Experiment 3

Three Phase AC Circuits

Objectives

- To apply three phase AC circuit using lab-volt device in the lab practically and simulation using (LVVL) program.
- To be familiar how can be connection star and delta load and the difference between them.
- Using the phasor diagram and oscilloscope window to show the relationship between the currents and voltages in the phases.

Theory

There are two types of electrical system, the first one is single phase system that has only one phase wire and one return wire thus it is used for low power transmission and the second one is three-phase system that has three live wire and one returns path as shown in Figure 1. The three phase system is used for transmitting a large amount of power.

![Figure 1: Three phase system](image)

The 3 Phase system is divided mainly into two types. One is Balanced three phase system and another one is unbalanced three phase system. A three-phase generator consists of three single-phase generators with voltages of equal amplitudes and phase differences of 120 as shown in Figure 2.

![Figure 2: waves of three phase](image)
Analysis of Balanced 3 Phase Circuits:

There are two phase sequences in three phase AC circuits: positive and negative sequence as shown in figure below. (In this lab we will use abc (+) sequence).

![Figure 3 Phase sequences](image)

There are two ways to connect three phase system:

- Star(Y) connection.
- Delta (Δ) connection.

As the three phase supply is connected in star and delta connections. Similarly, the three-phase loads are also connected either as Star connection or as Delta Connection.

**Firstly//Star (Y) connection:**

The star connection requires four wires in which there are three phase conductors and one neutral conductor. Such type of connection is mainly used for long distance transmission because it has a neutral point. The neutral point passes the unbalanced current to the earth and hence make the system balance.

![Figure 4 Connection of three phase Y – Y](image)
The current flowing through each phase is called Phase current $I_{\text{ph}}$, and the current flowing through each line conductor is called Line Current $I_{L}$. Similarly, the voltage across each phase is called Phase Voltage $V_{\text{ph}}$, and the voltage across two line conductors is known as the Line Voltage $V_{L}$.

$V_{AN}, V_{BN}, V_{CN} \rightarrow \text{Phase Voltages}$

$V_{AN} = V \perp 0$.

$V_{BN} = V \perp -120.$

$V_{CN} = V \perp +120.$

$V_{AB}, V_{BC}, V_{CA} \rightarrow \text{Line Voltages}.$

$V_{AB} = V_{AN} - V_{BN} = \sqrt{3} V_{\text{ph}} \perp +30.$

$V_{BC} = V_{BN} - V_{CN} = \sqrt{3} V_{\text{ph}} \perp -90.$

$V_{CA} = V_{CN} - V_{AN} = \sqrt{3} V_{\text{ph}} \perp +150.$

$I_{AB}, I_{BC}, I_{CA}, I_{aA}, I_{bB}, I_{cC} \rightarrow \text{Line and phase Currents}.$

- The phase angle between each voltage is 120°.
- The line to line voltage leads the line to neutral voltage by 30 in abc(+) sequence.
- The current in any line is the same as the current in the corresponding phase. ($I_{L} = I_{\text{ph}}$).
- The amplitude of the line to line voltage is equal to $\sqrt{3}$ times the amplitude of the phase voltage.

**Power in 3 Phase Circuits:**

Power in a single phase system or circuit is given by the relation shown below:

$$P_{\text{ph}} = |V_{\text{ph}}| |I_{\text{ph}}| \cos \theta$$

$$\theta = \theta_{V_{\text{ph}}} - \theta_{I_{\text{ph}}}.$$  

In a 3 phase circuits (balanced load), the power is defined as the sum of various powers in a three phase system. i.e.

$$P_{\text{total}} = 3 |V_{\text{ph}}| |I_{\text{ph}}| \cos \theta$$

$$P_{\text{total}} = \sqrt{3} |V_{L}| |I_{L}| \cos \theta$$

$$P_{\text{total}} = P_{\text{ph}_1} + P_{\text{ph}_2} + P_{\text{ph}_3} = 3P_{\text{ph}}$$
**Measurement of Three Phase Power:**

Power measurement in an AC circuit is measured with the help of a Wattmeter. A Wattmeter is an instrument which consists of two coils called Current coil and Potential coil. The current coil having low resistance is connected in series with the load so that it carries the load current. The potential coil having the resistance is connected across the load and carries the current proportional to the potential difference.

For measuring the power in a 3 phase, more than one wattmeter is required, or more than one readings are made by one wattmeter. The number of wattmeter’s required to measure power is determined as follows:

1- Balanced circuits (Y-connected with neutral):
   
   One Wattmeter method is employed to get one reading, then multiply this reading by 3.

   \[ P_{total} = 3 \times \text{wattmeter reading} \]

2- Unbalanced circuits (Y-connected with neutral):
   
   Three Wattmeter method is employed to measure power in a 3 phase, 4 wire system. The connections for star connected loads for measuring power is shown below:

![Diagram of Three Wattmeter Method](image)

Figure 6 Three wattmeter method

The total power is given by the algebraic sum of the readings of Three wattmeters.

\[ P_{total} = W_1 + W_2 + W_3 \]
3- Balanced or unbalanced circuits without neutral:

Two Wattmeter method can be employed to measure the power in a 3 phase, three wire star or delta connected the balanced or unbalanced load. In Two wattmeter method the current coils of the wattmeter are connected with any two lines, say R and Y and the potential coil of each wattmeter is joined on the same line, the third line i.e. B as shown in figure below.

\[ W_1 = I_{aA} \cdot V_{ab} \cdot \cos(\theta_{V_{ab}} - \theta_{I_{aA}}) \]
\[ W_2 = I_{cc} \cdot V_{cb} \cdot \cos(\theta_{V_{cb}} - \theta_{I_{cc}}) \]

OR

\[ W_1 = I_{aA} \cdot V_{ab} \cdot \cos(\theta + 30) \]
\[ W_2 = I_{cc} \cdot V_{cb} \cdot \cos(\theta - 30) \]

Therefore, the total power measured by the two wattmeters \( W_1 \) and \( W_2 \) will be obtained by adding the equation (1) and (2):

\[ P_{tot} = W_1 + W_2 = \sqrt{3} V_L I_L \cos \theta \]

The total reactive power measured by the two wattmeters \( W_1 \) and \( W_2 \) will be obtained by subtracting the equation (1) and (2)

\[ Q_{tot} = \sqrt{3}(W_2 - W_1) = \sqrt{3} V_L I_L \sin \theta \]
Note:

- If $\theta = 60^\circ$ that leads to P.F = 0.5 → one of the readings of the wattmeter will be zero.
- If $\theta < 60^\circ$ that leads to P.F > 0.5 → the readings of the two wattmeter will be positive.
- If $\theta > 60^\circ$ that leads to P.F < 0.5 → one of the readings of the wattmeter will be negative.

**Secondly// Delta (A) connection:**

The delta connection has three wires, and there is no neutral point. The delta connection is shown in the figure below.

\[ I_{AB}, I_{BC}, I_{CA} \rightarrow \text{Phase Currents} \]
\[ I_{AB} = I_{\perp 0} \]
\[ I_{BC} = I_{\perp -120} \]
\[ I_{CA} = I_{\perp +120} \]

\[ I_{aA}, I_{bB}, I_{cC} \rightarrow \text{Line Currents} \]
\[ I_{aA} = I_{AB} - I_{CA} = \sqrt{3} I_{\text{ph}} \perp -30 \]
\[ I_{bB} = I_{BC} - I_{AB} = \sqrt{3} I_{\text{ph}} \perp +90 \]
\[ I_{cC} = I_{CA} - I_{BC} = \sqrt{3} I_{\text{ph}} \perp -150 \]

\[ V_{AB}, V_{BC}, V_{CA}, V_{aA}, V_{bB}, V_{cC} \rightarrow \text{Line and phase Voltages} \]

- The phase angle between each current is $120^\circ$.
- The line currents lags the phase currents by 30 in in abc(+) sequence.
- The Line-to-line voltage magnitudes are the same as the phase voltages. ($V_L = V_{\text{ph}}$).
- The amplitude of the line current is equal to $\sqrt{3}$ times the phase current.
Experimental Procedures:

Prove that a three-phase generator consists of three single-phase generators with voltages of equal amplitudes.

\[ V_{\text{ph}} = 220 \text{ v} \quad \text{and} \quad V_L = 380 \text{v} \]

1- Ensure that the power supply is switched off. Then connect the circuit by (LVVL) program as shown in figure below to get star-connection source.
2- Switch on the power then use the indicator to set phase voltage at 110V(by put the voltage control Knob 50%).

![Figure 9 Y-connected generator](image)

![Figure 10 Clarification of voltage source](image)
If you put voltage control Knob=50%, that means $V_{ph} = 50\% \times 220V = 110V, V_L = 50\% \times 380V = 190V$, that satisfy $V_L = \sqrt{3}V_{ph}$ in Y-connected source. You can show that in Metering window:

![Figure 10 Phase voltages in Y-connection](image)

![Figure 11 Line voltages in Y-connection](image)
3- Use Phasor and oscilloscope window to prove that phase differences between each phase voltage is equal 120.

**Figure 124 Phasor diagram between phase voltages in Y-connection**

**Figure 15 AC signals in Y-connection**
The First case: Y-connection Load

1- Ensure that the power supply is switched off. Then connect the circuit by (LVVL) program as shown in figure below to get Y-Y connection.

2- Switch on the switch in the resistive load to get the resistor value 2200Ω.

3- Switch on the power then use the indicator to set phase voltage at 110V (by put the voltage control Knob 50%).

4- If you put voltage control Knob=50%, that means $V_{ph} = E1 = 115.2V, V_L = E2 = 199.6V$, that satisfy $V_L = \sqrt{3}V_{ph}$ in Y-Connection. You can show that in Metering window:

![Figure 13: The circuit of 3-phase Y-Y connection](image)

![Figure 14: Phase and line voltage in Y-Y connection](image)
5- Use phasor and oscilloscope window to prove that the line to line voltage leads the line to neutral voltage by 30° in abc(+) sequence.

Figure 158 Phasor diagram between phase and line voltage in Y-Y connection

Figure 169 AC signals for phase and line voltage in Y-Y connection
6- To measure power: You can use two methods:
   ➢ One wattmeter:
     1. Make the appropriate connection as you can show in figure 6.
     2. Switch on the resistive load to get the resistor value 2200Ω.
     3. Measure phase voltage and current for one phase.

   ➢ Two wattmeter:
     1. Make the appropriate connection as you can show in figure 7.
     2. Switch on the resistive load to get the resistor value 2200Ω.
     3. Measure line voltage and current for two phases.

   As you can see: $P_{3ph} = 8.98 + 8.98 = 17.8$ W.
The Second case: Λ connection Load

1- Ensure that the power supply is switched off. Then connect the circuit by (LVVL) program as shown in figure below to get Y-Δ connection.
2- Switch on the switch in the resistive load to get the resistor value 2200Ω.
3- Switch on the power then use the indicator to set phase voltage at 110V(by put the voltage control Knob 50%).

![Circuit Diagram]

Figure 182 The circuit of 3-phase Y-Δ connection

4- You can see the relationship between line and phase current in metering window.

\[ I_L = \sqrt{3} I_{ph} = \sqrt{3} \times 0.090 = 0.157A \]

![Meter Display]

Figure 193 Phase and line currents in Y-Δ connection
5- Using phasor and oscilloscope window to prove that line currents lags the phase currents by 30° in abc(+) sequence.

**Figure 204** Phasor diagram between phase and line current in Y-Δ connection

**Figure 215** AC signals for phase and line current in Y-Δ connection
Exercises:

1- What is the effect of changing the 3-phase resistive load on dissipated power
   - One phase of star load is disconnected ............................
   - One phase of star load is shorted....................................

2- By two methods, measure the power for 3-phase Y-∆ connection circuit that consist of:
   \[ V_L = 50 \text{ V} \], Load: 1100Ω.

3- For a 174 V three-phase Y-Y ideally balanced system, Find mathematically and practically: (Load: 885 Ω)
   a) The magnitude of the line current.
   b) The magnitude of the load line and phase voltages.
   c) The real, reactive, and the apparent powers consumed by the load.
   d) The power factor of the load.

4- Prove that Line voltage = phase voltage in three phase ∆-∆ connection and draw phasor diagram using LVVL program.