to measure the inverter output voltage.
2. Make the following basic settings of DL 2309a1:

Set the key switch to "off".

Set JOG switch to "L".

3. Press both (  $\Delta$  ) and (  $\nabla$  ) keys simultaneously and then switch on the main supply closing the rear switch.
  - a. The display shows [**rSt**]: release the two keys.
  - b. The parameters are reset to factory defaults.
  - c. Press (**M**) key: now the display shows [**rdY**] .

4. Set the desired frequency range programming the digital control:

Parameter **P2** = (70Hz)

5. Set the inverter maximum output frequency at which maximum voltage is reached according to motor specific characteristics ( Motor 1.1kW/220V  $\Delta$ /50Hz):
6. Parameter **P7** = (50Hz) base frequency
7. With display showing [**rdY**] enter the local mode:

Press (  $\Delta$  ) and (  $\nabla$  ) simultaneously: the display will begin to spell LOC.

When all three letters are displayed and the word [**LOC**] is flashing release the (  $\Delta$  ) and (  $\nabla$  ) keys.

The display now shows the local setpoint of the frequency which can be increased using the (  $\Delta$  ) or decreased using the (  $\nabla$  ) key.

Set the first running frequency  $f_i=f_B$ : [**70.0**].

8. Now the (**E**) green key can be used to start the inverter.
9. Supply the brake and increase the brake setting so the motor absorbs a set current of 4.3A , measure and record in the table the voltage, the speed and torque values .
10. Decrease the frequency value to 30 Hz value by 5Hz at a time using the (  $\nabla$  ) key.

At each frequency setting adjust the brake supply so the absorbed current is always equal to 4.3A, and measure and record in the table the voltage, the speed and torque values.

11. Stop the motor pressing the (M) key, de-energise the brake and open the rear switch.
12. Construct the motor-inverter characteristic curves T vs n and Po vs n.

➤ **PARTC :Closed Loop Speed Regulation:**

The object of this exercise is to check the motor speed regulation by tachometric feedback.

Connect the following circuit.

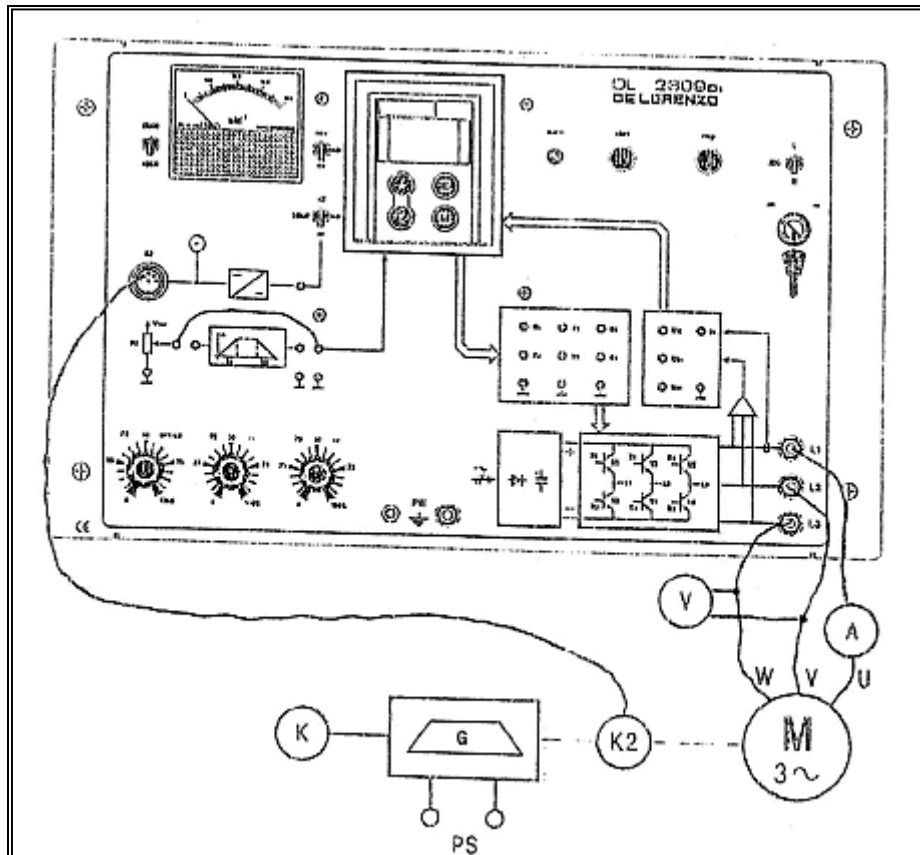


Figure 8.3

1. Connect the motor M to terminals L1(U), L2(V) and L3(W) with the ammeter A to measure the motor current and the voltmeter V to measure the inverter output voltage.
2. Make the following basic settings of DL 2309a1:

Set the key switch to "on".

Set JOG switch to "L".

Set P1=0

Set switch " cw/ccw" to "cw"



3. Press both (  $\Delta$  ) and (  $\nabla$  ) keys simultaneously and then switch on the main supply closing the rear switch.
  - a. The display shows [**rSt**]: release the two keys.
  - b. The parameters are reset to factory defaults.
  - c. Press (**M**) key: now the display shows [**rdY**].

2. Set the frequency control from potentiometer P1 ( Remote Mode: Parameter **P13/Mode 0**) and the desired motor frequency range programming the digital control:

Parameter P1 = 0Hz

Parameter P2 = 70Hz

3. Set the inverter maximum output frequency at which maximum voltage is reached according to motor specific characteristics ( Motor 1.1kW/220V  $\Delta$ /50Hz):

Parameter **P7** = (50Hz) base frequency

4. Turn "on" the key switch.

Push "start" button and increase the SPEED signal adjusting the potentiometer P1 to desired speed value, for example the base frequency  $f_B(50\text{Hz})$ .

5. Supply the brake and increase the brake setting by 0.5 N.m up to 4N.m, at each brake setting measure and record in a table the torque , the speed and the output frequency of the inverter shown on the display.
6. Repeat step 7 for a frequency of 40Hz and 60Hz .
7. Stop the motor pressing the button "stop" and set the key switch to"off", de-energise the brake and open the rear switch.
8. Construct on a graph the torque T vs n the speed for the different frequency values.

## Experiment # 8

### Reluctance Motor & Universal Motor

➤ **Objectives:**

After carrying out the experiments, the trainee will be capable of:

1. Connecting a reluctance motor in a star circuit and reversing its direction of rotation with and without a reversing switch.
2. Performing measurements to determine a reluctance motor's efficiency and making a comparison of this value to the value derived from rating plate data.
3. Recording and interpreting various reluctance motor characteristics as a function of load torque or speed.

➤ **Equipment Required:**

Reluctance motor 0.3	732 45
Machine test system	731 989
CBM 10 computer-based analysis of electrical machines,V.5.76	728 421
Three pole on/off switch	731 42
Three-phase supply unit with FCCB	726 75
Motor protection switch, 1 ... 1.6 A	732 14
Shaft end guards	731 07
RMS meter	727 10
Power factor meter	727 12
Resistive load	73240
Field Regulator	731 95
Universal motor	732 00
Power Circuit Breaker Module	745 561
Motor protection switch, 2.4...4 A	732 84
Isolating variable transformer 0 ...260 V	726 85

➤ **Notations:**

$P_1$	Input power
$P_2$	Output power
$T$	Nominal torque
$\eta$	Efficiency
$n$	Mechanical speed
$I$	Current
$V$	Voltage

➤ **Theory:**

The so-called "reluctance motor" represents a special case. Its rotor, in contrast to the squirrel cage rotor, has pronounced poles whose number corresponds to the number of poles in the stator's winding. This results in different magnetic resistances (Reluctance) around the circumference of the rotor that is smallest in the vicinity of the pole and greatest near pole gaps.

This allows the reluctance motor to come up to speed like an induction motor with squirrel-cage rotor but then be pulled into synchronism with the stator's field, thereby subsequently running as a synchronous motor (with no excitation). It can now run at a constant speed until it is loaded up to a certain torque. When it becomes overloaded it, will drop out of step and again run asynchronously. Its power factor and efficiency are less favorable than those of comparably sized asynchronous motors.

➤ **Advantages:**

Simple construction- no brushes, sliprings, or permanent magnets, no Cu or Al in the rotor, high reliability compared to conventional AC or DC motors, high starting torque, cost effective

compared to brushless DC motor in high volumes, adaptable to very high ambient temperature and low cost accurate speed control possible if the volume is high enough.

➤ **Disadvantages:**

Current versus torque is highly nonlinear, phase switching must be precise to minimize ripple torque, phase current must be controlled to minimize ripple torque, acoustic and electrical noise and not applicable to low volumes due to complex control issues.

The universal motor can be operated with either direct current DC power or on alternating current power. It exhibits a series characteristic, whereby – with increasing load torque – its speed does drop somewhat more when operating on AC power than it does when operating on DC power.

➤ **Procedure:**

Note: Do not turn on any equipment without prior notice from your lab supervisor.

➤ **PART A: Basic Circuits:**

1. Set up the circuit as shown in Figure 7.1

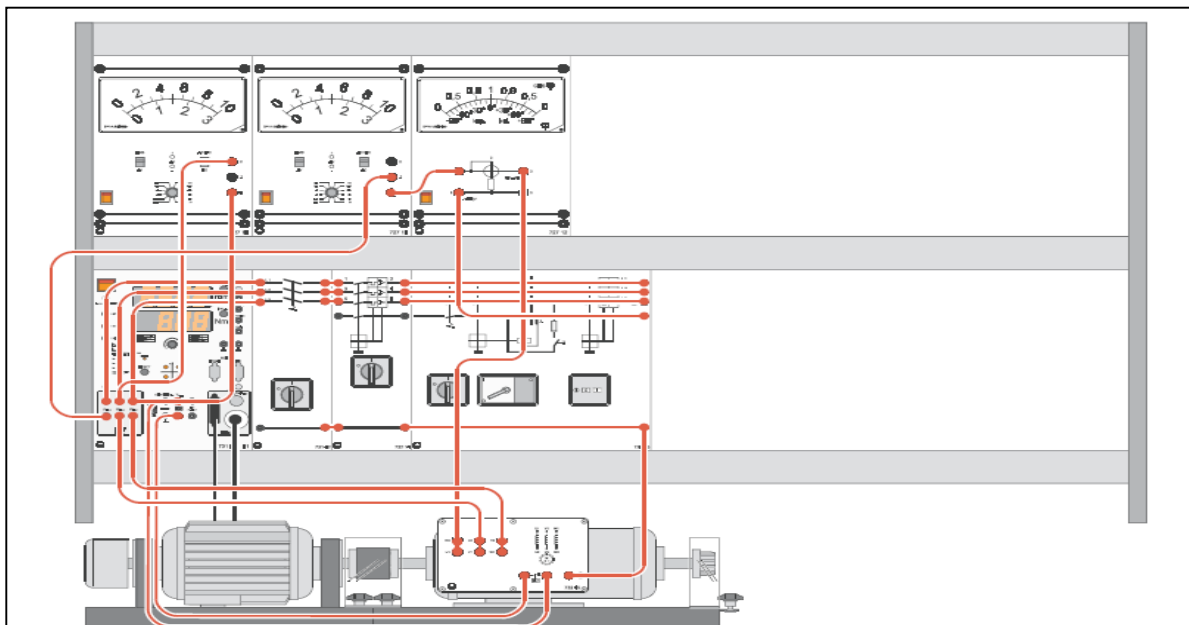


Figure7.1: Arrangement of Units for the Basic Circuits

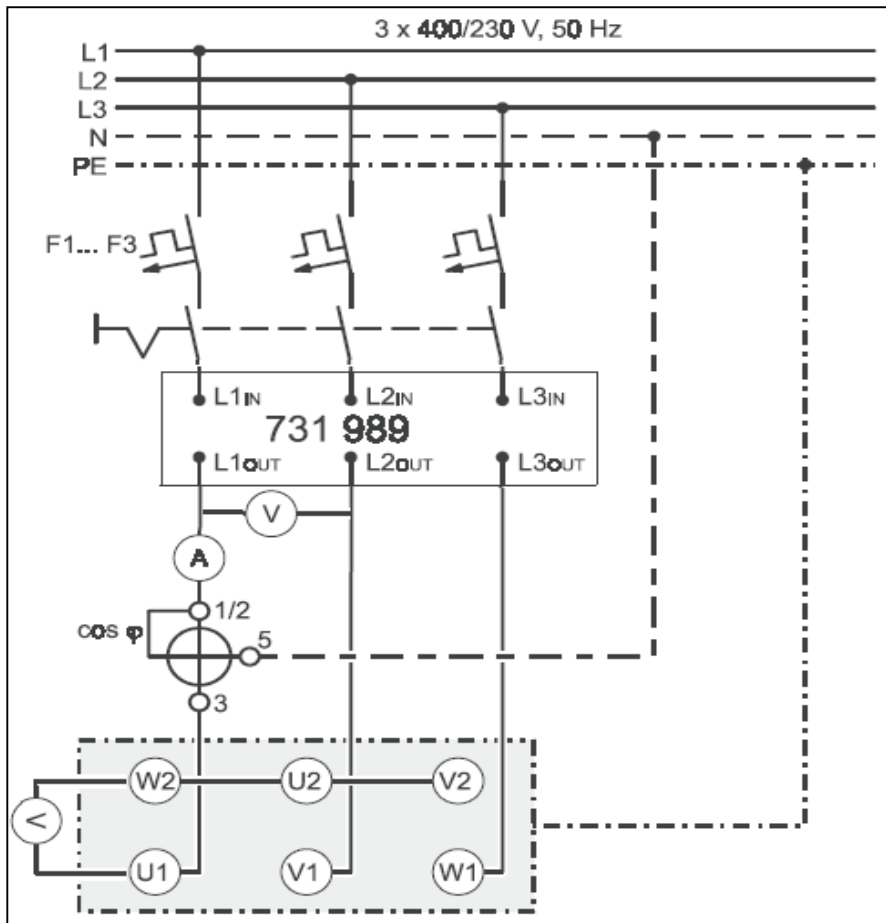


Figure 7.2: Connecting the Reluctance Motor in a Star Circuit

1. Turn on the Main switch on the test machine system.
2. Turn on the AC supply, then turn on the power circuit breaker module.
3. Press RED button ( $M \neq 0$ ) and select torque mode to flywheel by using mode button.
4. Observe its direction of rotation and measure its speed. (look at the motor from the direction of the coupling).
5. Measure line-to-line voltage and phase voltage at the motor as well as the current in a supply lead.
6. Turn off the load by pressing RED button ( $M \neq 0$ ) on the test machine system and turn off the power circuit breaker module.
7. Change motor direction of rotation
8. Repeat step 2, 3, 4, 5 and 6.

➤ **PART B: Determining Efficiency and Recording Characteristics:**

1. Set up the circuit as shown in Figure 7.2
2. Enter the rating plate data for the machine to be tested into Table 7.1

Table7.1: Nominal Data for the Machine Under Test

Nominal voltage $V_N$ when connected in star:	
Nominal voltage $V_N$ when connected in delta:	
Nominal current $I_N$ when connected in star:	
Nominal current $I_N$ when connected in delta:	
Nominal power factor, $\cos \varphi_N$ :	
Nominal output power $P_N$ :	
Nominal speed $n_N$ :	

3. First calculate the nominal torque that the machine can produce. Determine the present machine's output nominal torque from its rating plate data.
4. Turn on the AC supply, then turn on the power circuit breaker module.
5. Press RED button ( $M!=0$ ) and select torque mode to Torque regulation by using mode button and set value then apply the nominal torque.
6. With the motor in this operational state, measure the line-to-line voltage, the current in one supply line, the power factor  $\cos \phi$  and the speed.
7. Determine the machine's input power.
8. Determine the efficiency  $\eta$  theor which can theoretically be expected on the basis of the rating plate's data and the actual efficiency  $\eta$  from the measured values.
9. To normalize the values in Table 7.2, use the nominal values for  $I_N$ ,  $V$ ,  $T_N$ ,  $P_N$ .
10. Change the load torque from zero to 1.5 N.m, then measure values for  $n$ ,  $I$ , and  $\cos \varphi$  values .
11. Find  $P_1$  and  $P_2$  and  $\eta$  to be calculated, then fill the following Table7.2

Table7.2: Measurements for Producing a Reluctance Motor's Load Characteristic

	T/ $T_{N,act}$	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
	T[Nm]								
Measure	n [ rpm]								
	I [A]								
	Cos( $\varphi$ )								

Calculate	$n / n_s$								
	$I / I_{N,act}$								
	$P_1 [W]$								
	$P_1 / P_{1N}$								
	$P_2 [W]$								
	$P_2 / P_{2N}$								
	$\eta / \%$								
	$T / T_{N,act}$	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
	$T [Nm]$								
Measure	$n / rpm$								
	$I [A]$								
	$\text{Cos}(\varphi)$								
Calculate	$n / n_s$								
	$I / I_{N,act}$								
	$P_1 [W]$								
	$P_1 / P_{1N}$								
	$P_2 [W]$								
	$P_2 / P_{2N}$								
	$\eta / \%$								

12. Turn off the load by pressing RED button ( $M!=0$ ) on the Machine Test System and turn off the power circuit breaker module.

13. Graphically present the measured values with load torque  $T$  as the X-axis and the values  $n$ ,  $I$ ,  $P_1$ ,  $P_2$ ,  $\cos \phi$  and  $\eta$  plotted in the Y-direction.

➤ **PART C: Computer-based Recoding of Run-up Characteristics:**

In this step we shall use the computer to plot curves that represent the behavior of motor:

Open the CBM 10 software by going to Start>>All Program>>CBM10>>MOMO.exe (click on MOMO) the software will open up.

1. Choose the machine under test type by going to “Machine Type” in the toolbar, then click on Reluctance motor.
2. Click on  $T$ ,  $I$ ,  $P_1$ ,  $P_2$  and  $\eta$  from the left side column to display these values plots versus the speed.
3. Change the axis setting from Presentations>>Axis Setting, first check all the nominal value boxes, fill in the Nominal Values fields (the ones that you have obtained for the machine in this experiment), modify the values of the Y-axis for the parameters according to Table7.3

Table7.3 Y-axis limits for the stated parameter for plotting

Parameter	From	To
$n$	0	1
torque	0	5
$I$	0	5
$P_1$ and $P_2$	0	15

4. Go to Measurements>>Settings, in the popup window, tick on the only motor operation box, set the operational mode to Load Characteristics, set the start up speed to 1500rpm, set the stop speed to 5 rpm, then press ok.
5. Turn on the dc supply, then turn on the power circuit breaker module.
6. On the CBM 10 software press on the Green button on the left hand column (this is the synchronization button that will synchronize the machine test system with the motor), wait for synchronization, make sure you choose the Automated Mode recording, then start the plotting by pressing on the RUN button on the software (the blue arrow to up left corner).



7. When the plotting is over, press on the RED button on the software to isolate the Machine Test System from the motor
8. Press on the OFF the power circuit breaker module.
9. Save your plots by copying it to clip board by the copy to clip board function on the software, copy it to a document file, or you can take a photo for the curves and use it in your report.
10. Comment on the plot you have .
11. Turn off all equipments, disconnect the circuit , and tidy the connecting wires on the wire rack.

## **Universal Motor**

### ➤ **Objectives:**

After carrying out the experiments, the trainee will be capable of:

2. Connecting a universal motor to an AC power source and reversing its direction. Performing measurements to determine the motor's efficiency when it is operating on AC power and making a comparison of this value to the value derived from rating plate data.
3. Controlling the universal motor's speed in AC powered operation by changing its terminal voltage.
4. Recording and interpreting various universal motor load characteristics when it is operating on AC power.
5. Applying computer-based techniques to measure and interpret the universal motor's load characteristics when it is operating on AC power.

### ➤ **Theory**

The universal motor can be operated with either direct current DC power or on alternating current power. It exhibits a series characteristic, whereby – with increasing load torque – its speed does drop somewhat more when operating on AC power than it does when operating on DC power.

### ➤ **PART A : Basic Circuits of Universal Motor :**

Set up the circuit as shown in Figure 7.4.

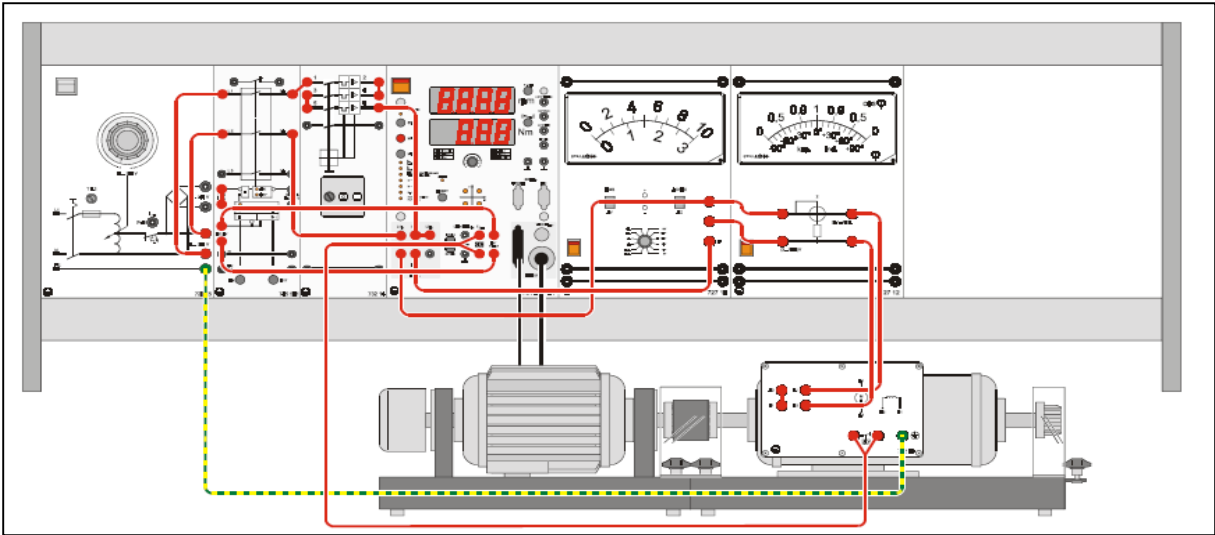


Figure 7.3: Arrangement of units in the experiment rack for determining efficiency and recording characteristics of a universal motor

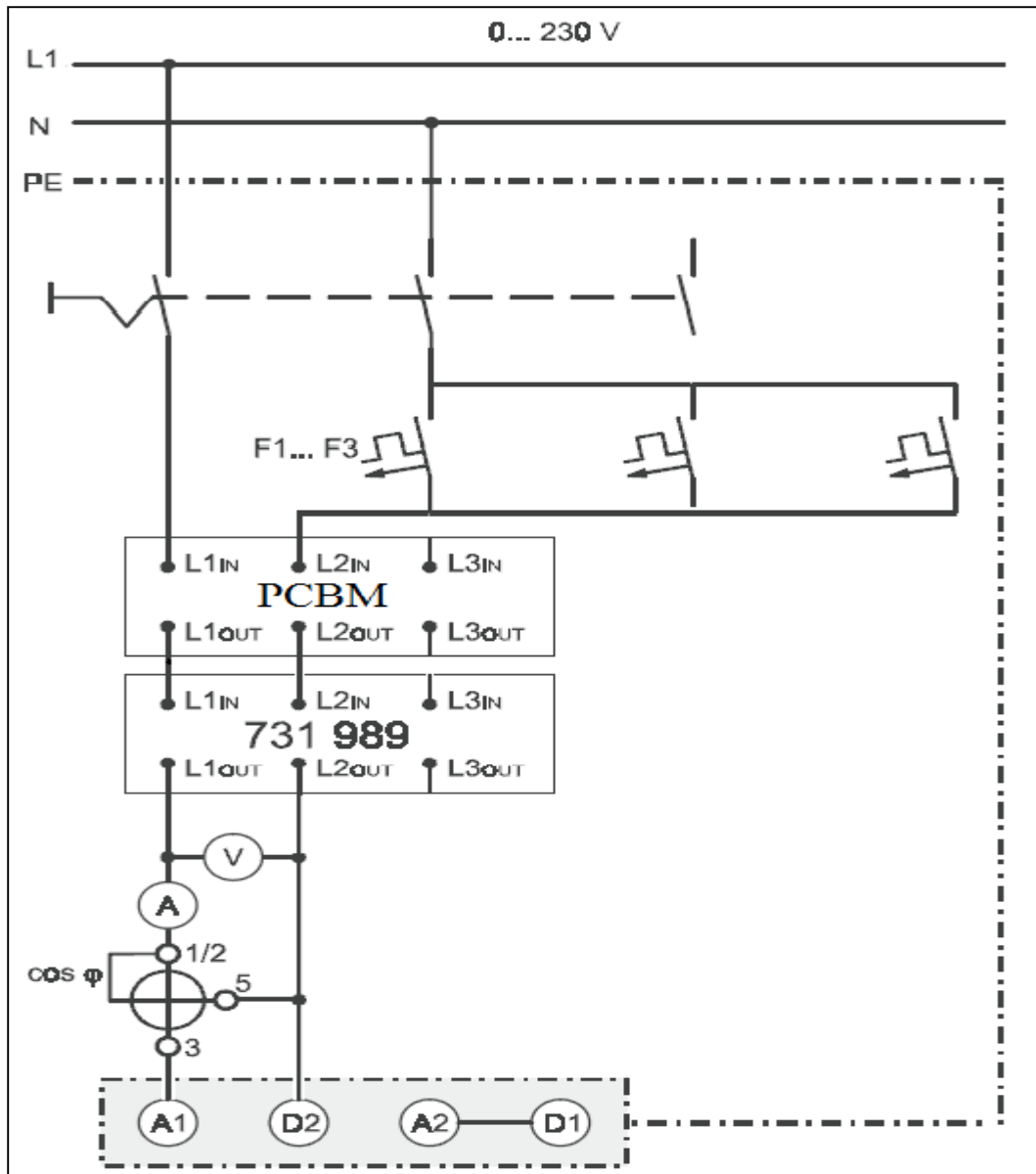


Figure 7.4: Circuit for determining the efficiency of a universal motor when it is operated on an AC power source

1. Turn on the Main switch on the Machine Test System.
2. Start the motor with an AC voltage that is about half of its nominal voltage (115V), then turn on the power circuit breaker module.
3. Observe its direction of rotation and measure its speed.
4. Turn off the motor (turn off the power circuit breaker module, then turn off the AC supply).
5. Change its direction of rotation and repeat steps 1 to 4.

➤ **PART B: Efficiency Test and Recording Load Characteristics of Universal Motor:**

1. Undo the connect you made to reverse direction of rotation (to obtain the circuit in Figure 7.4).
2. Using the data printed on machine plate, fill in Table 7.4

Table 7.4: Nominal Data for the Machine Under Test

Nominal voltage $V_N$ :	
Nominal current $I_N$ :	
Nominal speed $n_N$ :	
Nominal power $P_N$ :	

3. Determine the machine's nominal torque, input power, and efficiency
4. Turn on the Main switch on the Machine Test System
5. Start the motor with an AC voltage that is about half of its nominal voltage(115V), then turn on the power circuit breaker module.
6. Press RED button ( $M!=0$ ) and select torque mode on the control unit (operational mode "Torque regulation") by using the mode button and set the torque to 0.27Nm then gradually increase the voltage to its nominal value (230V), afterwards set the torque to nominal value.
7. Observe its direction of rotation and measure its speed .
8. Calculate the actual output power from torque and speed. Compare this calculated value with the machine's nominal value. If necessary, make a small correction to the load torque on the control unit and recalculate output power from the new speed. Change the load torque on the control unit until the nominal operation point has been reached, i.e. until the machine actually produces its nominal power.
9. Continue to measure voltage, current , and power factor that develop in the machine for this operational state. These measured values represent nominal values for the object under test. These actual values are differentiated from those printed on the rating plate by virtue of "act" in their subscript designations.
10. Determine the machine's effective input power, output power and the actual efficiency.
11. Change the load torque, beginning with 0.27 Nm, according to Table 7.5 (at higher loads it may be necessary to readjust voltage to keep it at its nominal value), record the speed, current, power factor.

12. Use the data to find  $P_1, P_2$  and, efficiency for every torque value

Table 7.5: Measured values for producing universal motor load characteristics

	T/ $T_{N,act}$	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3
	T [ Nm]											
Measure	N [rpm]											
	I [A]											
	cos $\phi$											
Calculate	n / $n_N$											
	I / $I_N$											
	$P_1$ [W]											
	$P_1 / P_{1N}$											
	$P_2$ [W]											
	$P_2 / P_{2N}$											
	$\eta$ [%]											

13. Now reduce AC voltage that is about half of its nominal voltage (115V), then disconnect the load by pressing RED button ( $M!=0$ ), turn off the power circuit breaker module and then turn off the AC power supply

14. Produce graphs as a function of load torque T for the values: speed, current, power factor, input power, output power and efficiency.

15. Comment on the graphs.

➤ **PART C: Computer-based Recording of Load Characteristics of Universal Motor:**

In this step we shall use the computer to plot curves that represent the behavior of universal motor:

- Open the CBM 10 software by going to Start>>All Program>>CBM10>>MOMO.exe (click on MOMO) the software will open up.
- Choose the machine under test type by going to “Machine Type” in the toolbar click on universal motor (AC).
- Click on T, I, P<sub>1</sub>, P<sub>2</sub> and efficiency from the left side column to display these values plots versus the speed.
- Change the axis setting from Presentations>>Axis Setting, first check all the nominal value boxes, fill in the Nominal Values fields (the ones that you have obtained for the machine in this experiment), modify the values of the Y-axis for the parameters according to Table 7.5

Table 7.5 Y-axis limits for the stated parameter for plotting

Parameter	From	To
n	0	2
torque	0	2
I	0	2
P <sub>1</sub> and P <sub>2</sub>	0	2
$\eta$	0	1

- Go to Measurements>>Settings, in the popup window, tick on the only motor operation box, set the operational mode to Run-up Characteristics, set the start up speed to 5000rpm, set the stop speed to 1500 rpm, then press ok.
- Turn on the AC supply, then set its output to 230V, then turn on the power circuit breaker module.
- On the CBM 10 software press on the Green button on the left hand column (this is the synchronization button that will synchronize the machine test system with the motor), wait for synchronization, make sure you choose the Automated Mode recording, then start the plotting by pressing on the RUN button on the software (the blue arrow to the up to left corner.)

- When the plotting is over, press on the RED button on the software to isolate the machine test system from the motor
- Set the AC voltage to 110V, and repeat steps 7 and 8.
- Press on the OFF the power circuit breaker module.
- Save your plots by copying them to clip board by the copy to clip board function on the software, copy them to a document file, or you can take a photo for the curves and use it in your report.
- Comment on the plots.

➤ **Questions:**

1. To what category of machines does the reluctance motor belong ?
2. Why is a reluctance motor's power factor relatively low ?
3. Describe the universal motor's speed and current relationships to load torque?
4. What is wrong about operating a universal motor at no-load with nominal voltage?
5. Name methods for speed control of a universal motor?

## Experiment # 9

# Shading Analysis, OFF Grid & ON Grid PV Systems

## 3. Objective

This experiment aims to introduce students to the main the components of different types of PV systems, in particular off-grid and on-grid PV system along with issues related to these system topologies

Also the effect of shading on PV system performance, possible problems and solutions are investigated

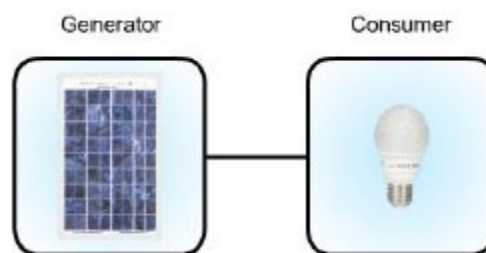
## 4. Theory

### 4.1. Layout of a stand-alone (off-grid) PV system

#### 4.1.1. Direct mode

If a consumer is operated **directly** by means of the solar generator's power, one speaks of direct mode. A disadvantage of this operating mode is that consumers work only while the sun is shining. Consequently, use of such systems is confined to fountains and water pumps, for instance. These systems do not store the generated energy.

Provided below is a simplified scheme of the components making up a stand-alone photovoltaic system operating in direct mode.



#### 4.1.2. Storage mode

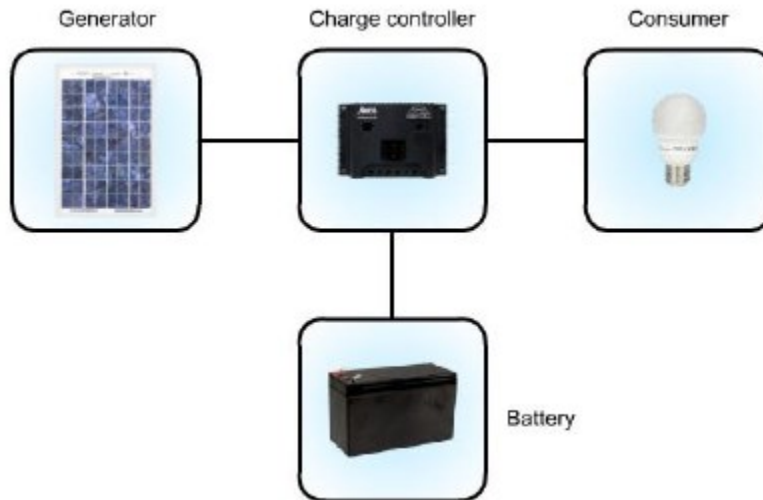
Stand-alone or off-grid systems capable of operating in storage mode are used, e.g. if a connection to the electrical power grid is either impossible or very complicated to realize.

The energy currently required from the solar generator is consumed **directly** while any remaining energy is **stored** in solar batteries (accumulators) for later use.

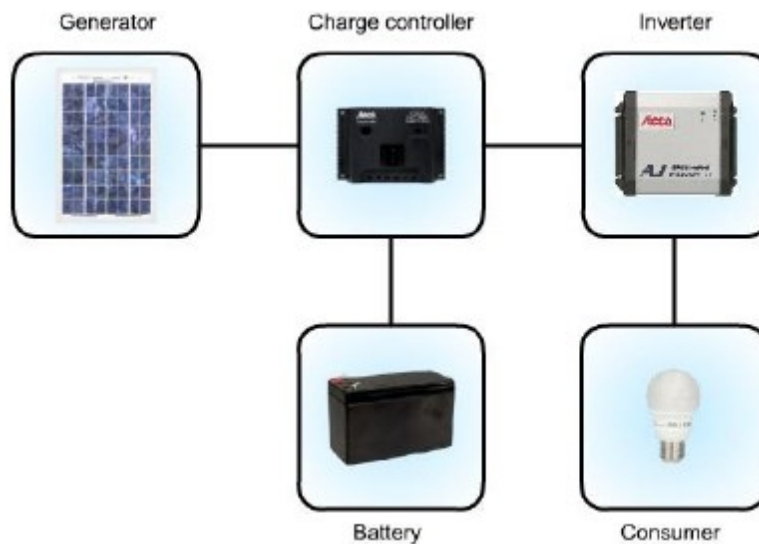
Off-grid inverters use direct current to produce alternating current which can power standard commercial appliances like refrigerators, coffee machines, water pumps etc.

Typical applications of off-grid, storage-mode systems involve independent power supply, e.g. for allotments, traffic information systems, parking receipt dispensers, huts / weekend homes and mobile homes). Illustrated below are the components forming part of an off-grid photovoltaic system operating in storage mode.





Direct mode off grid system



Storage mode off grid system

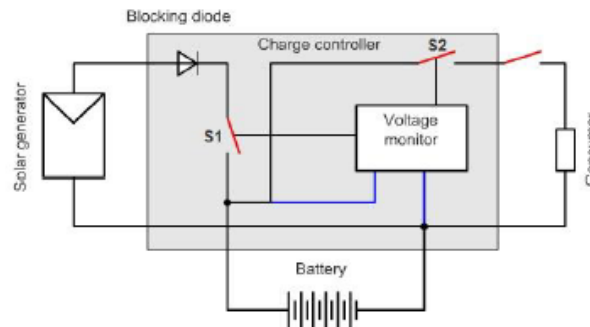
## 4.2. Charge Controller

A charge controller for lead-acid batteries operates on the principle of voltage monitoring ,i.e. measurement of battery voltage in this case. As a consumer draws energy from the battery, its voltage drops gradually. If the voltage drops below the deep-discharge level (approximately 11.4V in the case of a 12V battery), the charge controller disconnects the consumer from the battery.

If the battery is recharged by means of solar cells, for instance, its voltage rises again. Once the voltage attains a defined threshold, the charge controller re-connects the consumer. Once the battery voltage exceeds the final charging voltage (approximately 14.4V in the case of 12V lead-acid batteries), the charge controller stops the charging process. If the battery voltage drops below a certain threshold, the charge controller resumes the charging process.

### 4.2.1. Series charge controller

A series charge controller interrupts charging via switch S1, usually comprising a power field-effect transistor. A disadvantage of this principle are the transmission losses occurring in the switch or power FET while the battery is being charged. These losses are attributable to the power FET's on-state resistance.

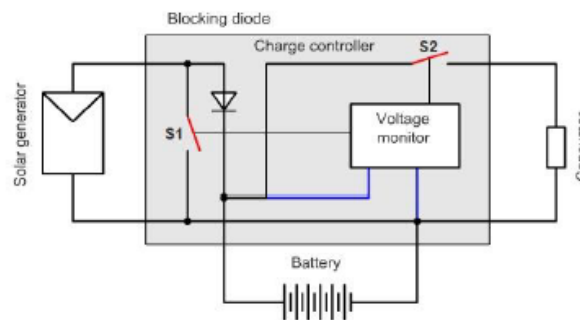


A series charge controller can dispense with a blocking diode if the controller monitors the solar generator's voltage in addition to the battery voltage. As soon as the solar generator's voltage drops below the battery's voltage, the charge controller disconnects the generator from the battery via switch S1 to interrupt the flow of current between these two components.

#### 4.2.2. Parallel charge controller

Once the final charging voltage is attained, the charge controller short-circuits the solar generator via switch S1. The blocking diode prevents a flow of current from the battery to the solar generator.

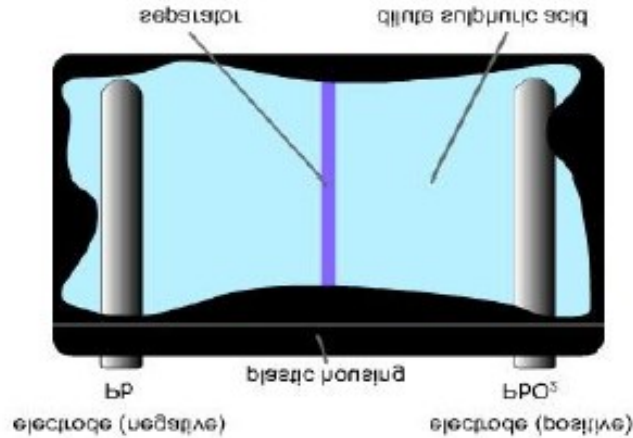
Short-circuiting the generator does not pose any problems during regular operation (with uniform irradiation). If individual cells of the solar generator are shaded, however, they might be subjected to extreme loads resulting in damage to the cells and/or the module.



### 4.3. Energy Storage (Batteries)

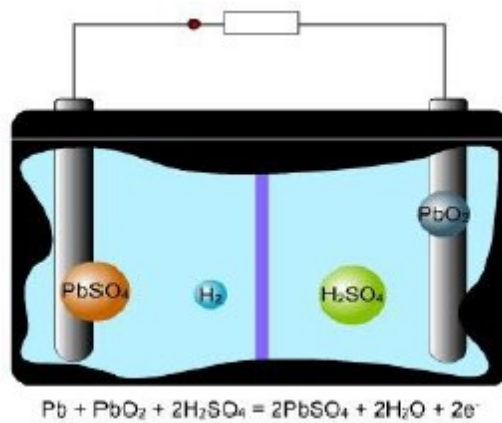
Due to their economy, lead-acid batteries have established themselves as a means of storing large amounts of energy. These accumulators are similar to car batteries but slightly modified in order to provide a longer service life.

A lead accumulator's basic design is illustrated below. It consists of two electrodes: A positive one made of lead dioxide ( $\text{PbO}_2$ ) and a negative one made of lead ( $\text{Pb}$ ) for cases when the accumulator is charged. The two electrodes are isolated from each other by means of separators in a plastic housing. The electrodes as well as the separators are installed in an electrolyte comprising dilute sulphuric acid ( $\text{H}_2\text{SO}_4$ ).

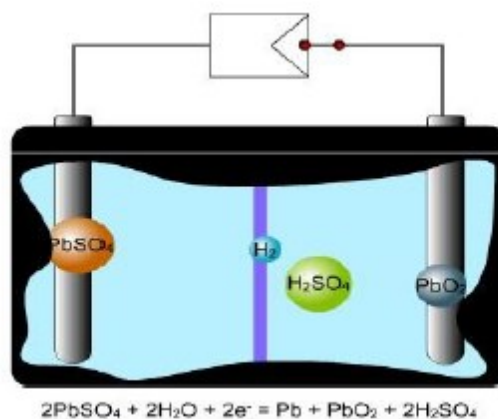


A lead accumulator cell has a rated voltage of 2V. To achieve an operating voltage of 12V, 6 such cells are connected in series.

During discharge, the positive (PbO<sub>2</sub>) and negative (Pb) electrodes react with the dilute sulphuric acid. As a result, lead sulphate (PbSO<sub>4</sub>) arises at the negative electrode and electrons are released. The positive electrode accepts electrons, also giving rise to lead sulphate (PbSO<sub>4</sub>) besides water (H<sub>2</sub>O).



On application of a charging voltage to the accumulator, the discharge reactions are reversed, i.e. the negative electrode accepts electrons and the lead sulphate (PbSO<sub>4</sub>) decomposes, leaving pure lead at the electrode. Lead sulphate (PbSO<sub>4</sub>) also decomposes at the positive electrode, accompanied by a release of electrons, thus leaving behind lead dioxide as shown in the next animation



### 4.3.1. Care of a lead accumulator

When using a lead accumulator, make sure to protect it against overcharging and deep discharge, the latter giving rise to lead sulphate crystals which are very difficult or impossible to decompose during re-charging. Deep discharge can be prevented by deactivating loads connected to the accumulator as soon as its voltage drops below 11.4V.

A different problem occurs if the accumulator is charged with an excessively high voltage (overcharging). From a voltage of about 13.8V, the accumulator begins to emit gases.

Electrolysis decomposes the electrolyte's water into hydrogen and oxygen which escape from the accumulator. Check the accumulator's water level at regular intervals and top it up with distilled water when necessary.

For a lead accumulator to provide long-term operation, its rated capacity should never be fully exploited. The accumulator's regular operating capacity is specified on its data sheet, and usually amounts to about 50% of the rated capacity.

Since the escaping oxyhydrogen is explosive, ensure adequately ventilated rooms.

## 4.4. Inverter

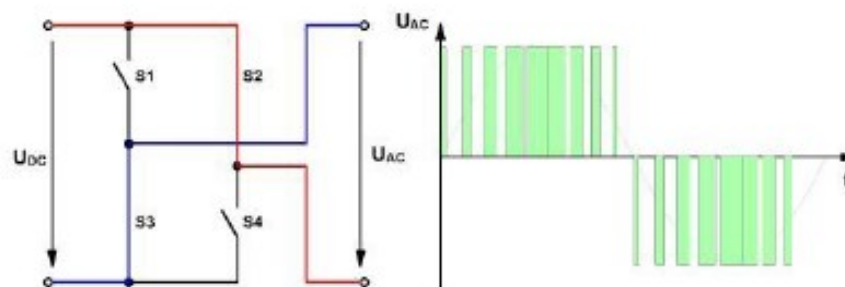
If a stand-alone photovoltaic system is to power common household appliances, it is necessary to convert the generated direct current and voltage into alternating current and voltage.

Conversion is performed by means of power electronics components comprising switchable valves. These valves are made of semiconductors capable of switching voltages in excess of 1000V and currents in excess of 1000A. Semiconductors used here include:

- Bi-polar power transistors
- Power field-effect transistors (power MOSFETs)
- Controllable diodes (thyristors)

### 4.4.1. Square-wave inverter

Illustrated below is a two-pulse bridge circuit (B2 circuit), one of the simplest inverter circuits.



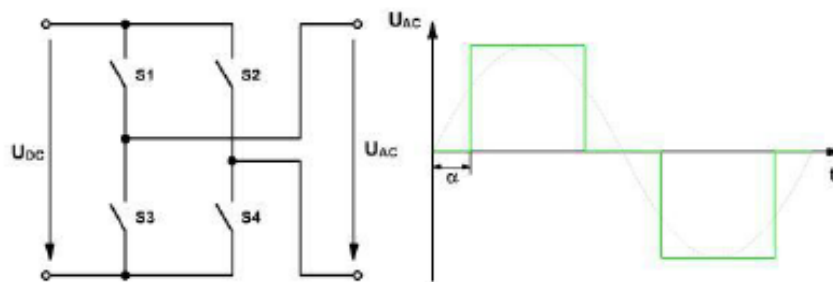
Valve pairs 1/4 and 2/3 are switched through at constant time intervals. As a result, the bridge circuit outputs an alternating voltage of an approximately square-wave profile. The square-wave profile can be made to assume a slightly sinusoidal characteristic by switching the valves

at points offset with respect to the zero crossings. This offset is termed control angle  $\alpha$ . The animation above elucidates the current flow through the bridge circuit. The voltage processing technique is not dealt with in any more detail here.

#### 4.4.2. Sinusoidal inverter

Modern sinusoidal inverters usually operate on the principle of pulse-width modulation. A B2 bridge circuit is used here too, as in the case of a square-wave inverter. Instead of being turned on and off over entire half-waves, however, the valves are switched repeatedly as illustrated below.

This switching process generates pulses of different widths. The pulse sequence is filtered to supply a nearly sinusoidal voltage characteristic.



#### 4.5. Saving Energy

We have just established that not enough roof area is available for installing the required power generation elements. Because the customer is not disposed toward selecting more expensive, higher-performance modules, you need to advise the customer on how to lower the holiday home's energy demands.

On average, 10% of the household's total energy is consumed by lights; this is nearly equal to the proportion of energy consumed by cooking and baking. The lighting energy consumption could be reduced by as much as 50% through a use of energy-saving lights.

When purchasing such lights, you should compare their energy efficiency classes, ranging from class A (most efficient) to G (least efficient).

##### **Incandescent lamps:**

90 to 95% of the energy is converted into heat, only 5 to 10% being converted into light. Belonging to efficiency class D or G, an incandescent lamp can operate for up to 1000 hours before its filament burns out.

##### **Halogen lamps:**

Converting about 15% of input energy into light, these lamps have a lifetime of up to 2000 operating hours. Such lamps are nonetheless assigned to energy efficiency classes D and E. A halogen lamp usually comes with a power supply unit which should be unplugged when the lamp is not use; this saves standby power.

##### **Fluorescent lamps:**

Fluorescent lamps consume little energy and have a service life of about 10,000 hours or more. Due to their design, however, such lamps are firstly not installable everywhere, and secondly must be disposed of as toxic waste.

##### **Energy-saving lamps:**

An energy-saving lamp is a compact fluorescent lamp with a ballast and a screw base. Converting 35% of the input energy into light, this type of lamp belongs to energy efficiency classes A and B, and has a rated lifetime of 10,000 operating hours.

In general, lamps should be left on only for as long as actually needed; select energy saving lamps with a pre-heater if you expect to have to turn them on and off frequently.

#### 4.6. Grid-parallel photovoltaic systems

While performing the usual function of directly supplying local consumers with energy, a photovoltaic facility operating in parallel with the electrical grid feeds surplus energy into the grid instead of storing it. The energy fed into the grid is recompensed by the responsible electricity supply company. Varying from one region to another, the compensation rate cannot be generalized. In Germany, the electricity compensation rate is presently higher than the price of consuming electricity. In view of this, all photovoltaic facilities here feed their entire power into the electrical grid.

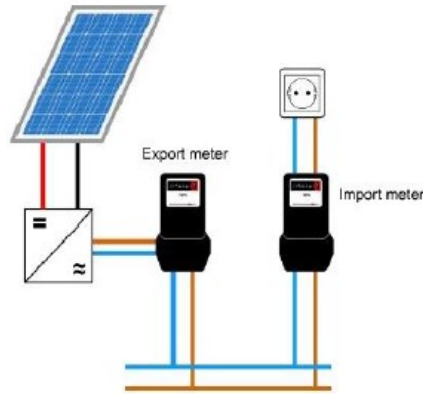
Illustrated below are all the components needed to set up and operate a photovoltaic facility connected to the electrical grid.



### Measurement concepts for PV systems

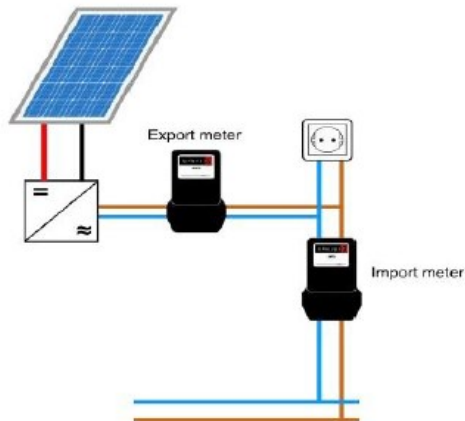
#### Full feed-in

All the locally generated energy is fed into the electrical grid. For this purpose, two separate meters are installed in the house connection box. A consumption meter measures the energy obtained from the electrical grid to power local consumers. An export meter measures the energy fed into the grid. This measurement concept is illustrated below.



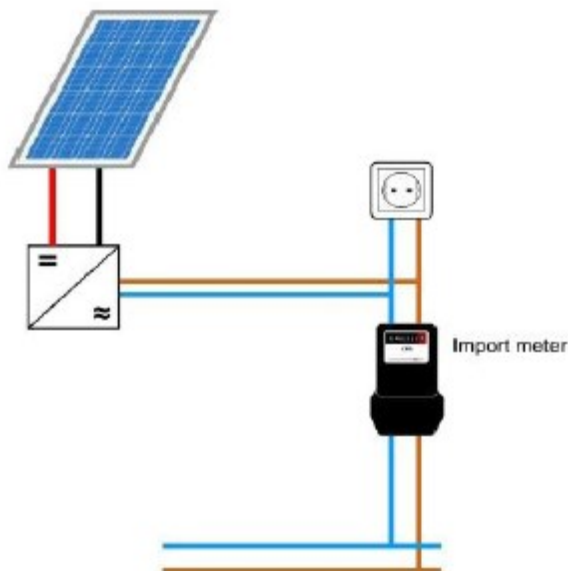
### Surplus feed-in

The local power generation facility feeds energy into the electrical grid only if local consumers are already receiving their required energy. A bi-directional meter measures the energy quantities supplied to, and received from, the electrical grid. This measurement concept is illustrated below.



### Zero feed-in

All the energy generated by the solar facility is consumed locally.



## 4.7. How hot-spots arise

Because it reduces a photovoltaic facility's output, shading should be avoided wherever possible. If shading cannot be avoided, its effects should be minimized by planning the photovoltaic facility expediently. Of considerable help here is the fact that a shadow's movements can be calculated just like those of the sun.

### Temporary shading

Temporary shading is caused by snow, leaves, bird droppings and soiling in general. Rain falling on the solar modules usually results in a self-cleaning effect which gets rid of the soiling again. To achieve self-cleaning, the solar modules must be inclined at an angle of at least 15°, larger angles enhancing the effect further.

Ensure that the rain water can drain off again properly without being hindered by edges on the frame or assembly elements, as this might lead to soiled borders resulting in permanent shading.

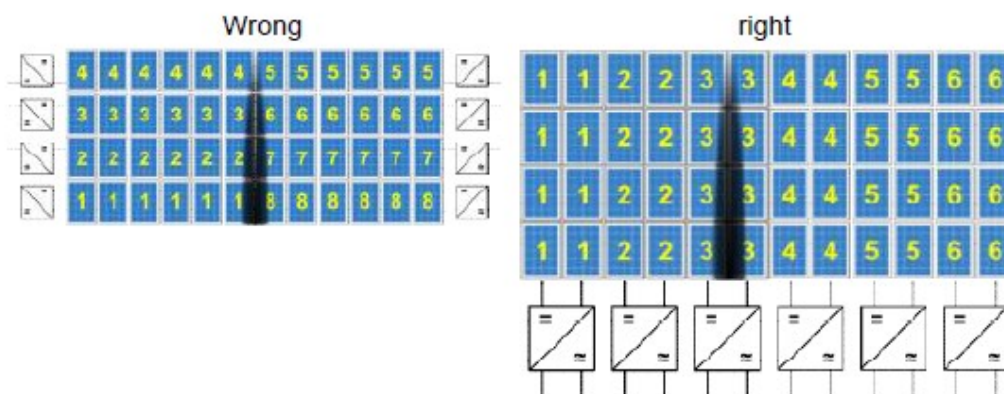
### Permanent shading

Permanent shading can be caused by objects located in the photovoltaic facility's vicinity. Large objects such as neighboring buildings and trees can cast shadows on the solar generator, as can chimneys, projections and fittings on the roof where the solar generator is mounted.

Some sources of permanent shading can be eliminated (e.g. through relocation or felling of trees). Permanent shading from the remaining sources should be minimized by planning the solar facility appropriately

### Example of optimal module arrangement

The shadow travels over the whole solar generator in the course of a day.



In this arrangement, the number of strings affected by shading increases progressively. In the worst circumstance, i.e. when the shadow falls on the middle of the solar generator, all strings are affected.

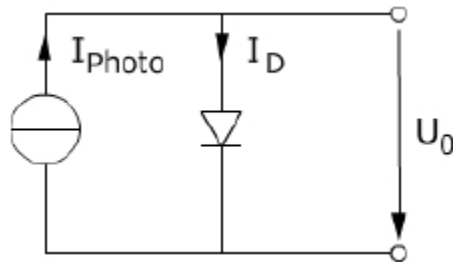
This arrangement not only requires less inverters, but also prevents more than two strings at a time from being shaded.

### hot-spot

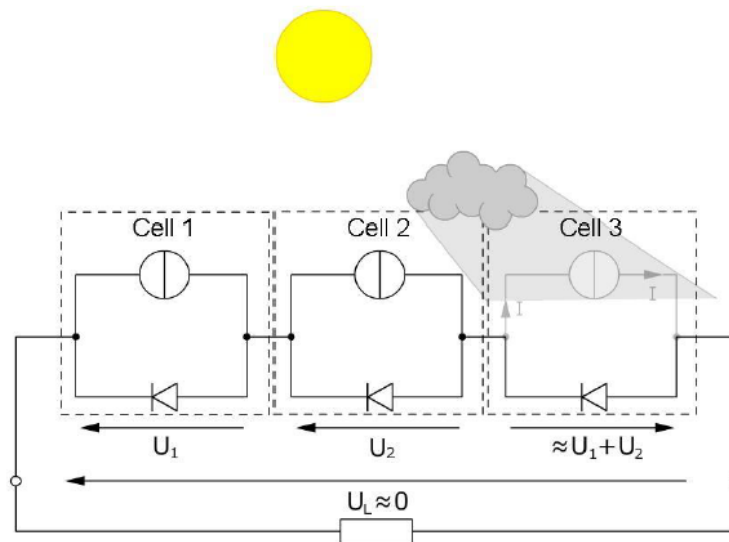


If a PV module's entire surface is shaded evenly, the module's output power naturally decreases, but the module suffers no damage. However, problems arise if the module is shaded unevenly, e.g. if just one PV cell is covered.

This can easily be demonstrated by a simplified, equivalent circuit diagram of a PV cell. This diagram represents a current source and diode connected in parallel.

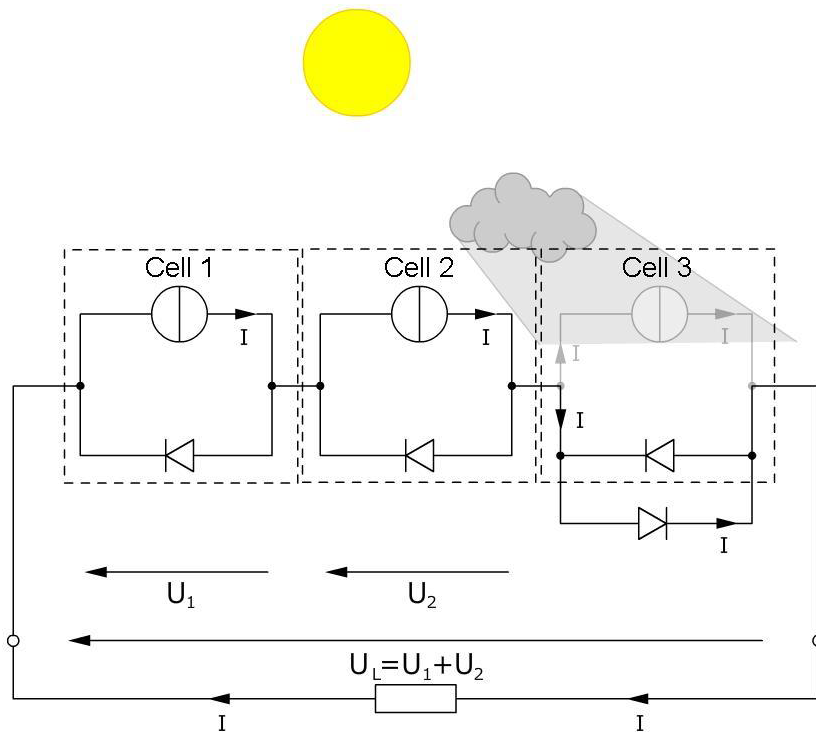


Because a covered PV cell theoretically produces no current, the current source in the equivalent circuit diagram vanishes, leaving just the diode. If connected in series with several PV cells making up a module, the covered cell's diode is switched to the reverse direction, so that the module's overall voltage can drop across this cell. If this overall voltage exceeds the diode's reverse voltage, the diode gets damaged. While this overall voltage remains below the diode's reverse voltage, the diode experiences a power loss causing the cell to heat up and potentially damage the module. This effect is termed *hotspot*.



## Bypass diode

Protection against hot-spots is afforded by a *bypass diode* connected anti-parallel to the PV cell. If a PV cell in a string is shaded, the cell stops supplying a voltage and the string's total voltage drops, but the flow of current is nevertheless maintained via the bypass diode.



Because the shaded PV cell no longer develops any power, it does not heat up and get damaged as a result.

Modules implement this type of protection somewhat differently. Instead of each individual PV cell being connected in parallel with a bypass diode, several PV cells or even entire strings are connected at once. The disadvantage of this is that shading one cell causes several other cells or even the entire string to fail. This must be taken into account during dimensioning.

## 5. Procedure

### 5.1. Flow of energy in a stand-alone facility (delayed)

In this experiment, we will measure a number of currents to investigate the various flows of energy in a storage-mode photovoltaic system. For this purpose, we will run the system at three specific operating points. Figure 3.1 shows how to set up the experiment.

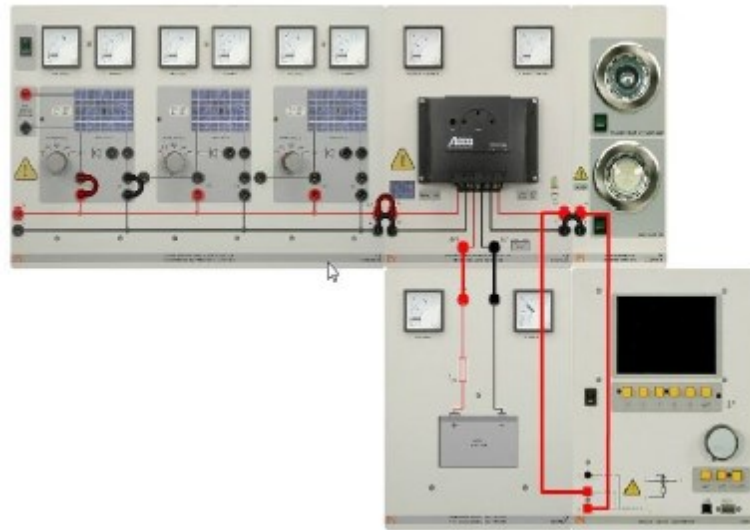


Figure 3.1

**Note: When setting up the experiment, make sure to first connect the battery to the charge controller.**

1. Connect the halogen lamp to the lamp board.
2. Set the first solar module simulation to an irradiance of  $800 \text{ W/m}^2$ .

The obtained results might deviate from the sample solution, depending on the battery's charge level. If the battery is fully charged (charge controller's green battery monitoring LED flashes slowly), discharge the battery for a few minutes by turning both lamps on. If the battery charge is insufficient, charge it for a few minutes with all connected consumers inactive. Then repeat the measurements.

Use the analog/digital multimeter to measure the load current at the charge controller's output.

If the integrated analog displays indicate ambiguous measurement values, the analog/digital multimeter's connections need to be interchanged.

3. Turn the halogen lamp on. Determine the solar module's current as well as the load and battery currents. Enter the values indicated by the integrated meters in the fields of table 3.1. provided for this purpose.
4. Repeat the measurement for  $E=600 \text{ W/m}^2$  and  $1000 \text{ W/m}^2$

	$E=600 \text{ W/m}^2$	$E=800 \text{ W/m}^2$	$E=1000 \text{ W/m}^2$
ISolar module simulation			
ILoad			
IBattery			

ILED			
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Table 3.1

5. Turn off the halogen lamp, and instead turn on the LED as the load.

Q1. Compare both lamps' currents.

.....Both lamps' currents are roughly equal.

.....The halogen lamp's current is lower than that of the LED.

.....The LED's current is much lower than that of the halogen lamp

Q2. Comment on the results and answers of Q1?

## 5.2. Off-grid inverter

In this experiment, we will conduct measurements on a photovoltaic system incorporating an inverter. The Figure 3.2.1 below shows how to set up the experiment.

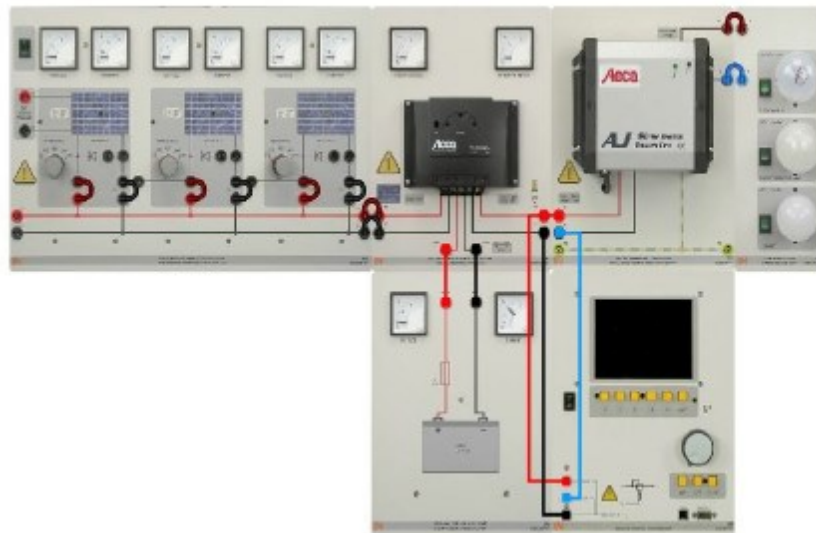


Figure 3.2.1

1. Set the solar module simulations to an irradiance of 200 W/m<sup>2</sup>.
2. Select the analog/digital multimeter's voltage display function by pressing the *U* button.
3. Select the analog/digital multimeter's current display function by pressing the *I* button.
4. Turn on the incandescent lamp (uppermost one) on the lamp board and measure the voltage as well as the current at the off-grid inverter's input.

$$V_{DC} = \underline{\quad} \text{ V}$$

$$I_{DC} = \underline{\quad} \text{ A}$$

5. Repeat step 4 for the other two bulbs ( Energy efficient and LED bulbs)
6. Modify the experiment setup as shown in Figure 3.2.2

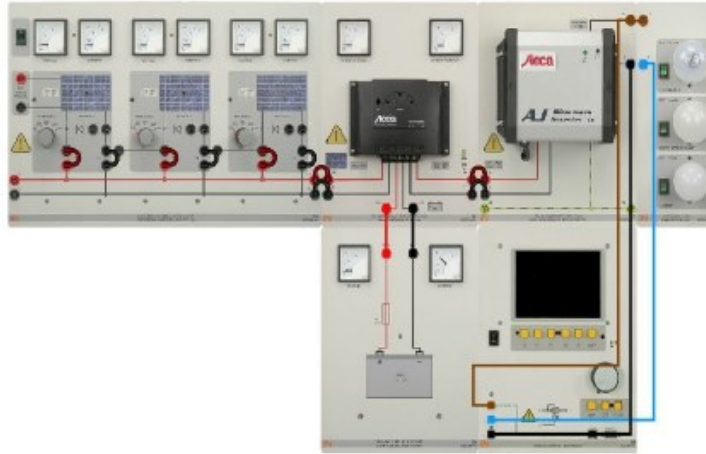


Figure 3.2.2

7. With the incandescent lamp turned on, measure the voltage and current at the inverter's output.  
 $V_{AC} = \underline{\hspace{2cm}} \text{ V}$   
 $I_{AC} = \underline{\hspace{2cm}} \text{ mA}$
8. Calculate the powers at the inverter's input and output.  
 $P_{DC} = \underline{\hspace{2cm}} \text{ W}$   
 $P_{AC} = \underline{\hspace{2cm}} \text{ W}$
9. Repeat steps 7 and 8 for the other two bulbs (Energy efficient and LED bulbs)
10. Based on previous measurement, Fill in table below and calculate power values both at the input and output of inverter and calculate the inverter's efficiency

	Incandescent	Energy Efficient	LED
$I_{DC}$			
$V_{DC}$			
$I_{AC}$			
$V_{AC}$			
$P_{AC}$			
$P_{DC}$			
$\eta \%$			

11. Open the analog/digital multimeter's Oscilloscope virtual instrument via the menu path Instruments | Oscilloscope. Click on the Config button to set the parameters.

Oscilloscope settings	
Parameter	Range
Voltage	300V
Current	1A

12. Trigger the oscilloscope on channel U and copy/take a shot of the obtained results for all/ three types of bulbs

### 5.3. Experiment: Grid Feeding

*If the red light between the neutral conductor and ground comes on during establishment of the single-phase mains connection (CO3211-1A), the phase and neutral conductor is interchanged; in this case, insert the training panel's plug the other way around.*

The all-pole OFF switch for the single-phase mains connection should initially remain on the "0" setting. Check whether the circuit breaker is active.

Refer to Fig 3.3.1 that shows how to set up the experiment.

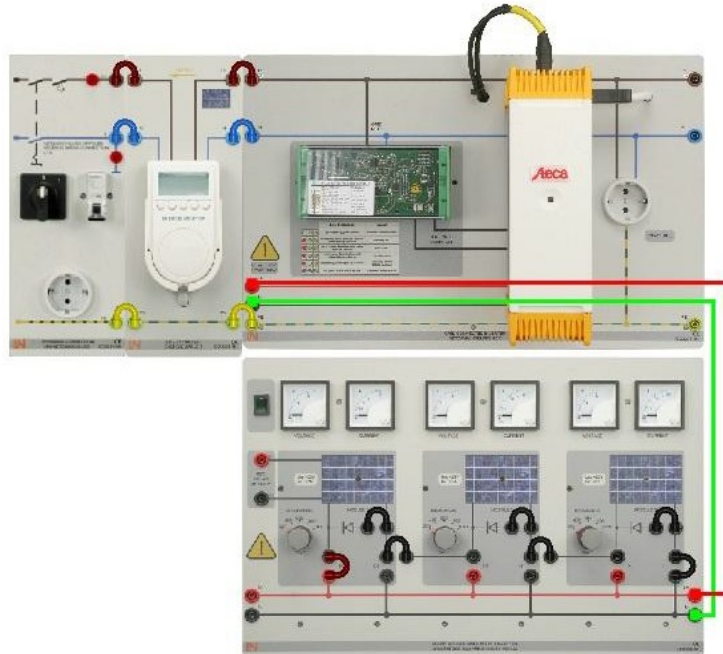


Figure 3.3.1

1. Set an irradiance of 1000 W/m<sup>2</sup> for the solar module simulations and turn them on. The inverter's green LED should flash slowly.
2. Move the single-phase mains connection's main switch to the "1" setting; wait until the inverter's LEDs turn on. The powers and voltages are measured using the energy meter.  
purpose.

$$V = \underline{\quad} V$$

$$P = \underline{\quad} W$$

3. Simulate a failure of the power mains by moving the main switch to the "0" setting. What happens?
  - ⇒ Less energy is fed into the grid.
  - ⇒ The inverter continues to operate normally.
  - ⇒ No energy is fed into the grid any longer.

4. Enter the voltage and power values in the fields provided for this purpose.  
What is the reason for the photovoltaic system's behaviour?
- V = \_\_\_\_\_ V  
P = \_\_\_\_\_ W
5. What is the reason for the photovoltaic system's behaviour?
- ⇒ On a failure of the power mains, the disruption in supply causes the inverter's power to break down too.
  - ⇒ The automatic release point detects the system failure and acts to prevent formation of an isolated system.
  - ⇒ The inverter switches over to stand-alone operation in order to establish a local energy source.
6. Vary the solar modules' irradiance and observe the resultant effect on the energy fed into the grid
7. How does the energy fed into the grid respond when the irradiance changes?
- ⇒ The feed-in power remains constant.
  - ⇒ As the irradiance decreases, so does the feed-in power.
  - ⇒ As the irradiance increases, so does the feed-in voltage.

## 5.4. Experiment: Grid feeding and local consumption

Refer to Fig 3.4.1 that shows how to set up the experiment.

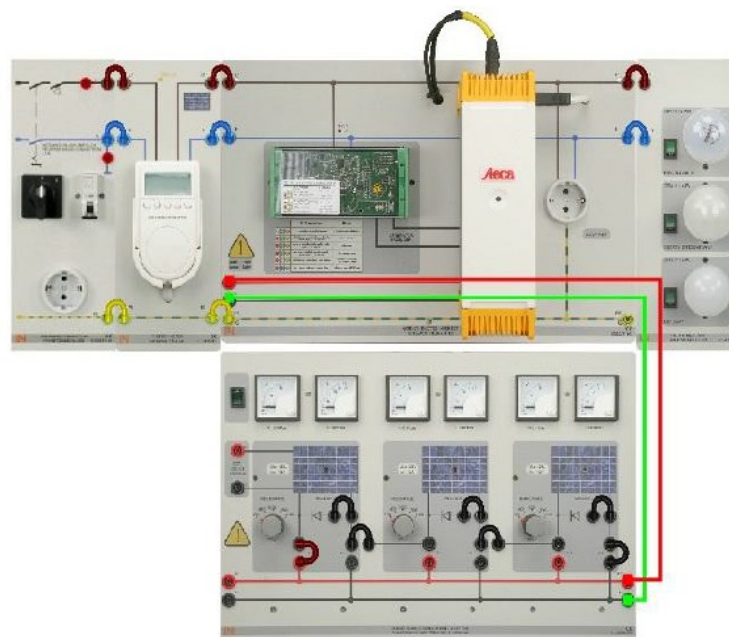


Fig. 3.4.1

1. Set an irradiance of 1000 W/m<sup>2</sup> for the solar module simulations.
2. Move the single-phase mains connection's main switch to the "1" setting; wait until the inverter displays the energy parameter and both its green LEDs come on.

6. Measure the voltage, current and power fed into the grid.  
 $V = \underline{\quad} V$   
 $P = \underline{\quad} W$
7. Successively turn on the lamps as consumers and measure the effect on the power fed into the grid.  
 $P_{\text{Incandescent lamp}} = \underline{\quad} W$   
 $P_{\text{Energy-saving lamp}} = \underline{\quad} W$   
 $P_{\text{LED lamp}} = \underline{\quad} W$
8. What happens to the feed-in power when the consumers are connected?
9. Which lamp saves the most energy?  
 ⇨ The feed-in power remains constant.  
 ⇨ The higher a consumer's power rating, the higher the feed-in power.  
 ⇨ The higher a consumer's power rating, the lower the feed-in power.
10. Which lamp saves the most energy?  
 ⇨ Incandescent lamp  
 ⇨ Energy-saving lamp  
 ⇨ LED lamp

### 3.5 Shading

In this experiment, we will investigate a solar module's response to shading. The module is connected in series to two further modules. Set up the experiment as shown below in Fig. 3.5.1

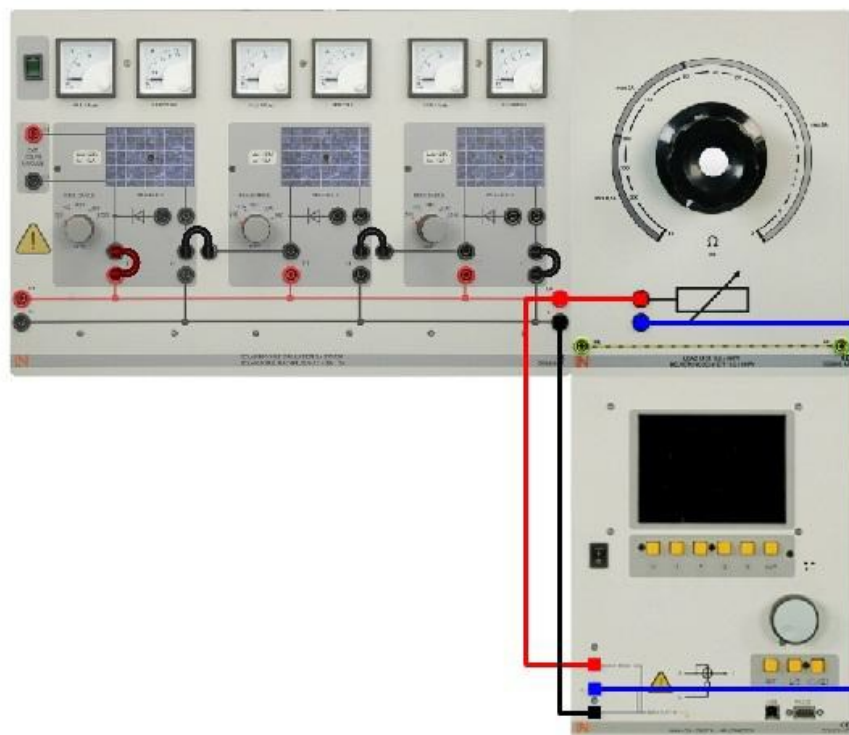


Fig. 3.5.1



1. **Turn on** the analog/digital multimeter and select the voltage/current display. Set the three solar module simulations to an irradiance of  $1000\text{W}/\text{m}^2$ . Set the potentiometer to about  $50\Omega$  and leave it at this value during all the measurements in this experiment.
2. **Vary** the irradiance on one of the solar module simulations while observing the analog/digital multimeter's voltage/current display as well as the analog displays on the solar module replicas.

What happens when one of the solar module simulations is shaded?

- ⇒ The current rises.
- ⇒ The solar module's voltage becomes negative.
- ⇒ The current and voltage remain unchanged.
- ⇒ The current drops to a low value.

Note: Several answers might be correct

3. **Set** the irradiance on all solar module simulations to  $1000\text{W}/\text{m}^2$ . Measure the current, voltage and power with the modules unshaded.
4. **Set** the irradiance on solar module G2 to  $200\text{W}/\text{m}^2$  while leaving the irradiance on the other modules at  $1000\text{W}/\text{m}^2$ . Measure the current, voltage and power once again.
5. Fill in the results in table below

	Without bypass diode	
	unshaded	shaded
I		
V		
P		

6. **Modify** the experimental setup by connecting the solar module simulation's bypass diodes.
7. **Set** the irradiance on all solar module simulations to  $1000\text{W}/\text{m}^2$ . Measure the current, voltage and power with the solar modules unshaded. Fill in the results in Table below.
8. Set the irradiance on solar module G2 to  $200\text{W}/\text{m}^2$ , while leaving the irradiance on the other modules at  $1000\text{W}/\text{m}^2$ . Measure the current and voltage once again and Fill in the results in Table below:

	With bypass diode	
	unshaded	shaded
I		
V		
P		

Which effect does shading of a solar module have on the solar generator, or shading of a solar cell have on the solar module?

- ⇒ The solar generator's total voltage drops merely by the voltage of the shaded solar module.
- ⇒ Shading has no effect.
- ⇒ The shaded solar module influences the amperage and, consequently, the power

What effect does the bypass diode have?

- ⇒ It protects the solar module against excess voltages.
- ⇒ It short-circuits the shaded solar module.

### 3.6. Characteristics of shaded solar modules (series)

In this experiment, we will more closely investigate the effect of shading a solar module forming part of a series-connected array. For this purpose, we will record and analyze the current/voltage and power characteristics

1. Set up the experiment as shown below in Fig. 3.6.1.

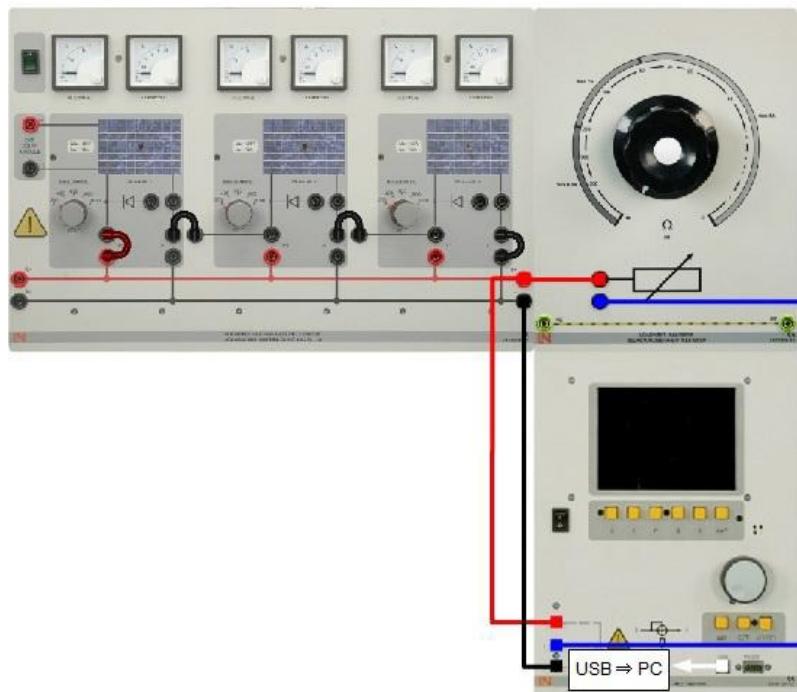
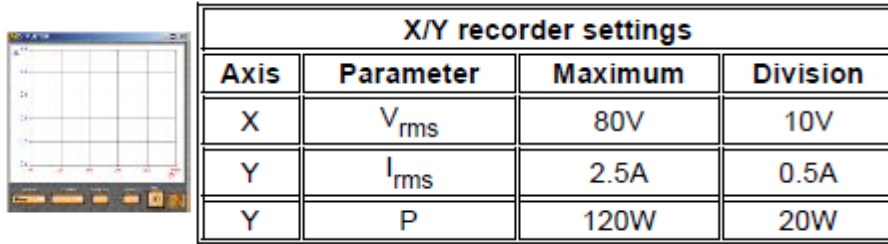
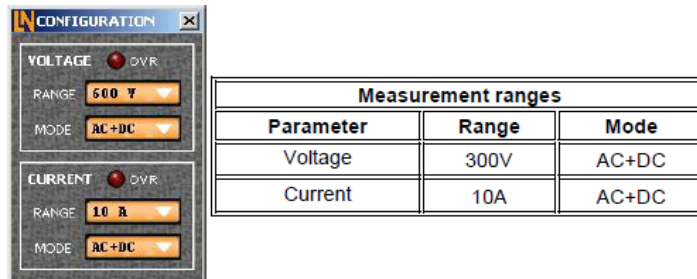


Fig. 3.6.1

2. Set the solar module simulations to an irradiance of  $1000\text{W}/\text{m}^2$ . Open the analog/digital multimeter's X/Y recorder virtual instrument via the menu path Instruments | X/Y recorder. Click the right-hand mouse button in the plotter area and select Properties from the context menu which appears. On the scaling tab, perform the settings shown below.



Use the *X/Y recorder's* “Config” button to set the measurement ranges shown below.



3. Record the power and V/I characteristics of the series-connected solar module replicas. For this purpose, proceed as described next.
  1. Set the potentiometer to  $0\Omega$  (short circuit).
  2. Start recording the characteristics by pressing the button.
  3. Slowly increase the potentiometer's resistance to its maximum value.
  4. Stop recording the characteristics by pressing the button.
4. Reduce the second solar module's irradiance from  $1000W/m^2$  to  $200W/m^2$  and record the characteristics once again.
5. Label the obtained characteristics and copy or take a picture of the obtained.
6. Connect the solar modules' bypass diodes. Set the modules to an irradiance of  $1000W/m^2$ . The experimental configuration is shown in Fig 3.6.2

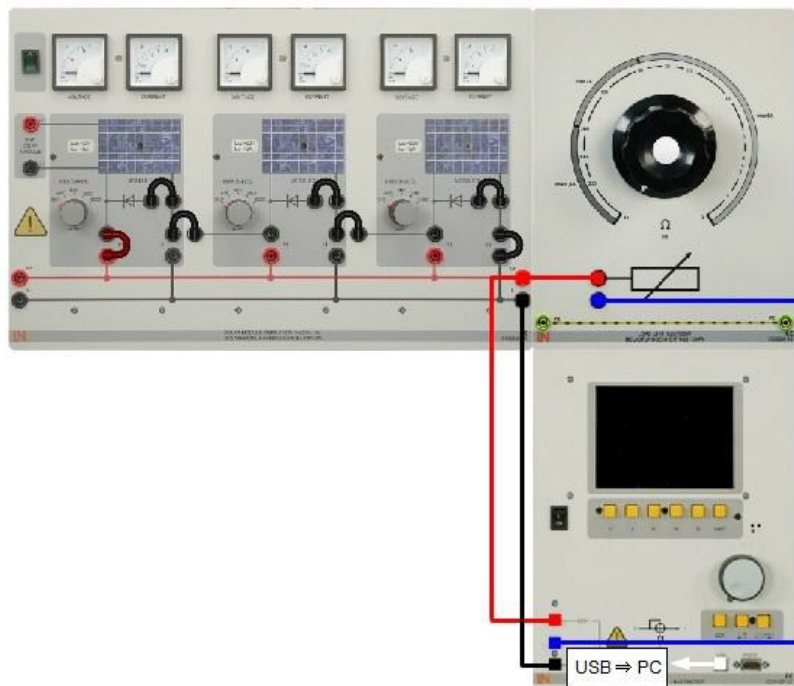



Fig. 3.6.2

Open the analog/digital multimeter's *X/Y recorder* virtual instrument via the menu path *Instruments | X/Y recorder* and set the parameters indicated in the table below.



X/Y recorder settings			
Axis	Parameter	Maximum	Division
X	$V_{rms}$	80V	10V
Y	$I_{rms}$	2.5A	0.5A
Y	P	120W	20W

7. Record the solar module's characteristics with the bypass diodes connected.
8. Reduce the second solar module's irradiance from 1000W/m<sup>2</sup> to 200W/m<sup>2</sup> and record the characteristics once again. Label the characteristics and copy your result

What do the recorded characteristics suggest?

- ⇒ Shading a solar module only has a negligible effect.
- ⇒ In the case of series-connected arrays without bypass diodes, shading reduces the output power to a very low level.
- ⇒ In the case of series-connected arrays with bypass diodes, shading a solar module slightly reduces the output power to two-thirds of the original level.
- ⇒ The bypass diodes prevent the output power from dropping significantly when a solar module is shaded.

Note: Several answers may be correct.

### 3.7. Characteristics of shaded solar modules (parallel)

1. Set the solar module simulations to an irradiance of 1000W/m<sup>2</sup>.
2. Open the analog/digital multimeter's *X/Y recorder* virtual instrument via the menu path *Instruments | X/Y recorder*. Click the right-hand mouse button in the plotter area and select *Properties* from the context menu which appears. On the scaling tab, perform the settings shown below.

In this experiment, we will more closely investigate the effect of shading a solar module forming part of a parallel-connected array. For this purpose, we will record and analyze the current/voltage and power characteristics.

3. Set up the experiment as shown in Fig. 3.7.1.

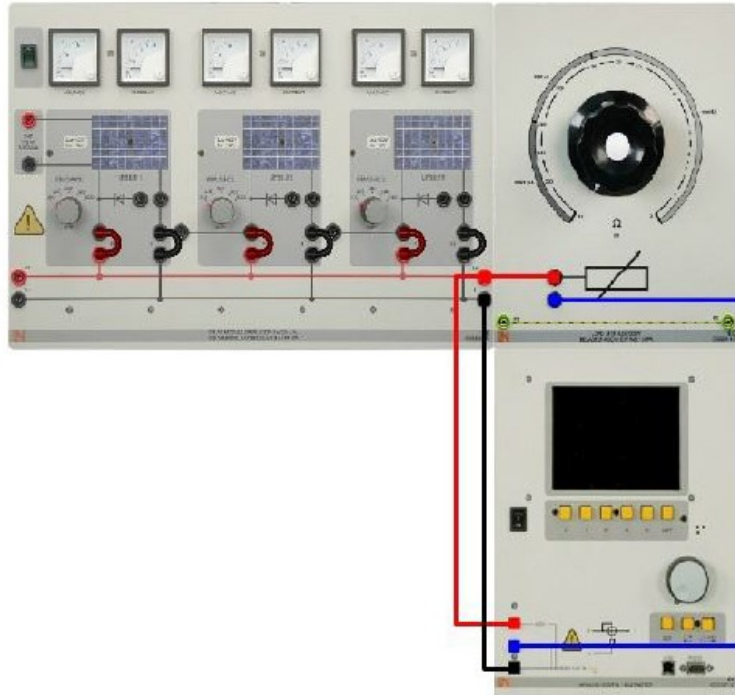



Fig. 3.7.1.

4. Set the solar module simulations to an irradiance of  $1000\text{W}/\text{m}^2$ .
5. Open the analog/digital multimeter's *X/Y recorder* virtual instrument via the menu path *Instruments | X/Y recorder*. Click the right-hand mouse button in the plotter area and select *Properties* from the context menu which appears. On the scaling tab, perform the settings shown below.



X/Y recorder settings			
Axis	Parameter	Maximum	Division
X	$V_{\text{rms}}$	30V	5V
Y	$I_{\text{rms}}$	8A	1A
Y	P	120W	20W

Use the *X/Y recorder's* “Config” button to set the measurement ranges shown below.

**CONFIGURATION**

VOLTAGE OVR

RANGE **500 V**

MODE **AC+DC**

---

CURRENT OVR

RANGE **10 A**

MODE **AC+DC**

Measurement ranges		
Parameter	Range	Mode
Voltage	30V	AC+DC
Current	10A	AC+DC

6. Record the power and V/I characteristics of the three parallel-connected solar module replicas. For this purpose, proceed as described next.
  1. Set the potentiometer to  $0\Omega$  (short circuit).
  2. Start recording the characteristics by pressing the button.

3. Slowly increase the potentiometer's resistance to its maximum value.  
 4. Stop recording the characteristics by pressing the button.  
 Reduce the second solar module's irradiance from 1000W/m<sup>2</sup> to 200W/m<sup>2</sup> and record the characteristics once again.  
 Label the obtained characteristics and copy your results (or take a photo) .

7. As shown in Fig. 3.7.2, modify the experimental configuration by connecting bypass diodes in parallel with the solar module simulations.

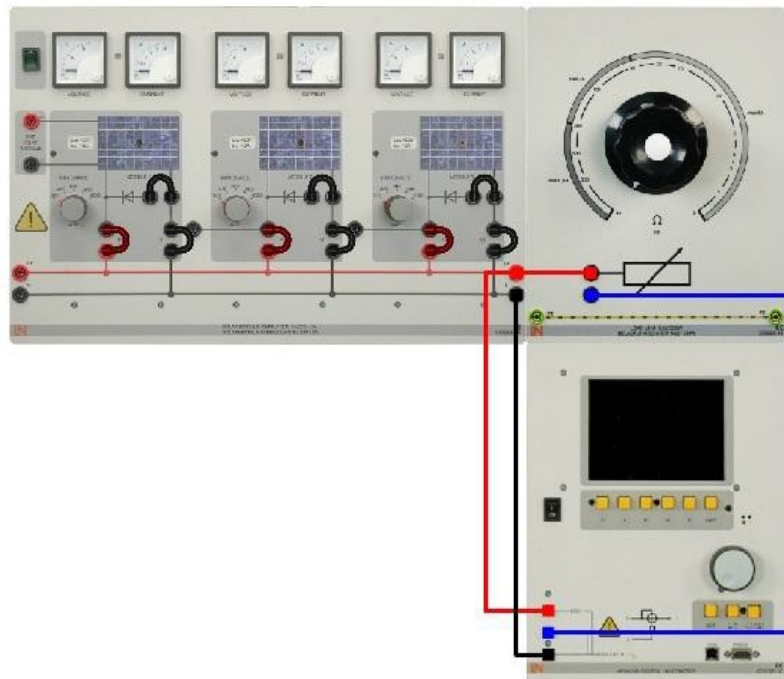


Fig. 3.7.2

Open the analog/digital multimeter's *X/Y recorder* virtual instrument via the menu path *Instruments | X/Y recorder* and set the parameters indicated in the table below.

X/Y recorder settings			
Axis	Parameter	Maximum	Division
X	V <sub>rms</sub>	30V	5V
Y	I <sub>rms</sub>	8A	1A
Y	P	120W	20W

8. Set the parallel-connected solar modules to an irradiance of 1000W/m<sup>2</sup>. Record the modules' power and V/I characteristics.  
 Reduce the second solar module's irradiance from 1000W/m<sup>2</sup> to 200W/m<sup>2</sup> and record the characteristics once again. Label the characteristics and copy ( or take a photo of the plots)

What do the recorded characteristics suggest?

- ⇒ The current remains constant when a solar module is shaded.
- ⇒ The power drops when a solar module is shaded.
- ⇒ Adding bypass diodes to the circuit compensates the power drop which occurs when a solar module is shaded.

⇒ Bypass diodes do not achieve any power compensation in the case of parallel-connected solar modules.

Note: Several answers may be correct.

## **Experiment #10**

### **Electric Energy Simulation**

➤ **Objectives:**

1. Describing the different sections of a complete system of production, distribution and use of electric energy, and their operation.
2. To become familiar with electric energy simulator, with using the software to analysis the system.
3. Enabling an easy and intuitive learning by an interaction with the same system via control and display devices available in both panel and software.

4. To use the automatic control of the distribution of electric power according to the daily demand of users.
5. To find the effect of changing line resistance, and power factor correction.

➤ **Equipments Required:**

1. One Synoptic Panel Of The Simulator of the cycle of electric energy mod.SEE-1EV .
2. Software Drivers And The Software SEE01.
3. USB Cable For Interconnection.
4. Power Cord For The Panel.

➤ **Theory:**

The schematic diagram of the system is shown blow, which consist of the peak power plant, the national and international eclectic power net, the transmission substation, the large industry, the medium/small industries and the area of commercial and residential users, as shown in the following Figure 9.1

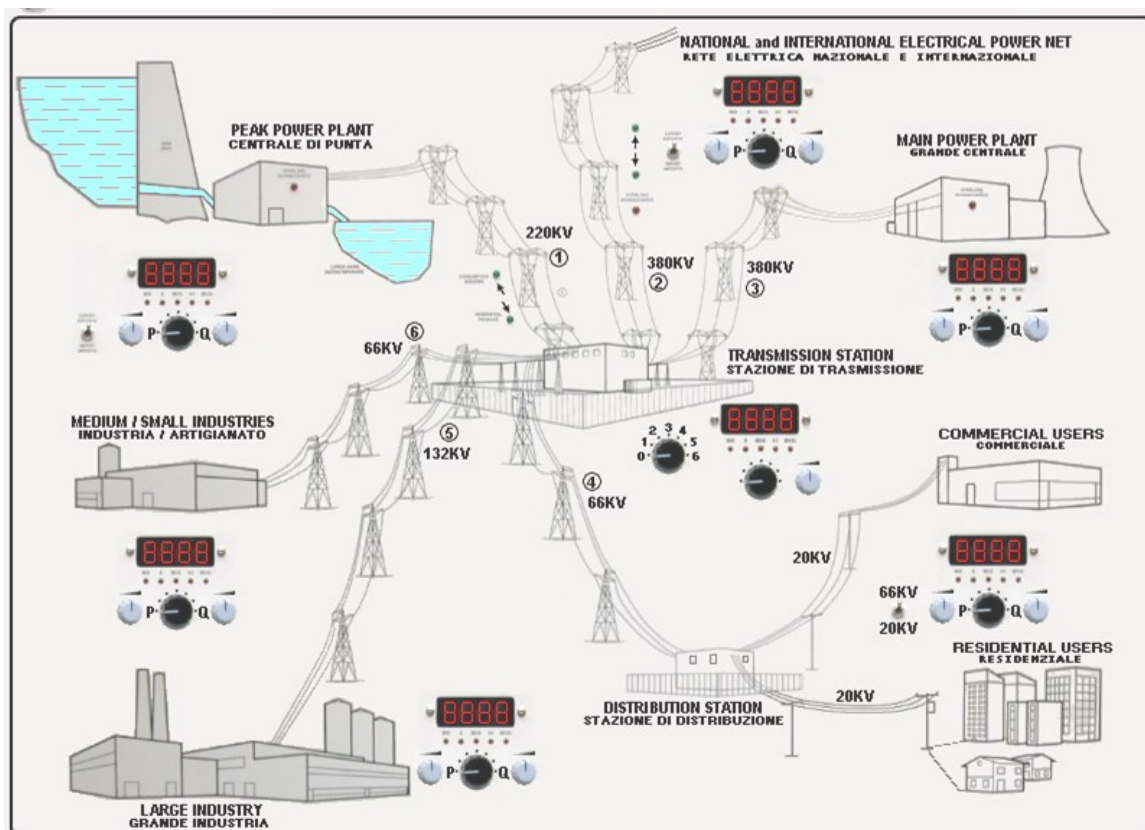




Figure 9.1 The schematic diagram of the system

➤ PEAK POWER PLANT:

The turbines of accumulation power stations are driven by the water stored in artificial lakes. These power plants are characterized by great differences in height and consequently by high pressures, but by low flow rates of water. Accumulation power stations can start and stop in few minutes, according to needs. This is the reason why they are used especially to cover the load during the peak periods – at noon and in wintertime.

➤ THERMOELECTRIC POWER PLANT:

This type of plant will transform the thermal energy of fuels into electric energy by producing steam or using the burnt gases.

Generally these power plants consist of one or more steam generators, or thermoelectric prime movers, of one or more generator sets and main transformers, of regenerative cycle and of various auxiliary services and circuits.

➤ NUCLEAR POWER PLANT:

This type of plant will convert nuclear energy into electric energy. It consists of a nuclear reactor that includes the nucleus with the feed materials where fission reactions occur, of a set of auxiliary equipment for using the steam produced by the fission heat, and of the steam turbine that drives the electric generator.

➤ GEOTHERMAL POWER PLANT:

This type of plant will use the geothermal energy for the production of electricity. In detail, after being filtered and purified from the dissolved salts the pressurized steam coming from underground is used (through a heat exchanger) to produce new steam that is blown into the turbines coupled with generators.

➤ HYDROELECTRIC POWER PLANT:

The technology of most great plants had not changed for all the century. Plants are fed by a wide reservoir upstream a dam, where the water flow can be controlled to keep a nearly constant level. Water enters the turbines from pressure water pipes through valves that control the quantity of flow according to the power demand, then it comes out crossing the tail race.

➤ LONG-DISTANCE LINE:

It consists of conductors for the transmission of electric energy, and of their supports (lattice towers or masts). Generally these lines are aerial (usually with bare conductors).

It includes one or more triads of conductors for the transmission of electricity.

This is the intermediate phase of the activities of an electric system.

It consists in carrying the electric energy on long distances, from the import or production centres to the power consuming centres, by using electric stations and lines at the highest voltage levels (generally 220 kV and 380 kV).

➤ **PANEL:**

It shows the principal areas like Generation Electricity, Distribution and Users of Electricity system, they are connected in a typical system with following functional areas:

- Peak Power plant, Import/Export distribution system,
- Main Power plant, Transmission Station,
- Medium and Small Industries users
- Commercial and Residential users.

Besides on panel there are commands, display measurement instruments and LEDs.

➤ **The SOFTWARE:**

It is interactive and made with more pages.

This is the main page with the keys to open the next multimedial pages that enable:

- General Information, (enable with green key),
- Main Electrical Power System Manager, (enable with green key),
- Line Resistance and Power Factor Correction, (enable with green key)
- Simulator Supervision Panel, (enable with yellow key).

➤ **SIMULATOR SUPERVISION:**

By SIMULATOR SUPERVISION option, it is possible to have the complete control of simulator:

- Peak Power plant, Import/Export Electrical system,
- Main Power plant,
- Medium/Small Industries, Large Industry, Residential users.

All parameters of all functional areas are enabled directly on panel by controls.

➤ **CONTROLS available on SIMULATOR PANEL**

P and Q potentiometers of each functional area allow to set the values of the active power (Watt) and reactive power (VAR).

Switches of each functional area allow to select and display the electrical parameters.

➤ **Experimental Procedure:**

➤ **PARTA: SIMULATOR USE:**

1. Switch ON the computer.
2. Switch ON the simulator main switch.
3. Connect, with USB cable, the simulator to personal computer.
4. The computer automatically will found the USB device.
5. The first time follow these commands:
  - Start → Programs → Visual Designer → RUN.
  - From new window: File →Open →C: →Program Files → Visual Designer → SEE → SEE\_intro.fco.
6. The next times follow these commands:
  - Start → Programs → Simulator SEE → SEE.
7. After the program has started, the screen showing the drawing of the Simulator in the background will be displayed in Figure 9.2

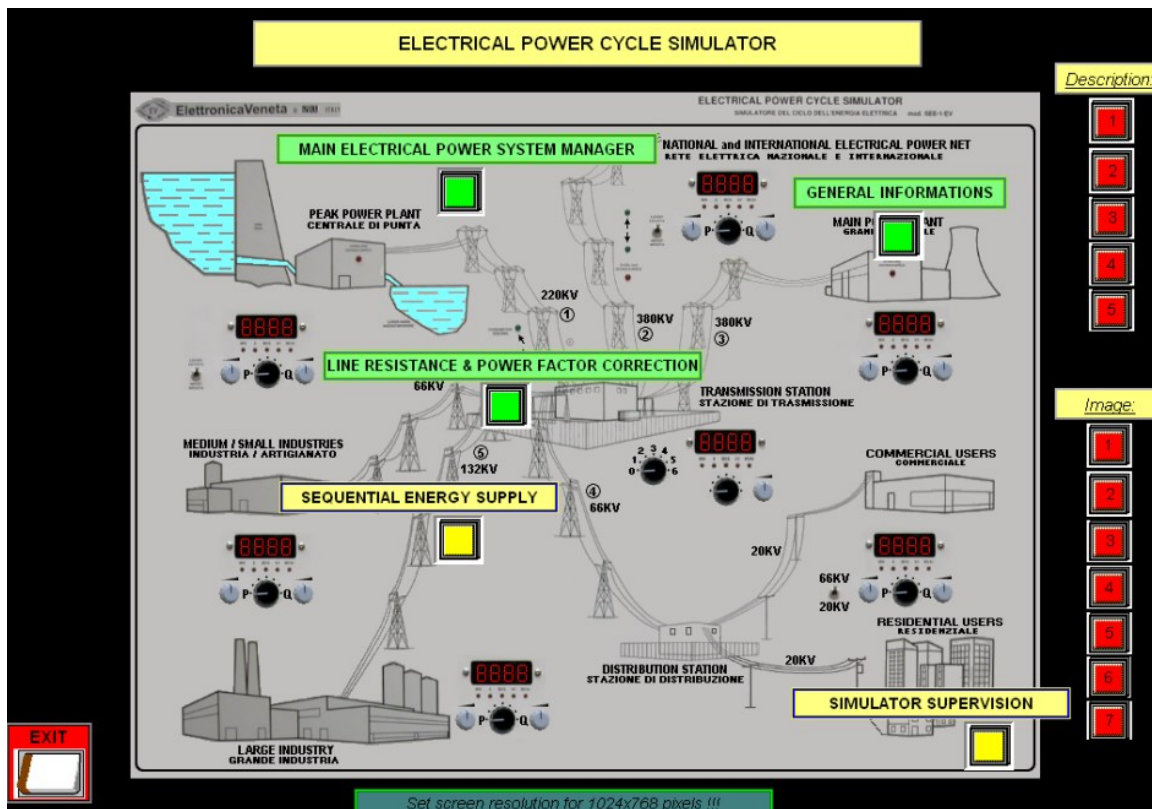


Figure 9.2 Electrical power cycle simulator

8. The RED buttons available under Description will enable to read some remarks concerning the simulator.

9. The RED buttons available under Image will enable to see some image and remarks concerning power plants and long distance lines.
10. The GREEN button available under GENERAL INFORMATION enables to enter an option where the structures of power lines are explained .
11. The GREEN button available under MAIN ELECTRICAL POWER SYSTEM MANGER enables to enter an option where the daily trend of the demand of electric power and the automatic control of the simulator are simulated.
12. The GREEN button available under LINE RESISTERANCE and PHASING enable to enter an option where the electrical resistance of power lines are examined .
13. The YELLOW button available under SUPERVISION of the SIMULTOR enable to enter an option where all the controls of the simulator are used, the total supervision is carried out on the PC and consequently all the electric quantities and operating modes are displayed.

- **CHECKING THE OPERATION :**

The main screen of application program of the simulator will include :

- Indication concerning the various functional areas, such as National Electrical Power Net, available in green squares.
- GREEN buttons corresponding to the functional areas.
- RED buttons corresponding to the areas of description and image, available in the upper right part of the screen.
- YELLOW buttons corresponding to the area of supervision of simulator.
- A button EXIT to quit the program.

- **CHECKING THE OPERATION OF TYHE APPELICATION PROGRAM**

1. Pressing the RED button 1 will open a window of description, this operation will prevent the GREEN and YELLOW buttons from being pressed, only after the relevant key OFF has been pressed, the other buttons mentioned above can be pressed again.
2. For instance, pressing both the RED buttons 1 will open windows of description.
3. Read all remarks from 1 to 5, then press OFF buttons.
4. Pressing the RED button 1 in the Image window, read all remarks in all image, after reading this remarks from 1 to 7, answer the following questions:
  - Why peak power plant are used especially to cover the load during the peak periods?
  - What is the best type of electric power plants, and why?

5. Press OFF buttons, then Pressing the button RETURN will display the main screen again.

➤ **PART B:GETTING INFORMATION OF SYSTEM:**

1. Pressing GREEN buttons under general information, will display the following figure 9.3

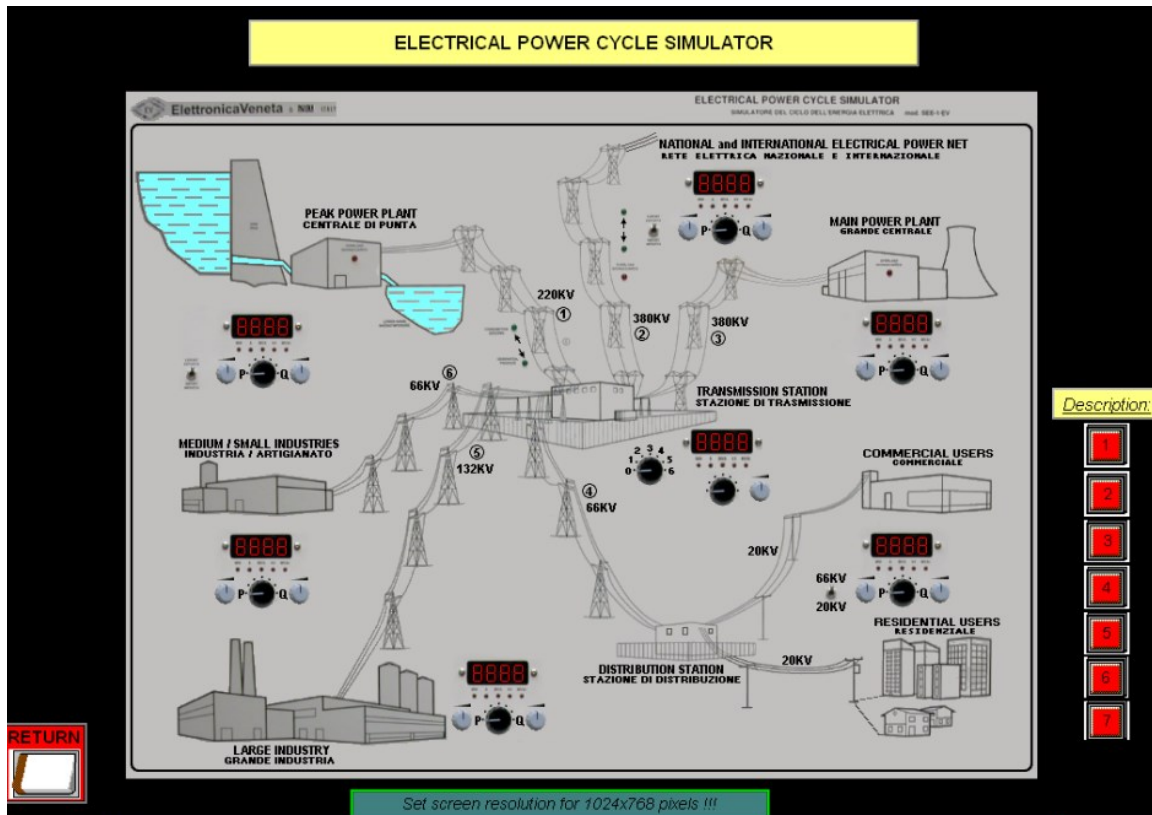


Figure 9.3 Electrical power cycle simulator

2. Press any RED button, then read all remarks from 1 to 7 , then answer the following questions:

- What are the types power line, and which is prefer to use ?
- What advantage and disadvantage of Aerial Line?

3. Press OFF buttons, then Pressing the button RETURN will display the main screen again.

➤ **PART C:NATIONAL ELECTRICAL POWER NET :**

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

The simulator is controlled completely by the personal computer, the trend of the national absorption of electric power will be displayed.

The power supply comes from the main power plant and from the national and international electrical power net.

During the peak hours the peak power plant of hydroelectric type is set at work. In the hours around midnight the peak power plant becomes a user and it pumps water into the headbay to restore the water supply required for future needs.

1. Press on the GREEN buttons in main screen under the main electrical system power manger.
2. As showing , it will start in drawing of power carve VS hours.
3. Also you can talk the reading of power in MW for all line from 1 to 6, and total electrical power required, fall this data in the following Table 9.1

NOTE :

You can use wait button to stop the drawing at any time, so you can read the measurements

Table 9.1 Electrical Power Required measurements for every line vs Hours

Hours	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Electrical Power Required
4							
8							
12							
14							
16							
18							
20							
22							
24							

4. Save the carve in a file, then press return to end this part.
5. Plot electrical power required VS hours, then compare it with the first curve.
6. Find when the electrical power required maximum and minimum, comment in your results.

➤ **PART D: 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 controls of digital instruments' and the potentiometer P and Q of the simulator so that the various electric quantities can be displayed and the value of active power (W) and of reactive power (Var) can be set.

The screen will display all electric quantities of every power supply and of every user at the same time.

1. Pressing the YELLOW button will enable to enter the section corresponding to the supervision of simulator and this will enable the interaction with the personal computer.
2. Use the potentiometer P and Q on the synoptic panel and check the corresponding variations of the quantities on the screen.
3. Set all station to minimum value, measuring MinP, MinQ.
4. Repeat to the measurements with maximum value, then full the following Table9.2

Table 9.2 Minimum and maximum values for every station in the system

Station Name	Min P	Max P	Min Q	Max Q	Voltage
Main power plant					
Peak power plant					
National and international eclectic power net					
Large industry					
Medium/Small industries					
Commercial and residential users					

5. In the national and international eclectic power net, set the switch to export, so this station will export the energy from the system, and the green led will on, with direction out of system.
6. Set peak power plants as a load, do this by setting the switch to consumption, so the consumption assorbe led will on.
7. Set Transmission substation with 220V.
8. Set the values of P and Q for all panels as in the following Table 9.3

Table 9.3 Setting Values P and Q for every station in system

Station Name	PMW	VAR
Main power plant	1125	536
Peak power plant	300	154
National and international eclectic power net	253	120
Large industry	360	135
Medium/Small industries	120	86
Commercial and residential users	80	41

9. Measure MVA, current, voltage, and power factor for every stations and fill it in the following Table 9.4.

10. Measure MVA total used, and MVA total supplied.

Table 9.4 MVA, current, voltage, and power factor measurement for every stations

Station Name	MVA	A	KV	Cos $\phi$
Main power plant				
Peak power plant				
National and international eclectic power net				
Large industry				
Medium/Small industries				
Commercial and residential users				

11. Calculate total active, reactive, and apparent power generated and consume in the system? Its equal? Explain!

12. In the national and international eclectic power net, set the switch to import, so this station will export the energy from the system, and the green led will on, with direction in to system.

13. Repeat steps from 6 to 11.

14. Set peak power plants as a generation station, do this by setting the switch to generation, so the generation produce led will on, keeping the setting for national and international eclectic power net as in step 12.

15. Repeat steps from 7 to 11.

➤ **PART E: LINE RESISTANCE AND POWER FACTOR CORRECTION:**

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



1. Pressing the GREEN buttons on the line resistance and power factor correction, will display the following figure 9.4, there is two transmission line 3, and line 5.
2. In the panel you can change P, and Q just for Main power plant, and Large industry.

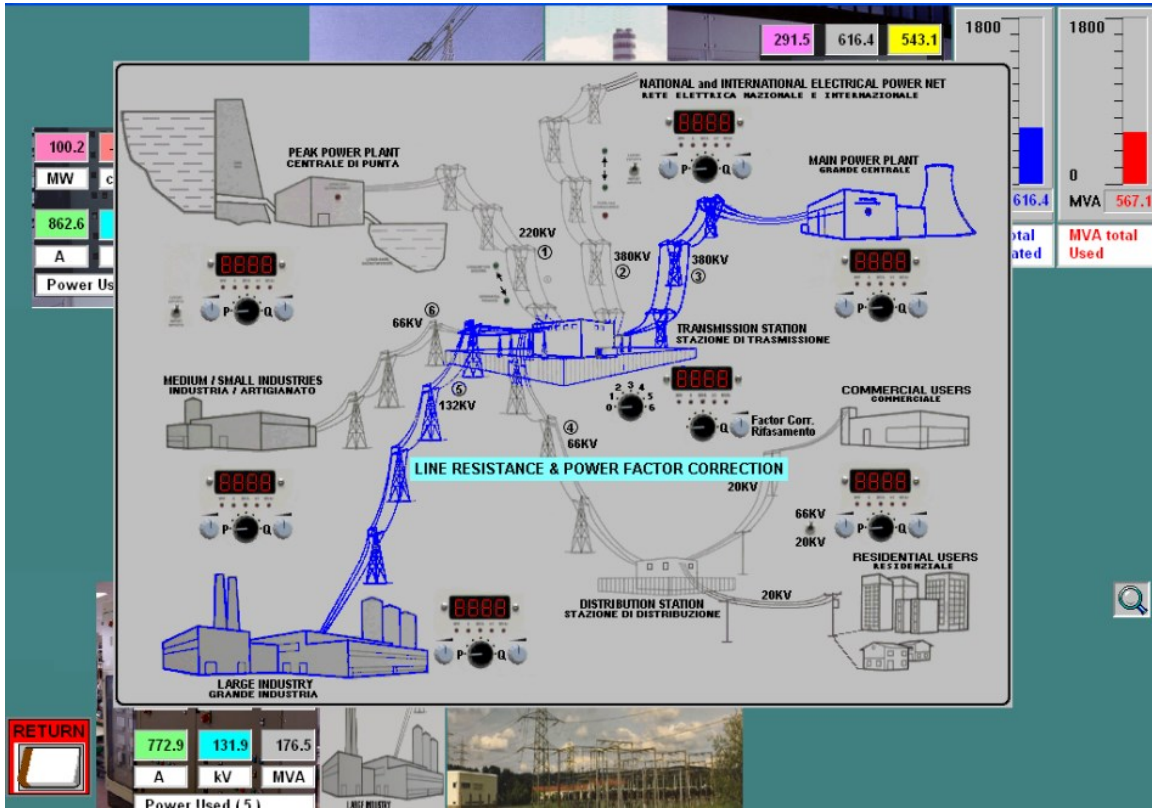


Figure 9.4 Electrical power cycle simulator

3. Find default value for R Line3, XL Line3, R Line5, and XL Line5.
4. Set Voltage for Transmission substation to 220 V.
5. Set all values of P and Q for the station as in Table 9.5.

Table 9.5 Setting Values P and Q for Main power plant and Large industry

Station Name	PMW	VAR
Main power plant	1125	536
Large industry	360	135

6. Change the setting for R Line3 as in the Table 9.6, then measure P, Q, A, VA, V and PF for Power Required(3) ,and Power Used(3).

Table 9.6 :MVA, current, voltage, and power factor measurement for changing R line 3 in Region (3)

R Line 3	Power Required (3)						Power Used(3)					
	W	PF	VAR	A	V	VA	W	PF	VAR	A	V	VA
0.1												
1												
2												
3												
4												
5												

7. Set value of then set value for XL Line 3 as in the Table 9.7 , then measure P, Q,A,VA,V and PF for Power Required(3), and Power Used(3)

Table 9.7: MVA, current, voltage, and power factor measurement for changing XL line 3 in Region (3)

XL Line 3	Power Required (3)						Power Used(3)					
	W	PF	VAR	A	V	VA	W	PF	VAR	A	V	VA
0.1												
2												
4												
6												
8												
10												

8. Then set value for R Line 5 as in the Table.8 , then measure P, Q,A,VA,V and PF for Power Required(5)and Power Used(5).

Table 9.8: MVA, current, voltage, and power factor measurement for changing R line 5 in Region (5)

R Line 5	Power Required (5)						Power Used(5)					
	W	PF	VAR	A	V	VA	W	PF	VAR	A	V	VA
0.1												
1												
2												
3												
4												
5												

9. Set value of Then set value for XL Line 5 as in the Table 9.9 , then measure P, Q,A,VA,V and PF for Power Required(5)and Power Used(5).

Table 9.9: MVA, current, voltage, and power factor measurement for changing XL line 5 in Region (5)

XL Line 5	Power Required (5)						Power Used(5)					
	W	PF	VAR	A	V	VA	W	PF	VAR	A	V	VA
0.1												
2												
4												
6												
8												
10												

10. Set RLine 3,Xline3= 0.1, RLine5,Xline5= 0.1, and keep the sitting for Q, P as in Table 9.5, use correction factor pot to change power factor, choose three value, then measure the P, Q,A,VA,V as in the following Table 9.10.

Table 9.10 :MVA, current, voltage, and power factor measurement for changing power factor

Power Factor Correction	Power Required (5)						Power Used(5)					
	W	PF	VAR	A	V	VA	W	PF	VAR	A	V	VA
Power Factor Correction	Power Required (3)						Power Used(3)					
	W	PF	VAR	A	V	VA	W	PF	VAR	A	V	VA

11. Compare between the three state, which is the best stat and why? Explain !

➤ **PART F:**

1. In the program, pressing the Yellow button will enable to enter the section corresponding to the supervision of simulator and this will enable the interaction with the personal computer.

2. Set Commercial and residential users voltage 20kV.
3. Set the following values for P&Q for every station as in Table 9.11

Table 9.11: Setting Values P and Q for every station in system

Station Name	PMW	VAR
Main power plant	1125	536
Peak power plant	300	154
National and international eclectic power net	253	120
Large industry	360	135
Medium/Small industries	120	86
Commercial and residential users	80	41

4. Change the voltage in the Transmission substation from zero to 6, the record voltage at every position, then measure P,Q,A,VA,V, and PF for Power Required(1)&Power Used(2)&....6 as in the following Table 9.12

Table 9.12: MVA, current, voltage, and power factor measurement when voltage in the Transmission substation change from zero to 6.

Position	KV	Power Required (1)						Power Required (2)					
		W	PF	VAR	A	V	VA	W	PF	VAR	A	V	VA
0													
1													
2													
3													
4													
5													
6													

Position	KV	Power Required (3)						Power Required (4)					
		W	PF	VAR	A	V	VA	W	PF	VAR	A	V	VA
0													
1													

2													
3													
4													
5													
6													

Position	KV	Power Required (5)						Power Required (6)					
		W	PF	VAR	A	V	VA	W	PF	VAR	A	V	VA
0													
1													
2													
3													
4													
5													
6													

5. Measure total MVA used and total MVA supplied.
6. Set commercial and residential users voltage 66kV, then repeat step3,4.&5.
7. Compare between two states.

