



Islamic University of Gaza  
Faculty of Engineering  
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# Electric Circuits II Laboratory Manual

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## Experiment1

### AC Simple Circuits

#### Objectives:

- To identify some basic concepts of AC circuits.
- To study phasor diagram for purely resistive, capacitive and inductive circuits.

#### Theory:

The path for the flow of alternating current is called an **AC Circuit**. The alternating current (AC) is used for domestic and industrial purposes. In an AC circuit, the value of the magnitude and the direction of current and voltages is not constant, it changes at a regular interval of time. It travels as a sinusoidal wave completing one cycle as half positive and half negative cycle and is a function of time ( $t$ ) or angle ( $\theta = \omega t$ ) as shown in Fig.1 .

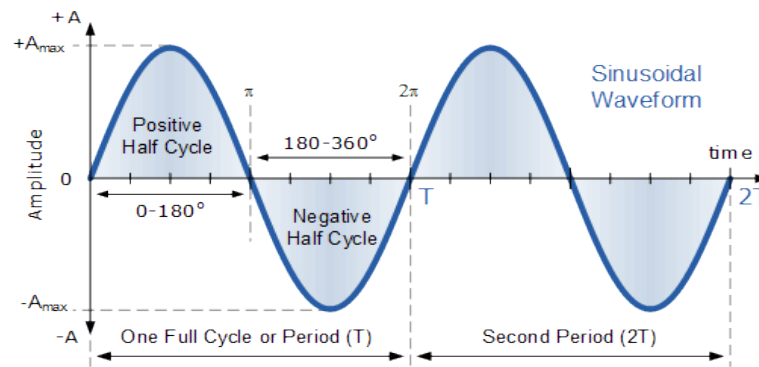


Figure 1: Sinusoidal Waveform

But, why **study AC circuits**? You probably live in a house or apartment with sockets that deliver AC. Your radio, television and portable phone receive it, using (among others) circuits like those below. As for the computer you're using to read this, its signals are not ordinary sinusoidal AC, but, thanks to Fourier's theorem, any varying signal may be analyzed in terms of its sinusoidal components. So AC signals are almost everywhere. And you can't escape them, because even the electrical circuits in your brain use capacitors and resistors.

There are various types of AC circuit such as AC circuit containing only resistance (R), AC circuit containing only capacitance (C), AC circuit containing only inductance (L), the combination of RL Circuit, AC circuit containing resistance and capacitance (RC), AC circuit containing inductance and capacitance (LC) and resistance inductance and capacitance (RLC) AC circuit.

Before examining the driven R,L,C circuits, Let's get to know some of the basic concepts of AC circuits:

❖ **Amplitude**

The maximum positive or negative value attained by an alternating quantity in one complete cycle is called Amplitude or peak value or maximum value. The maximum value of voltage and current is represented by  $E_m$  or  $V_m$  and  $I_m$  respectively.

❖ **Frequency**

The number of cycles made per second by an alternating quantity is called frequency. It is measured in cycle per second (c/s) or hertz (Hz) and is denoted by (f).

❖ **Cycle**

When one set of positive and negative values completes by an alternating quantity or it goes through 360 degrees electrical, it is said to have one complete Cycle.

❖ **Instantaneous Value**

The value of voltage or current at any instant of time is called an instantaneous value. It is denoted by (i or e).

❖ **Time Period**

The time taken in seconds by a voltage or a current to complete one cycle is called Time Period. It is denoted by (T).

❖ **Wave Form**

The shape obtained by plotting the instantaneous values of an alternating quantity such as voltage and current along the y axis and the time (t) or angle ( $\theta=wt$ ) along the x axis is called waveform.

❖ **Phase Difference**

The two alternating quantities have phase difference when they have the same frequency, but they attain their zero value at the different instant. The angle between zero points of two alternating quantities is called angle of phase differences.

### ○ Part I// Purely Resistive load:

The circuit containing only a pure resistance of  $R$  ohms in the AC circuit is known as Pure Resistive AC Circuit. The Alternating current and voltage both move forward as well as backwards in both the direction of the circuit. Hence, the Alternating current and voltage follows a shape of Sine wave or known as the sinusoidal waveform.

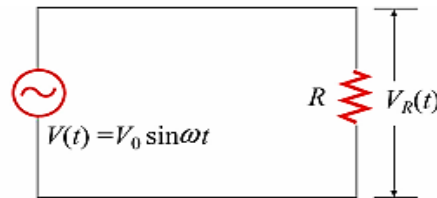


Figure 2: Pure Resistive AC circuit

In the pure resistive circuit, the power is dissipated by the resistors and the phase of the voltage and current remains same i.e., both the voltage and current reach their maximum value at the same time. The resistor is the passive device which neither produce nor consume electric power. It converts the electrical energy into heat.

Let the alternating voltage applied across the circuit be given by the equation:

$$V = V_m \sin(\omega t).$$

Then the instantaneous value of current flowing through the resistor will be:

$$I = \frac{V}{R} = \frac{V_m}{R} \sin(\omega t) \gg I = I_m \sin(\omega t).$$

The value of current will be maximum when  $\omega t = 90$  degrees or  $\sin \omega t = 1$ .

As shown in Fig.3, It is clear that there is no phase difference between applied voltage and the current flowing through a purely resistive circuit, the i.e. phase angle between voltage and current is zero. Hence, **in an AC circuit containing pure resistance, current is in phase with the voltage.**

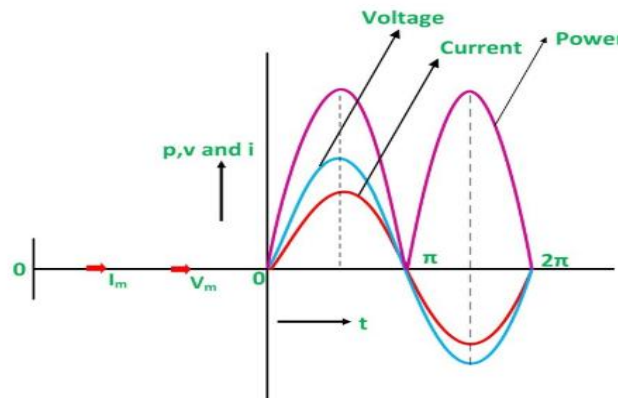


Figure 3: Waveform and Phasor Diagram of Pure Resistive Circuit

## ○ Part II// Purely Inductive Load:

The circuit which contains only inductance (L) and not any other quantities like resistance and capacitance in the Circuit is called a pure inductive circuit. ***In this type of circuit, the current lags behind the voltage by an angle of 90 degrees.***

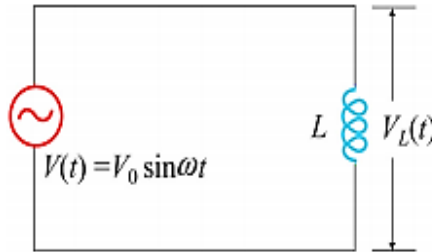


Figure 4: Pure Inductive AC circuit

The inductance is measured in Henry. The opposition of flow of current is known as the inductive reactance.

Let the alternating voltage applied to the circuit is given by the equation:

$$V = V_m \sin (\omega t)$$

The emf which is induced in the circuit is equal and opposite of the applied voltage. Hence, the equation becomes:

$$V_m \sin (\omega t) = L \frac{di}{dt}$$

After integrating both sides of the equation, we will get:

$$I = \frac{V_m}{\omega L} \sin(\omega t - \pi/2) = \frac{V_m}{X_L} \sin(\omega t - \pi/2)$$

Where,  $X_L = \omega L$  is the opposition offered to the flow of alternating current by a pure inductance and is called inductive reactance.

The value of current will be maximum when  $\sin(\omega t - \pi/2) = 1$ . Therefore,

$$I_m = \frac{V_m}{X_L} \gg I = I_m \sin(\omega t - \pi/2)$$

As shown in Fig.5, When the voltage drops, the value of the current changes. When the value of current is at its maximum or peak value of the voltage at that instance of time will be zero, and therefore, the voltage and current are out of phase with each other by an angle of 90 degrees. The phasor diagram is also shown on the left-hand side of the waveform where current ( $I_m$ ) lag voltage ( $V_m$ ) by an angle of  $\pi/2$ .

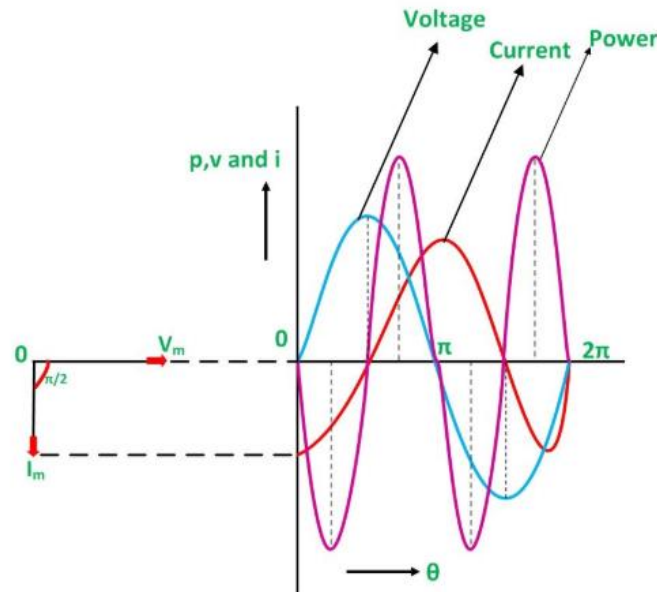


Figure 5: Phasor Diagram and Waveform of Pure Inductive Circuit

### ○ Part III // Purely Capacitive Load:

The circuit containing only a pure capacitor of capacitance  $C$  farads is known as a Pure Capacitor Circuit. The capacitors stores electrical power in the electric field. Their effect is known as the capacitance. It is also called the condenser. ***In pure AC capacitor Circuit, the current leads the voltage by an angle of 90 degrees.***

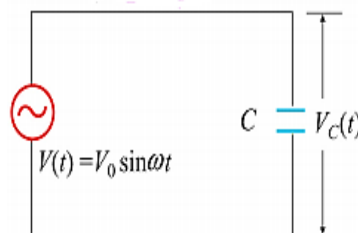


Figure 6: Pure Capacitive AC circuit

Let the alternating voltage applied to the circuit is given by the equation:

$$V = V_m \sin(\omega t)$$

Current flowing through the circuit is given by the equation:

$$I = \frac{dq}{dt} = \frac{d(CV)}{dt}$$

After the derivation process, we get:

$$I = \omega C V_m \sin(\omega t + \pi/2) = \frac{V_m}{X_C} \sin(\omega t + \pi/2)$$

Where  $X_C = 1/\omega C$  is the opposition offered to the flow of alternating current by a pure capacitor and is called Capacitive Reactance.

The value of current will be maximum when  $\sin(\omega t + \pi/2) = 1$ . Therefore, the value of maximum current  $I_m$  will be given as:

$$I_m = \frac{V_m}{X_C} \gg I = I_m \sin(\omega t + \pi/2)$$

If you examine the curve carefully, you will notice that when the voltage attains its maximum value the value of current is zero that means there is no flow of current at that time. When the value of voltage is decreased and reaches to a value of  $\pi$ , the value of voltage starts getting negative, and the current attains its peak value. As a result, the capacitor starts discharging. This cycle of charging and discharging of capacitor continues.

The value of voltage and current is not maximized at the same time because of the phase difference as they are out of phase with each other by an angle of 90 degrees. The phasor diagram is also shown in the waveform indicating that the current ( $I_m$ ) leads the voltage ( $V_m$ ) by an angle of  $\pi/2$ .

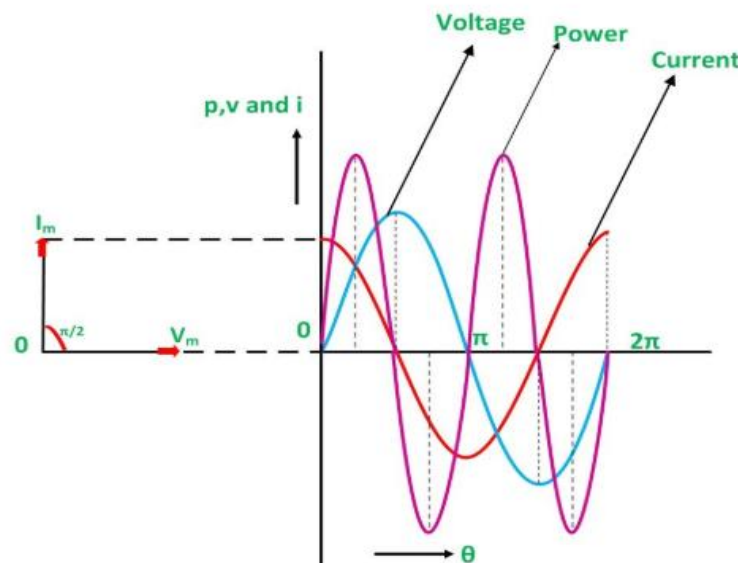


Figure 7: Phasor Diagram and Waveform of Pure Capacitor Circuit

## Practical Part:

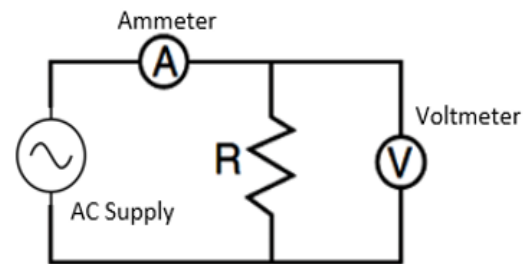
### ➤ Stage one: Studying the relation between AC Voltage and reactance of passive load.

#### 1- Resistive load

Procedures:

- 1- Construct the circuit shown in figure with 1K resistor.
- 2- Adjust the source at 1 KHz.
- 3- Change the rms amplitude as shown in the table.
- 4- In each value read the ammeter and write it down in the table.
- 5- In each value calculate the reactance  $R = V/I$ .
- 6- Plot the relation between reactance and amplitude and write your comment.

| Rms voltage (V) | Rms current (mA) | $Z = V/I$ ( $\Omega$ ) |
|-----------------|------------------|------------------------|
| 0.5             |                  |                        |
| 1               |                  |                        |
| 1.5             |                  |                        |
| 2               |                  |                        |
| 2.5             |                  |                        |

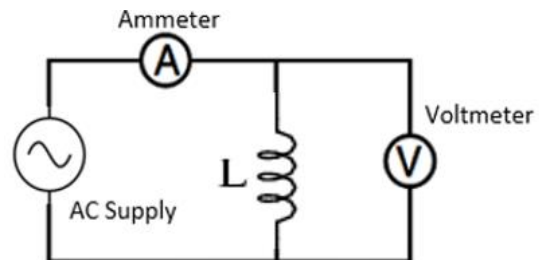


#### 2- Inductive load

Procedures:

- 1- Construct the circuit shown in figure with 10mH inductor.
- 2- Adjust the source at 1 KHz.
- 3- Change the rms amplitude as shown in the table.
- 4- In each value read the ammeter and write it down in the table.
- 5- In each value calculate the reactance  $X_L = V/I$ .
- 6- Plot the relation between reactance and amplitude and write your comment.

| Rms voltage (V) | Rms current (mA) | $Z = V/I$ ( $\Omega$ ) |
|-----------------|------------------|------------------------|
| 0.5             |                  |                        |
| 1               |                  |                        |
| 1.5             |                  |                        |
| 2               |                  |                        |
| 2.5             |                  |                        |

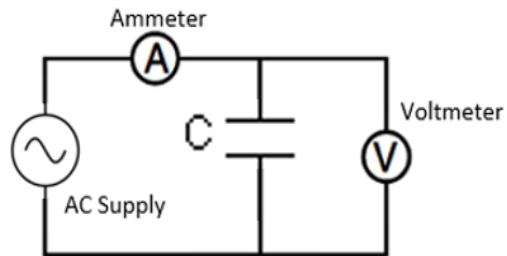


### 3- Capacitive load

Procedures:

- 1- Construct the circuit shown in figure with 1MF capacitor.
- 2- Adjust the source at 1 KHz.
- 3- Change the rms amplitude as shown in the table.
- 4- In each value read the ammeter and write it down in the table.
- 5- In each value calculate the reactance  $X_c = V/I$ .
- 6- Plot the relation between reactance and amplitude and write your comment

| Rms voltage (V) | Rms current (mA) | $Z = V/I$ ( $\Omega$ ) |
|-----------------|------------------|------------------------|
| 0.5             |                  |                        |
| 1               |                  |                        |
| 1.5             |                  |                        |
| 2               |                  |                        |
| 2.5             |                  |                        |



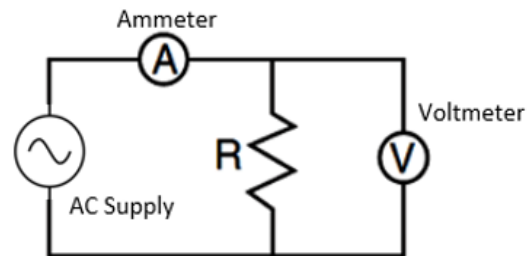
### ➤ *Stage two: Studying the relation between AC frequency and reactance of passive load.*

#### 1- Resistive load

Procedures:

- 1- Construct the circuit shown in figure with 1K resistor.
- 2- Adjust the source at max volt.
- 3- Change the frequency as shown in the table.
- 4- In each value read the ammeter and voltmeter and write it down in the table.
- 5- In each value calculate the reactance  $R = V/I$ .
- 6- Plot the relation between reactance and frequency and write your comment.

| Frequency (Hz) | Rms voltage (V) | Rms current (mA) | $Z = V/I$ ( $\Omega$ ) |
|----------------|-----------------|------------------|------------------------|
| 200            |                 |                  |                        |
| 400            |                 |                  |                        |
| 600            |                 |                  |                        |
| 800            |                 |                  |                        |
| 1000           |                 |                  |                        |

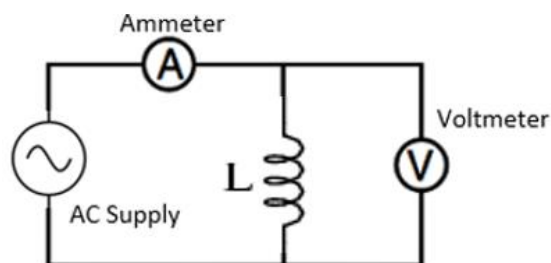


## 2- Inductive load

Procedures:

- 1- Construct the circuit shown in figure with 10 mH inductor.
- 2- Adjust the source at max volt.
- 3- Change the frequency as shown in the table.
- 4- In each value read the ammeter and voltmeter and write it down in the table.
- 5- In each value calculate the reactance  $X_L = V/I$ .
- 6- Plot the relation between reactance and frequency and write your comment.

| Frequency (Hz) | Rms voltage (V) | Rms current (mA) | $Z = V/I$ ( $\Omega$ ) |
|----------------|-----------------|------------------|------------------------|
| 200            |                 |                  |                        |
| 400            |                 |                  |                        |
| 600            |                 |                  |                        |
| 800            |                 |                  |                        |
| 1000           |                 |                  |                        |

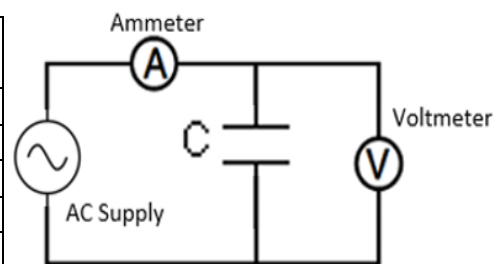


## 3- Capacitive load

Procedures:

- 1- Construct the circuit shown in figure with 1MF capacitor.
- 2- Adjust the source at max volt.
- 3- Change the rms amplitude as shown in the table.
- 4- In each value read the ammeter and write it down in the table.
- 5- In each value calculate the reactance  $X_C = V/I$ .
- 6- Plot the relation between reactance and frequency and write your comment

| Frequency (Hz) | Rms voltage (V) | Rms current (mA) | $Z = V/I$ ( $\Omega$ ) |
|----------------|-----------------|------------------|------------------------|
| 200            |                 |                  |                        |
| 400            |                 |                  |                        |
| 600            |                 |                  |                        |
| 800            |                 |                  |                        |
| 1000           |                 |                  |                        |



## Experiment 2

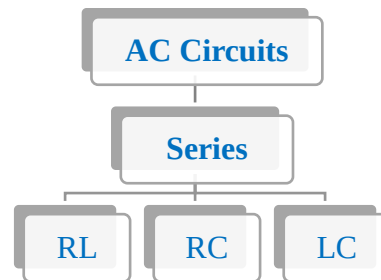
### Series AC Circuits

#### Objectives:

- To investigate the series RC, RL, LC circuits and determine the relationships between frequency and impedance on the voltages and currents in the circuits.

#### Theory :

Each of the following circuits will be identified and analyzed:



#### ➤ RL Series Circuit:

A circuit that contains a pure resistance  $R$  ohms connected in series with a coil having pure inductance of  $L$  (Henry) is known as **RL Series Circuit**. The circuit diagram of RL Series Circuit is shown below:

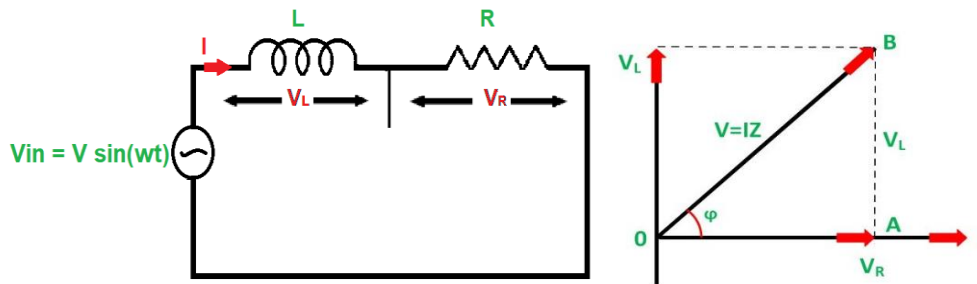


Figure 8 : Series RL Circuit and its Phasor diagram

$$V_R = IR \text{ , , , } V_L = IX_L \text{ , , , } X_L = 2\pi fL$$

$$|V_{in}| = \sqrt{(V_R)^2 + (V_L)^2}$$

$$|Z| = \sqrt{(R)^2 + (X_L)^2} \text{ , , , } Z = R + jX_L$$

Where:

**Z:** is the impedance (measured in ohms)

From the phasor diagram shown above it is clear that the current in the circuit lags the applied voltage by an angle  $\phi$  and this angle is called the phase angle.

$$\phi = \phi_V - \phi_i = \tan^{-1} \frac{V_L}{V_R} = \cos^{-1} \frac{V_R}{V_{in}} = \sin^{-1} \frac{V_L}{V_{in}}$$

$$\text{Power factor} = \cos(\phi)$$

❖ The effect of changing R on I,  $V_L$ ,  $V_R$ ,  $V_{in}$ ,  $\phi$ :

| R        | I   | $V_L$    | $V_R$    | $V_{in}$ | $\phi$     |
|----------|-----|----------|----------|----------|------------|
| 0        | max | $V_{in}$ | 0        | constant | $90^\circ$ |
| $\infty$ | 0   | 0        | $V_{in}$ | constant | $0^\circ$  |

❖ The effect of changing frequency of supply on I,  $V_L$ ,  $V_R$ ,  $V_{in}$ ,  $\phi$ :

| F        | I   | $V_L$    | $V_R$    | $V_{in}$ | $\phi$     |
|----------|-----|----------|----------|----------|------------|
| 0        | max | 0        | $V_{in}$ | constant | $0^\circ$  |
| $\infty$ | 0   | $V_{in}$ | 0        | constant | $90^\circ$ |

### ➤ RC Series Circuit:

A circuit that contains pure resistance R ohms connected in series with a pure capacitor of capacitance C farads is known as **RC Series Circuit**. A sinusoidal voltage is applied to and current I flows through the resistance (R) and the capacitance (C) of the circuit. The RC Series circuit is shown in the figure below:

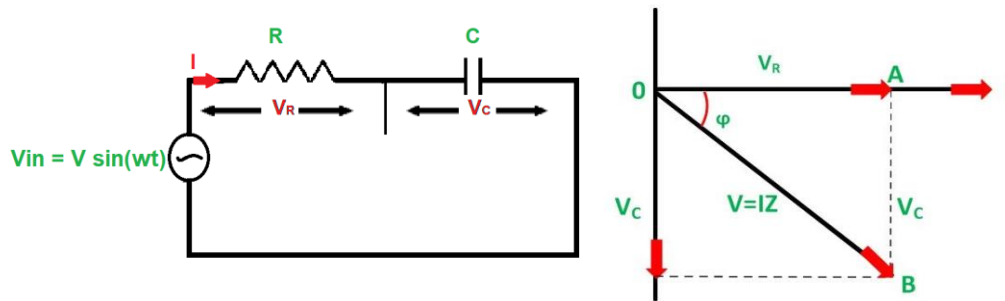


Figure 9: Series RC Circuit and its Phasor diagram

$$V_R = IR \text{ , , , } V_C = IX_C \text{ , , , } X_C = 1/2\pi fC$$

$$|V_{in}| = \sqrt{(V_R)^2 + (V_C)^2}$$

$$|Z| = \sqrt{(R)^2 + (X_C)^2} \text{ , , } Z = R + jX_C$$

From the phasor diagram shown above it is clear that the current in the circuit leads the applied voltage by an angle  $\phi$  and this angle is called the phase angle.

$$\phi = \phi_V - \phi_i = \tan^{-1} \frac{V_C}{V_R} = \cos^{-1} \frac{V_R}{V_{in}} = \sin^{-1} \frac{V_C}{V_{in}}$$

$$\text{Power factor} = \cos(\phi)$$

- ❖ The effect of changing R on I,  $V_L$ ,  $V_R$ ,  $V_{in}$ ,  $\phi$ :

| R        | I   | $V_C$    | $V_R$    | $V_{in}$ | $\phi$      |
|----------|-----|----------|----------|----------|-------------|
| 0        | max | $V_{in}$ | 0        | constant | $-90^\circ$ |
| $\infty$ | 0   | 0        | $V_{in}$ | constant | $0^\circ$   |

- ❖ The effect of changing frequency of supply on I,  $V_L$ ,  $V_R$ ,  $V_{in}$ ,  $\phi$ :

| F        | I   | $V_C$    | $V_R$    | $V_{in}$ | $\phi$      |
|----------|-----|----------|----------|----------|-------------|
| 0        | 0   | $V_{in}$ | 0        | constant | $-90^\circ$ |
| $\infty$ | max | 0        | $V_{in}$ | constant | $0^\circ$   |

### ➤ LC Series Circuit:

An LC circuit is also called a **tank circuit**, **tuned circuit** or **resonant circuit**, is an electric circuit built with a capacitor denoted by the letter 'C' and an inductor denoted by the letter 'L' connected together. These circuits are used for producing signals at a particular frequency or accepting a signal from a more composite signal at a particular frequency. LC circuits are basic electronics components in various electronic devices, especially in radio equipment used in circuits like tuners, filters, frequency mixers and oscillators.

The sum of the voltage across the capacitor and inductor is simply the sum of the whole voltage across the open terminals. The flow of current in the +Ve terminal of the LC circuit is equal to the current through both the inductor (L) and the capacitor (C).

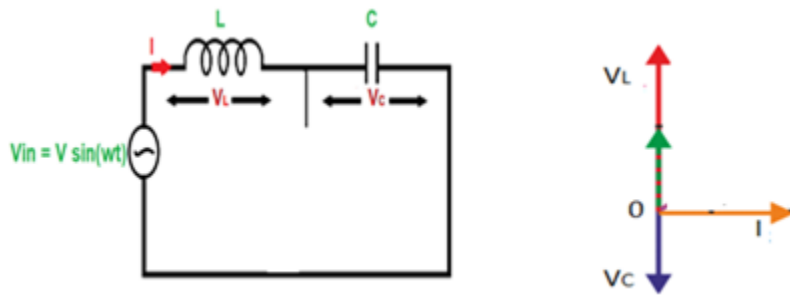


Figure 10: Series LC Circuit and its Phasor diagram

$$\vec{V_{in}} = \vec{V_L} + \vec{V_C}$$

- ❖ We must know that at higher frequencies  $X_L$  will increase while  $X_C$  decreases. At lower frequencies, of course,  $X_L$  will decrease while  $X_C$  increases.
- ❖ If  $X_L > X_C$ , the combined circuit looks purely inductive to the source. If  $X_C > X_L$ , the circuit looks capacitive.

The question that begs to be asked is, How does the circuit behave at the frequency where  $X_L = X_C$ ? Also, how can we determine what that frequency will be?

Since both  $X_L$  and  $X_C$  depend on frequency, we simply set the two to be equal to each other, and solve the resulting expression for frequency

$$\begin{aligned}X_L &= X_C \\ \omega L &= 1/\omega C \\ \omega_o &= \frac{1}{\sqrt{LC}}\end{aligned}$$

Which is termed as the resonant angular frequency of the circuit. Changing angular frequency into frequency, the following formula is used:

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

At resonance, since  $X_L = X_C$ , it is also true that  $X_L - X_C = 0$ . Therefore, there is absolutely no reactive component to  $Z$  at the resonant frequency. In the absence of any resistance, current  $i$  rises without limit, and becomes theoretically infinite. The voltage source behaves as if it were directly short-circuited.

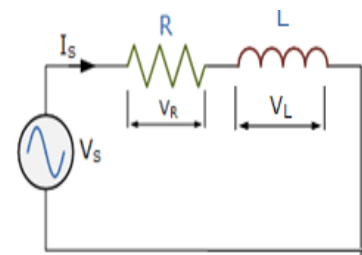
## Practical Part:

### 1- RL Series Circuit.

Procedures:

- 7- Construct the circuit shown in figure with 1K resistor and 10mH inductor.
- 8- Adjust the source at max volt.
- 9- Change the frequency as shown in the table.
- 10- In each value measure  $V_R$ ,  $V_L$ ,  $V_S$  and  $I_S$  and write them down in the table.
- 11- In each value calculate the reactance =  $V_S/I_S$  and phase angel =  $\tan (V_L/V_R)^{-1}$ .
- 12- Plot the relation between  $V_R$  impedance and frequency and write your comment.

| Frequency (KHz) | $I_S$ (mA) | $V_R$ (V) | $V_L$ (V) | $V_S$ (V) | $Z=V/I$ ( $\Omega$ ) | Phase Angel ( $\phi$ ) |
|-----------------|------------|-----------|-----------|-----------|----------------------|------------------------|
| 2               |            |           |           |           |                      |                        |
| 4               |            |           |           |           |                      |                        |
| 6               |            |           |           |           |                      |                        |
| 8               |            |           |           |           |                      |                        |
| 10              |            |           |           |           |                      |                        |

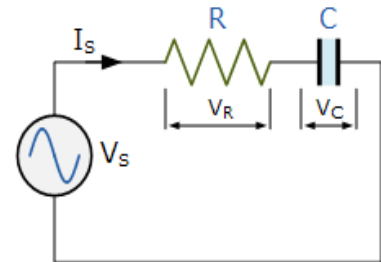


### 2- RC series circuit.

Procedures:

- 1- Construct the circuit shown in figure with 1K resistor and 1MF capacitor.
- 2- Adjust the source at max volt.
- 3- Change the frequency as shown in the table.
- 4- In each value measure  $V_R$ ,  $V_C$ ,  $V_S$  and  $I_S$  and write them down in the table.
- 5- In each value calculate the reactance =  $V_S/I_S$  and phase angel =  $\tan (V_C/V_R)^{-1}$ .
- 6- Plot the relation between impedance and frequency and write your comment.

| Frequency (KHz) | $I_S$ (mA) | $V_R$ (V) | $V_C$ (V) | $V_S$ (V) | $Z=V/I$ ( $\Omega$ ) | Phase Angel ( $\phi$ ) |
|-----------------|------------|-----------|-----------|-----------|----------------------|------------------------|
| 2               |            |           |           |           |                      |                        |
| 4               |            |           |           |           |                      |                        |
| 6               |            |           |           |           |                      |                        |
| 8               |            |           |           |           |                      |                        |
| 10              |            |           |           |           |                      |                        |

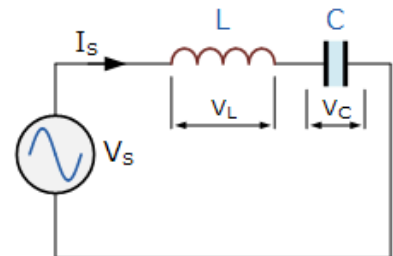


3- LC series circuit.

## Procedures:

- 1- Construct the circuit shown in figure with 10mH inductor and 1MF capacitor.
- 2- Adjust the source at max volt.
- 3- Change the frequency as shown in the table.
- 4- In each value measure  $V_L$ ,  $V_C$ ,  $V_S$  and  $I_S$  and write them down in the table.
- 5- In each value calculate the reactance =  $V_S / I_S$ .
- 6- Plot the relation between impedance and frequency and write your comment.

| Frequency (KHz) | $I_S$ (mA) | $V_L$ (V) | $V_C$ (V) | $V_S$ (V) | $Z=V/I$ ( $\Omega$ ) | Phase Angel ( $\phi$ ) |
|-----------------|------------|-----------|-----------|-----------|----------------------|------------------------|
| 2               |            |           |           |           |                      |                        |
| 4               |            |           |           |           |                      |                        |
| 6               |            |           |           |           |                      |                        |
| 8               |            |           |           |           |                      |                        |
| 10              |            |           |           |           |                      |                        |



### Experiment 3

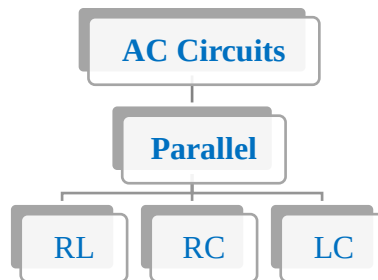
#### Parallel AC Circuits

##### Objectives:

- To investigate the parallel RC, RL, LC circuits and determine the relationships between frequency and impedance on the voltages and currents in the circuits.

##### Theory :

Each of the following circuits will be identified and analyzed:



##### ➤ Parallel RL circuit

Since the resistor and inductor are connected in parallel, the input voltage is equal to output voltage but the currents flowing in resistor and inductor are different. The circuit diagram of RL Parallel Circuit is shown below:

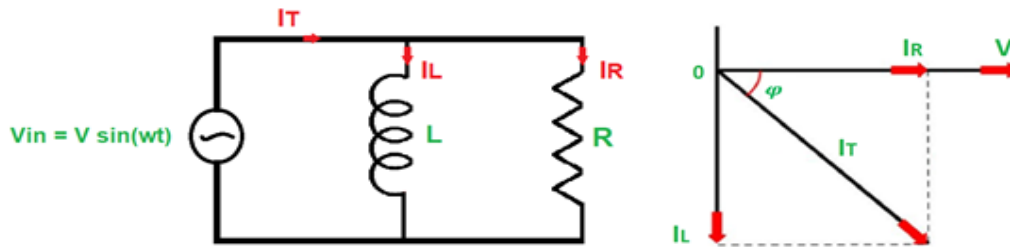


Figure 11: Parallel RL Circuit and its Phasor diagram

$$I_R = \frac{V_{in}}{R} \quad , \quad I_L = \frac{V_{in}}{X_L} \quad , \quad X_L = 2\pi fL$$

$$|I_T| = \sqrt{(I_R)^2 + (I_L)^2}$$

$$Z = \frac{R * jX_L}{R + jX_L} = \frac{V_{in}}{I_T} \text{ (Impedance)}$$

$$Y = \frac{1}{R} + \frac{1}{jX_L} = \frac{1}{R} - j \frac{1}{X_L} = G + jB$$

Where:

**Y**: is the admittance,,**G**: is the conductance,,**B**: is the susceptance(All measured in siemens).

From the phasor diagram, the value of phase angle will be:

$$\varphi = \tan^{-1} \frac{I_L}{I_R} = \cos^{-1} \frac{I_R}{I_T} = \sin^{-1} \frac{I_L}{I_T} = \tan^{-1} \frac{R}{X_L}$$

$$\text{Power factor} = \cos(\varphi)$$

❖ The effect of changing R on  $I_R, I_L, V_{in}, \varphi$ :

| R        | $I_R$    | $I_L$    | $V_{in}$ | $\varphi$ |
|----------|----------|----------|----------|-----------|
| Increase | Decrease | Increase | Constant | Increase  |

❖ The effect of changing frequency of supply on  $I_R, I_L, X_L, \varphi$ :

| F        | $X_L$    | $I_L$    | $I_R$    | $\varphi$ |
|----------|----------|----------|----------|-----------|
| Increase | Increase | Decrease | Increase | Decrease  |

### ➤ Parallel RC circuit

A resistor–capacitor circuit, or RC filter, is an electric circuit composed of resistors and capacitors driven by a voltage or current source. A first order RC circuit is composed of one resistor and one capacitor and is the simplest type of RC circuit.

The circuit diagram of RC Parallel Circuit is shown below:

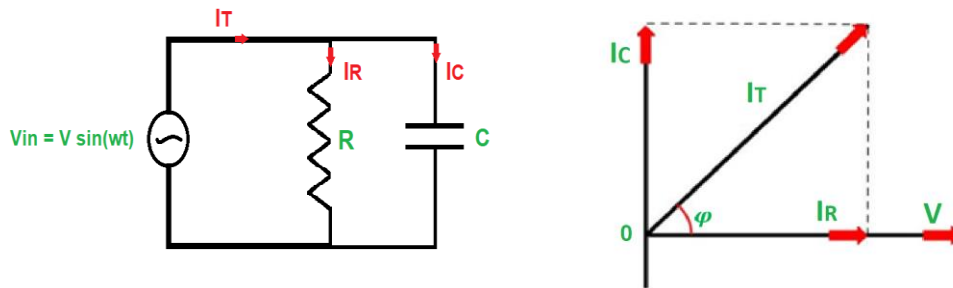


Figure 12: Parallel RC Circuit and its Phasor diagram

$$I_R = \frac{V_{in}}{R} \quad , \quad I_C = \frac{V_{in}}{X_C} \quad , \quad X_C = 1/2\pi fC$$

$$|I_T| = \sqrt{(I_R)^2 + (I_C)^2}$$

$$Z = \frac{R * jX_C}{R + jX_C} = \frac{V_{in}}{I_T}$$

From the phasor diagram, the value of phase angle will be:

$$\varphi = \tan^{-1} \frac{I_C}{I_R} = \cos^{-1} \frac{I_R}{I_T} = \sin^{-1} \frac{I_C}{I_T}$$

$$\text{Power factor} = \cos(\varphi)$$

### ➤ LC Parallel Circuit:

This circuit containing an ideal inductance and an ideal capacitance connected in parallel with each other and with an ideal signal voltage source.

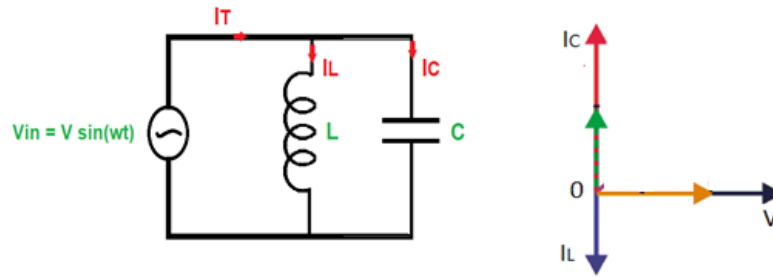


Figure 13: Parallel LC Circuit and its Phasor diagram

$$\vec{I_{in}} = \vec{I_L} + \vec{I_C}$$

The current drawn from the source is the difference between  $i_L$  and  $i_C$ . However, when  $X_L = X_C$  and the same voltage is applied to both components, their currents are equal as well. Therefore the difference is zero, and no current is drawn from the source. This corresponds to an infinite impedance, or an open circuit.

This doesn't mean that no current flows through L and C. Rather, *all* of the current flowing through these components is simply circulating back and forth between them without involving the source at all. The currents calculated with Ohm's Law still flow through L and C, but remain confined to these two components alone. As a result of this behavior, the parallel LC circuit is often called a "tank" circuit, because it holds this circulating current without releasing it.

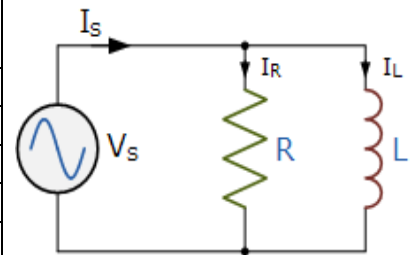
## Practical Part:

### 4- RL Parallel circuit.

Procedures:

- 13- Construct the circuit shown in figure with 1K resistor and 10mH inductor.
- 14- Adjust the source at max volt.
- 15- Change the frequency as shown in the table.
- 16- In each value measure  $I_R$ ,  $I_L$ ,  $I_S$  and  $V_S$  and write them down in the table.
- 17- In each value calculate the impedance =  $V_S/I_S$  and phase angel =  $\tan(I_L/I_R)^{-1}$ .
- 18- Plot the relation between impedance and frequency and write your comment.

| Frequency (KHz) | $I_S$ (mA) | $I_R$ (V) | $I_L$ (V) | $V_S$ (V) | $Z=V/I$ ( $\Omega$ ) | Phase Angel ( $\varphi$ ) |
|-----------------|------------|-----------|-----------|-----------|----------------------|---------------------------|
| 2               |            |           |           |           |                      |                           |
| 4               |            |           |           |           |                      |                           |
| 6               |            |           |           |           |                      |                           |
| 8               |            |           |           |           |                      |                           |
| 10              |            |           |           |           |                      |                           |

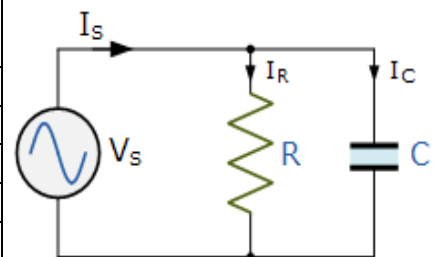


### 5- RC Parallel circuit.

Procedures:

- 7- Construct the circuit shown in figure with 1K resistor and 1MF capacitor.
- 8- Adjust the source at max volt.
- 9- Change the frequency as shown in the table.
- 10- In each value measure  $I_R$ ,  $I_C$ ,  $I_S$  and  $V_S$  and write them down in the table.
- 11- In each value calculate the reactance =  $V_S/I_S$  and phase angel =  $\tan(I_C/I_R)^{-1}$ .
- 12- Plot the relation between impedance and frequency and write your comment.

| Frequency (Hz) | $I_S$ (mA) | $I_R$ (V) | $I_C$ (V) | $V_S$ (V) | $Z=V/I$ ( $\Omega$ ) | Phase Angel ( $\varphi$ ) |
|----------------|------------|-----------|-----------|-----------|----------------------|---------------------------|
| 200            |            |           |           |           |                      |                           |
| 400            |            |           |           |           |                      |                           |
| 600            |            |           |           |           |                      |                           |
| 800            |            |           |           |           |                      |                           |
| 1000           |            |           |           |           |                      |                           |

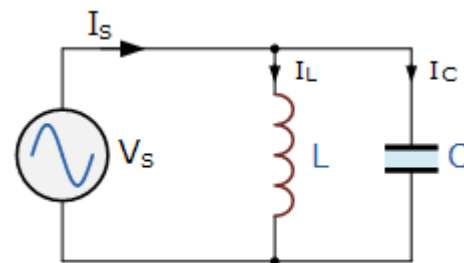


6- LC Parallel circuit.

## Procedures:

- 7- Construct the circuit shown in figure with 10mH inductor and 1MF capacitor.
- 8- Adjust the source at max volt.
- 9- Change the frequency as shown in the table.
- 10- In each value measure  $I_L$ ,  $I_C$ ,  $I_S$  and  $V_S$  and write them down in the table.
- 11- In each value calculate the reactance =  $V_S / I_S$ .
- 12- Plot the relation between impedance and frequency and write your comment.

| Frequency<br>(Hz) | $I_S$<br>(mA) | $I_L$<br>(V) | $I_C$<br>(V) | $V_S$<br>(V) | $Z=V/I$<br>( $\Omega$ ) | Phase Angel<br>( $\varphi$ ) |
|-------------------|---------------|--------------|--------------|--------------|-------------------------|------------------------------|
| 200               |               |              |              |              |                         |                              |
| 400               |               |              |              |              |                         |                              |
| 600               |               |              |              |              |                         |                              |
| 800               |               |              |              |              |                         |                              |
| 1000              |               |              |              |              |                         |                              |
| 1200              |               |              |              |              |                         |                              |
| 1400              |               |              |              |              |                         |                              |
| 1600              |               |              |              |              |                         |                              |
| 1800              |               |              |              |              |                         |                              |
| 2000              |               |              |              |              |                         |                              |



## Experiment 4

### RLC Series and Parallel AC Circuits

#### Objectives:

- To investigate RLC circuits and determine the relationships between frequency and impedance on the voltages and currents in the circuits.

#### Theory :

##### Part I //Series RLC AC Circuits

The **RLC Series Circuit** is defined as when a pure resistance of  $R$  ohms, a pure inductance of  $L$  Henry and a pure capacitance of  $C$  farads are connected together in series combination with each other. As all the three elements are connected in series so, the current flowing in each element of the circuit will be same as the total current  $I$  flowing in the circuit. The circuit diagram of RLC Series Circuit is shown below.

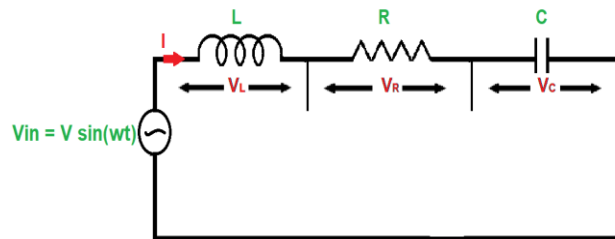


Figure 14: Series RLC Circuit

$$\vec{V}_{in} = \vec{V}_L + \vec{V}_C + \vec{V}_R$$

$$\vec{I}_{in} = \vec{I}_L = \vec{I}_C = \vec{I}_R$$

$$V_R = IR \text{ , , , } V_L = IX_L \text{ , , , } V_C = IX_C$$

$$X_C = 1/2\pi fC \text{ , , , } X_L = 2\pi fL$$

The phasor diagram of the RLC Series Circuit:

- ❖ When the circuit is acting as an inductive circuit that means ( $V_L > V_C$ ) ( $X_L > X_C$ ) as shown below:

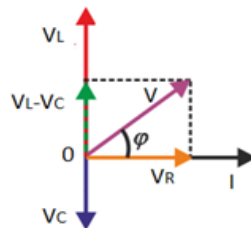


Figure 15 Phasor diagram for series RLC Circuit ( $V_L > V_C$ )

$$|V_{in}| = \sqrt{(V_R)^2 + (V_L - V_C)^2}$$

$$|V_{in}| = I \sqrt{(R)^2 + (X_L - X_C)^2} = IZ$$

$$Z = R + j(X_L - X_C)$$

From the phasor diagram, the value of phase angle will be:

$$\tan(\phi) = \frac{V_L - V_C}{V_R} = \frac{X_L - X_C}{R} \quad \text{,,,} \quad \phi = \tan^{-1} \frac{X_L - X_C}{R}$$

- ❖ When the circuit is acting as a capacitive circuit that means ( $V_L < V_C$ ) ( $X_L < X_C$ ) as shown below :

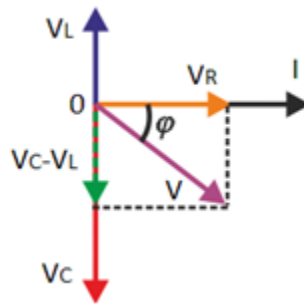


Figure 16 : Phasor diagram for series RLC Circuit ( $V_L < V_C$ )

$$|V_{in}| = \sqrt{(V_R)^2 + (V_C - V_L)^2}$$

$$|V_{in}| = I \sqrt{(R)^2 + (X_C - X_L)^2} = IZ$$

$$Z = R + j(X_C - X_L)$$

From the phasor diagram, the value of phase angle will be:

$$\tan(\phi) = \frac{V_C - V_L}{V_R} = \frac{X_C - X_L}{R} \quad \text{,,,} \quad \phi = \tan^{-1} \frac{X_C - X_L}{R}$$

### There are three cases of RLC Series Circuit:

- When  $X_L > X_C$ , the phase angle  $\phi$  is positive. The circuit behaves as a RL series circuit in which the current lags behind the applied voltage and the power factor is lagging.
- When  $X_L < X_C$ , the phase angle  $\phi$  is negative, and the circuit acts as a series RC circuit in which the current leads the voltage by 90 degrees.
- When  $X_L = X_C$ , the phase angle  $\phi$  is zero, as a result, the circuit behaves like a purely resistive circuit. In this type of circuit, the current and voltage are in phase with each other. The value of power factor is unity. The current value will be as high as possible. The value of resistance is minimal.

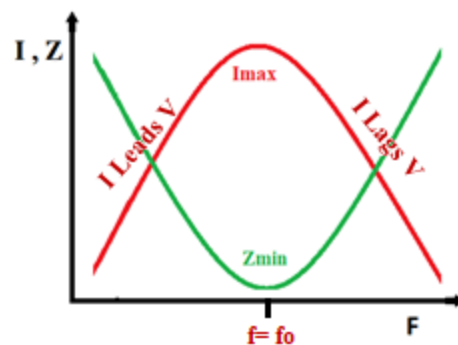


Figure 17: Relationship between impedance and current with frequency when  $X_L = X_C$  in series RLC

❖ The effect of changing frequency of supply :

| F        | $X_L$    | $X_C$    | I   | $V_C$    | $V_R$    | $V_L$    | $\phi$      |
|----------|----------|----------|-----|----------|----------|----------|-------------|
| 0        | 0        | $\infty$ | 0   | $V_{in}$ | 0        | 0        | $-90^\circ$ |
| $\infty$ | $\infty$ | 0        | 0   | 0        | 0        | $V_{in}$ | $+90^\circ$ |
| $f_o$    | $X_C$    | $X_L$    | max | $V_L$    | $V_{in}$ | $V_C$    | $0^\circ$   |

## ○ Part II //Parallel RLC AC Circuits

RLC Parallel circuit is the circuit in which all the components are connected in parallel across the alternating current source. The circuit diagram of RLC Parallel Circuit is shown below:

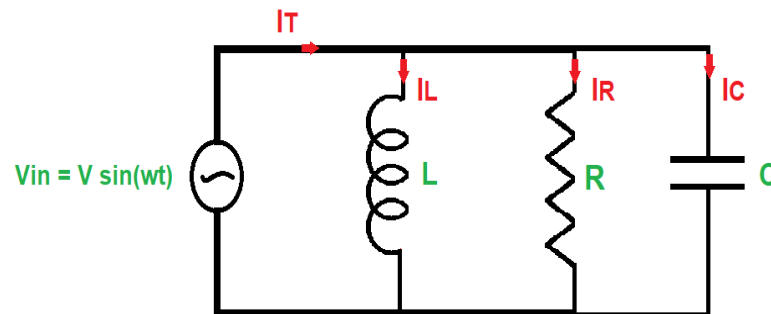


Figure 18: Parallel RLC Circuit and its Phasor diagram

$$\vec{I}_{in} = \vec{I}_L + \vec{I}_C + \vec{I}_R$$

$$\vec{V}_{in} = \vec{V}_L = \vec{V}_C = \vec{V}_R$$

The phasor diagram of the RLC Parallel Circuit :

- ❖ When the circuit is acting as a capacitive circuit that means ( $I_L < I_C$ ) ( $X_L > X_C$ ) is shown below:

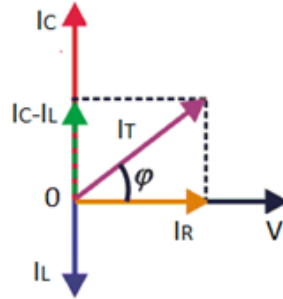


Figure 19: Phasor diagram for parallel RLC Circuit( $I_C > I_L$ )

$$|I| = \sqrt{(I_R)^2 + (I_C - I_L)^2}$$

From the phasor diagram, the value of phase angle will be:

$$\tan(\varphi) = \frac{I_C - I_L}{I_R} = \frac{R(X_L - X_C)}{X_C * X_L} \quad , , , \quad \varphi = \tan^{-1} \frac{R(X_L - X_C)}{X_C * X_L}$$

- ❖ When the circuit is acting as an inductive circuit that means ( $I_L > I_C$ ) ( $X_L < X_C$ ) the circuit will behave as an inductive circuit.

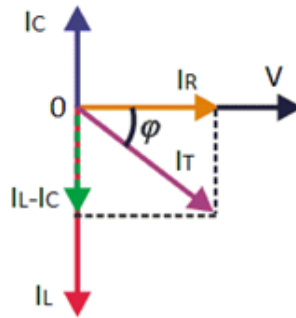


Figure 20: Phasor diagram for parallel RLC Circuit( $I_C < I_L$ )

$$|I| = \sqrt{(I_R)^2 + (I_L - I_C)^2}$$

From the phasor diagram, the value of phase angle will be:

$$\tan(\varphi) = \frac{I_L - I_C}{I_R} = \frac{R(X_C - X_L)}{X_C * X_L} \quad , , , \quad \varphi = \tan^{-1} \frac{R(X_C - X_L)}{X_C * X_L}$$

- When  $X_L = X_C$ , the phase angle  $\phi$  is zero, as a result, the circuit behaves like a purely resistive circuit. In this type of circuit, the current and voltage are in phase with each other. The value of power factor is unity. The resistance value will be as high as possible. The value of current is minimal.

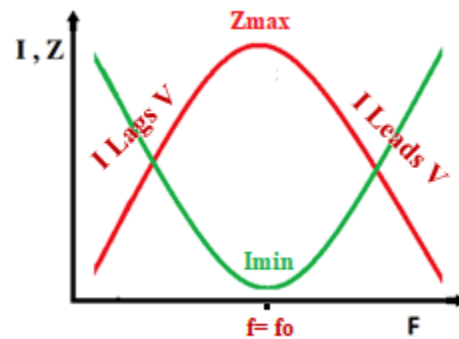


Figure 21: Relationship between impedance and current with frequency when  $X_L = X_C$  in parallel RLC

❖ The effect of changing frequency of supply :

| F        | $X_L$    | $X_C$    | $I_L$    | $I_C$    | $I_R$    | $\phi$      |
|----------|----------|----------|----------|----------|----------|-------------|
| 0        | 0        | $\infty$ | $I_{in}$ | 0        | 0        | $-90^\circ$ |
| $\infty$ | $\infty$ | 0        | 0        | $I_{in}$ | 0        | $+90^\circ$ |
| $f_o$    | $X_C$    | $X_L$    | max      | $I_L$    | $I_{in}$ | $0^\circ$   |

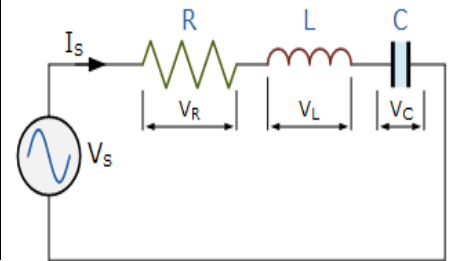
## Practical Part:

### 7- RLC Series circuit.

Procedures:

- 19- Construct the circuit shown in figure with 1K resistor and 10mH inductor and 1MF capacitor.
- 20- Adjust the source at max volt.
- 21- Change the frequency as shown in the table.
- 22- In each value measure  $V_R$ ,  $V_L$ ,  $V_C$ ,  $V_S$  and  $I_S$  and write them down in the table.
- 23- In each value calculate the impedance  $= V_S/I_S$  and phase angel  $= \tan ((V_L-V_C)/V_R)^{-1}$ .
- 24- Plot the relation between impedance and frequency and determine the resonance frequency
- 25- Write your comment.

| Frequency (Hz) | $V_S$ (V) | $V_R$ (V) | $V_L$ (V) | $V_C$ (V) | $I_S$ (mA) | $Z=V/I$ ( $\Omega$ ) | Phase Angel ( $\phi$ ) |
|----------------|-----------|-----------|-----------|-----------|------------|----------------------|------------------------|
| 200            |           |           |           |           |            |                      |                        |
| 400            |           |           |           |           |            |                      |                        |
| 600            |           |           |           |           |            |                      |                        |
| 800            |           |           |           |           |            |                      |                        |
| 1000           |           |           |           |           |            |                      |                        |
| 1500           |           |           |           |           |            |                      |                        |
| 2000           |           |           |           |           |            |                      |                        |
| 2500           |           |           |           |           |            |                      |                        |
| 3000           |           |           |           |           |            |                      |                        |

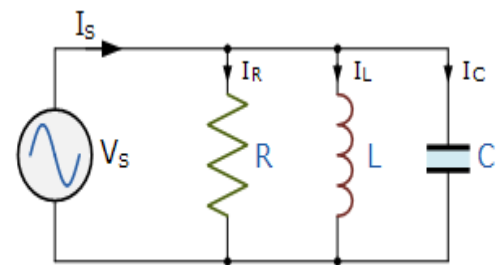


8- RLC Parallel circuit.

## Procedures:

- 1- Construct the circuit shown in figure with 1K resistor and 10mH inductor and 1MF capacitor.
- 2- Adjust the source at max volt.
- 3- Change the frequency as shown in the table.
- 4- In each value measure  $I_R$ ,  $I_L$ ,  $I_C$ ,  $I_S$  and  $V_S$  and write them down in the table.
- 5- In each value calculate the impedance =  $V_S/I_S$  and phase angel =  $\tan ((I_L-I_C)/I_R)^{-1}$ .
- 6- Plot the relation between impedance and frequency and determine the resonance frequency
- 7- Write your comment.

| Frequency (Hz) | $I_S$ (mA) | $I_R$ (mA) | $I_L$ (mA) | $I_C$ (mA) | $V_S$ (V) | $Z=V/I$ ( $\Omega$ ) | Phase Angel ( $\phi$ ) |
|----------------|------------|------------|------------|------------|-----------|----------------------|------------------------|
| 200            |            |            |            |            |           |                      |                        |
| 400            |            |            |            |            |           |                      |                        |
| 600            |            |            |            |            |           |                      |                        |
| 800            |            |            |            |            |           |                      |                        |
| 1000           |            |            |            |            |           |                      |                        |
| 1500           |            |            |            |            |           |                      |                        |
| 2000           |            |            |            |            |           |                      |                        |
| 2500           |            |            |            |            |           |                      |                        |
| 3000           |            |            |            |            |           |                      |                        |



## Experiment 5

### RLC Series / Parallel AC Circuits

#### Objectives:

- To investigate Combination of RLC circuits and determine the relationships between frequency and impedance on the voltages and currents in the circuits.

#### Theory :

##### 1- Parallel RC >>Series with L

For this circuit :

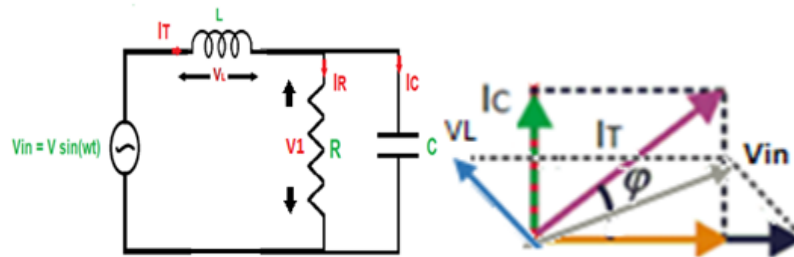


Figure 22 Combination of RLC circuit and it's phasor diagram

$$V_1 = V_R = V_C$$

$$V_R = I_R * R \text{ , , , } V_C = I_C * X_C \text{ , , , } X_C = \frac{1}{2\pi fC}$$

$$|I_T| = |I_L| = \sqrt{(I_R)^2 + (I_C)^2} \text{ , , , } V_L = I_l * X_l \text{ , , , } X_L = 2\pi fL$$

$$Z = \frac{R * jX_C}{R + jX_C} = \frac{V_1}{I_T} (\text{Impedance})$$

$$V_{in} = I_T * (X_L + Z)$$

##### 2- Parallel RL >>Series with C

For this circuit :

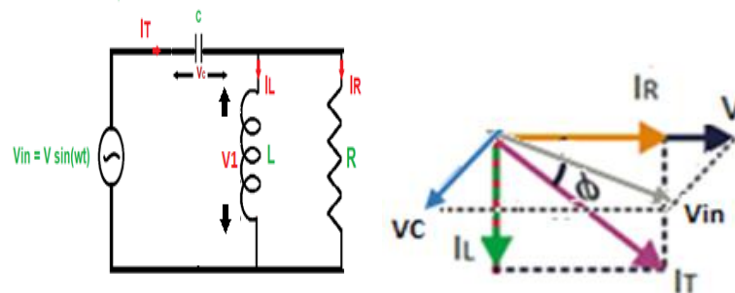


Figure 23 Combination of RLC circuit and it's phasor diagram

$$V_1 = V_R = V_L$$

$$V_R = I_R * R \text{ , , , } V_L = I_L * X_L \text{ , , } X_L = 2\pi fL$$

$$|I_T| = |I_C| = \sqrt{(I_R)^2 + (I_L)^2} \text{ , , , } V_C = I_C * X_C \text{ , , } X_C = \frac{1}{2\pi fC}$$

$$Z = \frac{R * jX_L}{R + jX_L} = \frac{V_1}{I_T} (\text{Impedance})$$

$$V_{in} = I_T * (X_C + Z)$$

### 3- Parallel LC >> Series with R

For this circuit :

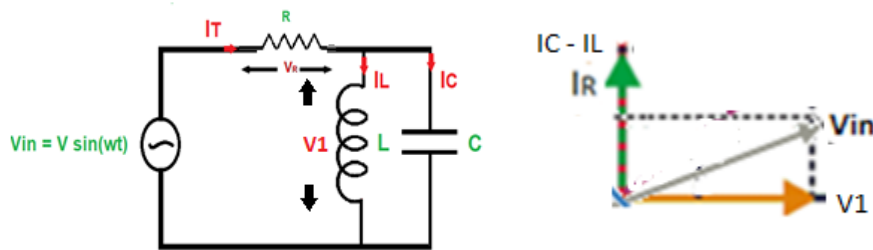


Figure 24 Combination of RLC circuit and it's phasor diagram

$$V_1 = V_C = V_L$$

$$V_C = I_C * X_C \text{ , , , } V_L = I_L * X_L \text{ , , } X_L = 2\pi fL \text{ , , } X_C = \frac{1}{2\pi fC}$$

$$|I_T| = |I_R| = \sqrt{(I_C)^2 + (I_L)^2} \text{ , , , } V_R = I_R * R$$

$$Z = \frac{jX_C * jX_L}{jX_C + jX_L} = \frac{V_1}{I_T} (\text{Impedance})$$

$$V_{in} = I_T * (R + Z)$$

## Experimental Procedures:

- RL-Parallel with C-Series circuit.

Procedures:

- 26- Construct the circuit with 1K resistor and 10mH inductor and 1MF capacitor.
- 27- Adjust the source at max volt.
- 28- Change the frequency as shown in the table.
- 29- In each value measure  $I_R$ ,  $I_L$ ,  $V_r$ ,  $V_S$  and  $I_S$  and write them down in the table.
- 30- In each value calculate the impedance =  $V_S/I_S$ .
- 31- In each value calculate the  $V_S = (V_R^2 + V_C^2)^{0.5}$  and  $I_S = (I_R^2 + I_L^2)^{0.5}$ .
- 32- Plot the relation between impedance and frequency and determine the resonance frequency
- 33- Write your comment.

| Frequency (Hz) | $V_C(V)$ | $V_R(V)$ | $V_S(V)$ | $I_R(mA)$ | $I_L(mA)$ | $I_S(mA)$ | $V_S$<br>calculated<br>(V) | $I_S$<br>calculated<br>(mA) | $Z=V/I$<br>( $\Omega$ ) |
|----------------|----------|----------|----------|-----------|-----------|-----------|----------------------------|-----------------------------|-------------------------|
| 200            |          |          |          |           |           |           |                            |                             |                         |
| 400            |          |          |          |           |           |           |                            |                             |                         |
| 600            |          |          |          |           |           |           |                            |                             |                         |
| 800            |          |          |          |           |           |           |                            |                             |                         |
| 1000           |          |          |          |           |           |           |                            |                             |                         |
| 1500           |          |          |          |           |           |           |                            |                             |                         |
| 2000           |          |          |          |           |           |           |                            |                             |                         |
| 2500           |          |          |          |           |           |           |                            |                             |                         |
| 3000           |          |          |          |           |           |           |                            |                             |                         |

- RC-Parallel with L-Series circuit.

Procedures:

- 8- Construct the circuit with 1K resistor and 10mH inductor and 1MF capacitor.
- 9- Adjust the source at max volt.
- 10- Change the frequency as shown in the table.
- 11- In each value measure  $I_R$ ,  $I_C$ ,  $I_S$ ,  $V_R$ ,  $V_L$  and  $V_S$  and write them down in the table.
- 12- In each value calculate the impedance  $= V_S / I_S$ .
- 13- In each value calculate the  $V_S = (V_R^2 + V_L^2)^{0.5}$  and  $I_S = (I_R^2 + I_C^2)^{0.5}$
- 14- Plot the relation between impedance and frequency and determine the resonance frequency
- 15- Write your comment.

| Frequency (Hz) | $V_L$ (V) | $V_R$ (v) | $V_S$ (v) | $I_R$ ( mA ) | $I_C$ ( mA ) | $I_S$ (mA) | $V_S$ calculated (V) | $I_S$ calculated (mA) | $Z=V/I$ ( $\Omega$ ) |
|----------------|-----------|-----------|-----------|--------------|--------------|------------|----------------------|-----------------------|----------------------|
| 200            |           |           |           |              |              |            |                      |                       |                      |
| 400            |           |           |           |              |              |            |                      |                       |                      |
| 600            |           |           |           |              |              |            |                      |                       |                      |
| 800            |           |           |           |              |              |            |                      |                       |                      |
| 1000           |           |           |           |              |              |            |                      |                       |                      |
| 1500           |           |           |           |              |              |            |                      |                       |                      |
| 2000           |           |           |           |              |              |            |                      |                       |                      |
| 2500           |           |           |           |              |              |            |                      |                       |                      |
| 3000           |           |           |           |              |              |            |                      |                       |                      |

- LC-Parallel with R-Series circuit.

Procedures:

- 1- Construct the circuit with 1K resistor and 10mH inductor and 1MF capacitor.
- 2- Adjust the source at max volt.
- 3- Change the frequency as shown in the table.
- 4- In each value measure  $I_L$ ,  $I_C$ ,  $I_S$ ,  $V_R$ ,  $V_L$  and  $V_S$  and write them down in the table.
- 5- In each value calculate the impedance  $= V_S / I_S$ .
- 6- In each value calculate the  $V_S = (V_R^2 + (V_L - V_C)^2)^{0.5}$  and  $I_S = (I_R^2 + (I_C - I_L)^2)^{0.5}$
- 7- Plot the relation between impedance and frequency and determine the resonance frequency
- 8- Write your comment.

| Frequency (Hz) | $V_L$ (V) | $V_R$ (v) | $V_S$ (v) | $I_L$ ( mA ) | $I_C$ ( mA) | $I_S$ (mA) | $V_S$ calculated (V) | $I_S$ calculated (mA) | $Z=V/I$ ( $\Omega$ ) |
|----------------|-----------|-----------|-----------|--------------|-------------|------------|----------------------|-----------------------|----------------------|
| 200            |           |           |           |              |             |            |                      |                       |                      |
| 400            |           |           |           |              |             |            |                      |                       |                      |
| 600            |           |           |           |              |             |            |                      |                       |                      |
| 800            |           |           |           |              |             |            |                      |                       |                      |
| 1000           |           |           |           |              |             |            |                      |                       |                      |
| 1500           |           |           |           |              |             |            |                      |                       |                      |
| 2000           |           |           |           |              |             |            |                      |                       |                      |
| 2500           |           |           |           |              |             |            |                      |                       |                      |
| 3000           |           |           |           |              |             |            |                      |                       |                      |

## Experiment 6

### Single Phase Transformer

#### Objectives:

- To study how transformers work.
- To know type of transformer.
- To study the voltages and currents curves when the operating single phase transformer.

#### Theory:

A transformer is an electrical device that transfers electrical energy between two or more circuits through electromagnetic induction. Commonly, transformers are used to increase or decrease the voltages of alternating current in electric power applications.

The coil to which the source supplies the power is called the *primary winding*. The coil that delivers power to the load is called the *secondary winding*.

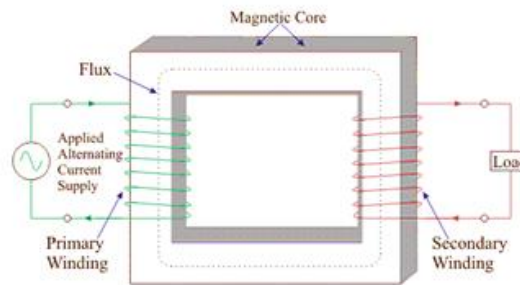


Figure 25 Single phase transformer

#### Construction of a Transformer

In order to keep the core loss to a minimum, the core of a transformer is built up of thin laminations of highly permeable ferromagnetic material such as silicon-sheet steel. Silicon steel is used because of its properties and low magnetic losses.

In all types of transformer construction, the central iron core is constructed from of a highly permeable material made from thin silicon steel laminations. These thin laminations are assembled together to provide the required magnetic path with the minimum of magnetic losses.

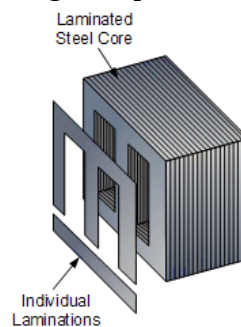


Figure 16: thin laminations from steel

## Types of Transformer:

For economic reasons, electric power is required to be transmitted at high voltage whereas it has to be utilized at low voltage from a safety point of view. This increase in voltage for transmission and decrease in voltage for utilization can only be achieved by using a step-up and step-down transformer.

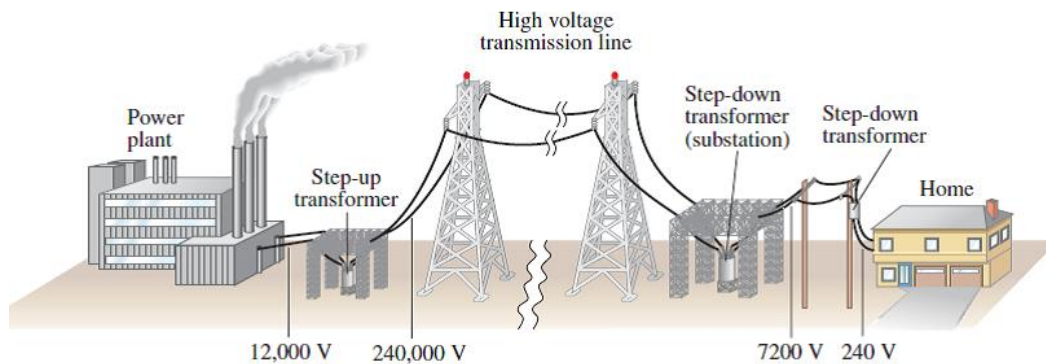


Figure 27 Transformer in transmission System

The major difference between step-up and step-down transformer is, step-up transformer raises the output voltage, whereas step-down transformer reduces the output voltage.

### 1- Step-Down Transformer:

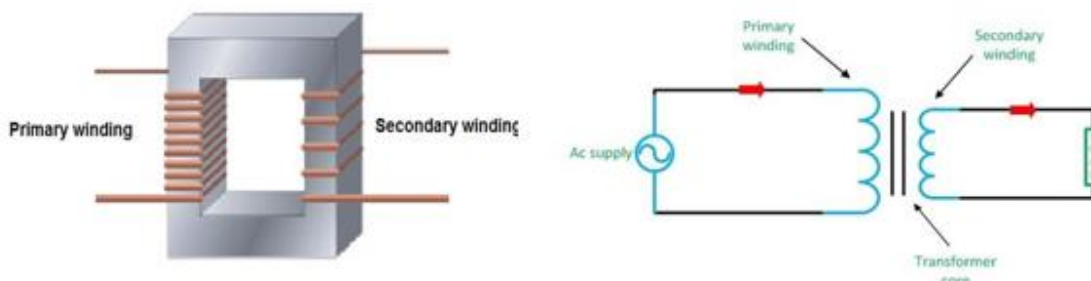


Figure 28 Step-Down Transformer

- Input voltage is high while the output voltage is low
- High voltage winding is the primary winding
- Current is high on the secondary winding.
- Rating of output voltage: 110v, 24v, 20v, 10v, etc.
- Application: Doorbell, voltage converter, etc.

## 2- Step-up Transformer:

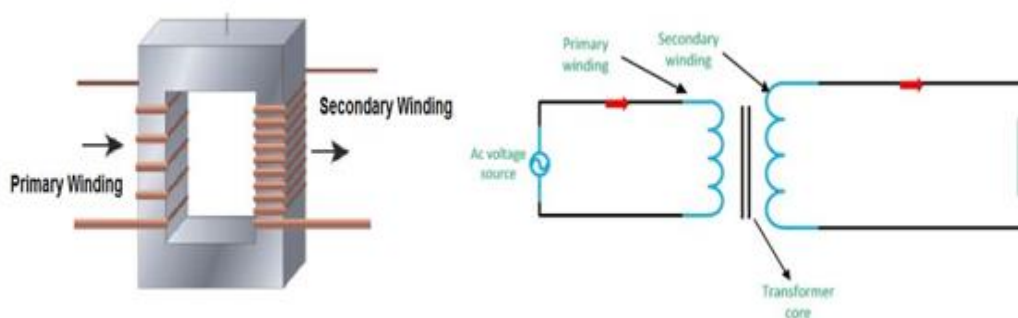


Figure 29 Step-up Transformer

- Input voltage is low while the output voltage is high
- High voltage winding is the secondary winding
- Current is low on the secondary winding.
- Rating of output voltage : 11000 volts or above
- Applications: Power plant, X-rays machine, microwaves, etc.

### ♣ Important Note:

The Same transformer can be used as a step-up or a step-down transformer. It depends upon the ways in which it is connected in the circuit. If input supply is given on the low voltage winding, then it becomes a step-up transformer. Alternately, if the input supply is provided on the high voltage winding, the transformer becomes a step-down one.

### Ideal Transformer:

A two-winding transformer with each winding acting as a part of a separate electric circuit. Let  $N_1$ , and  $N_2$  be the number of turns in the primary and secondary windings.

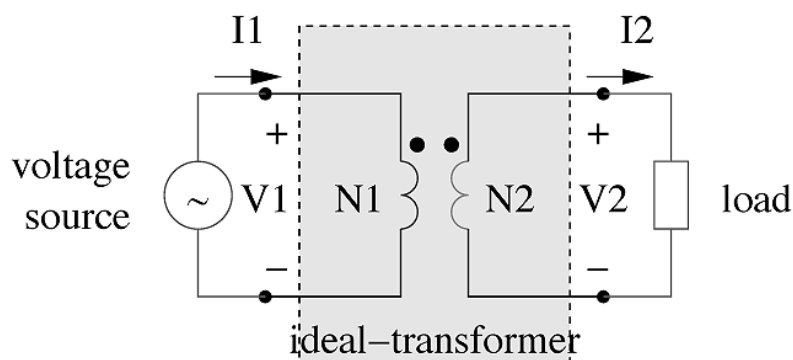


Figure 30 ideal transformer

**A transformer turns ratio (a):**

The total induced voltage in each winding is proportional to the number of turns in that winding and the current is inversely proportional to both voltage and number of turns.

$E_1$ : primary voltage

$I_1$ : primary current

$E_2$ : secondary voltage

$I_2$ : secondary current

$N_1$ : primary turns

$N_2$ : secondary turns

$a$ : turns ratio

$$a = \frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$$

**Experimental Procedures:*****Finding transformer turns ratio (a) by three methods:***

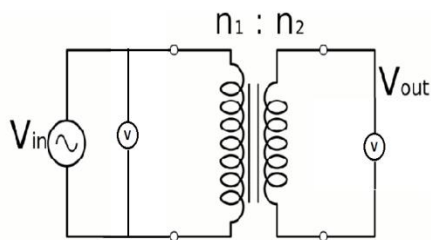
- Practical in Lab**

- Transformer Voltage Ratio.

Procedures:

- Construct the circuit shown in figure with open circuit at output.
- Adjust the source at 50 Hz frequency.
- Change the amplitude as shown in the table.
- In each value measure  $V_1$  and  $V_2$  and write them down in the table.
- Plot the relation between  $V_1$  and  $V_2$  and determine its slope (transformation ratio)
- Write your comment.

| Rms voltage(v) | Rms $V_1$ (v) | Rms $V_2$ (v) |
|----------------|---------------|---------------|
| 0.5            |               |               |
| 1              |               |               |
| 1.5            |               |               |
| 2              |               |               |
| 2.5            |               |               |

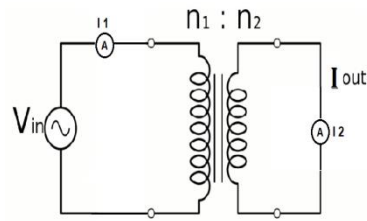


## 2- Transformer Current Ratio.

### Procedures:

1. Construct the circuit shown in figure with short circuit at output.
2. Adjust the source at 50 Hz frequency.
3. Change the amplitude to reach current at input as shown in the table.
4. In each value measure I1 and I2 and write them down in the table.
5. Plot the relation between I2 and I1 and determine its slope (transformation ratio)
6. Write your comment.

| Rms voltage(v) | Rms I1 (mA) | Rms I2 (mA) |
|----------------|-------------|-------------|
|                | 0.5         |             |
|                | 1           |             |
|                | 1.5         |             |
|                | 2           |             |
|                | 2.5         |             |

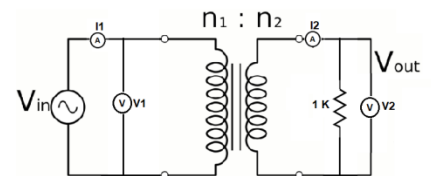


## 3- Transformer impedance Ratio.

### Procedures:

1. construct the circuit shown in figure with 1 K $\Omega$  at output.
2. Adjust the source at 50 Hz frequency.
3. Change the amplitude to reach volt at input as shown in the table.
4. In each value measure V1, V2, I1 and I2 and write them down in the table.
5. In each value calculate Z1 and Z2 and write them down in the table.
6. Plot the relation between Z1 and Z2 and determine its slope ( $a^2$ )
7. write your comment.

| Rms V1 (v) | Rms I1 (mA) | Rms V2 (v) | Rms I2 (mA) | Z1 | Z2 |
|------------|-------------|------------|-------------|----|----|
| 0.5        |             |            |             |    |    |
| 1          |             |            |             |    |    |
| 1.5        |             |            |             |    |    |
| 2          |             |            |             |    |    |
| 2.5        |             |            |             |    |    |



- **By Program**

- 1- Transformation voltage ratio.
- 2- Transformation current ratio.
- 3- Transformation impedance ratio.

Find the turn's ratio between nodes 1, 2 primary side and nodes 3, 4 secondary side.

🔗 Determine the turn's ratio using voltage ratio

- 1- Connect the circuit as shown in figure below.

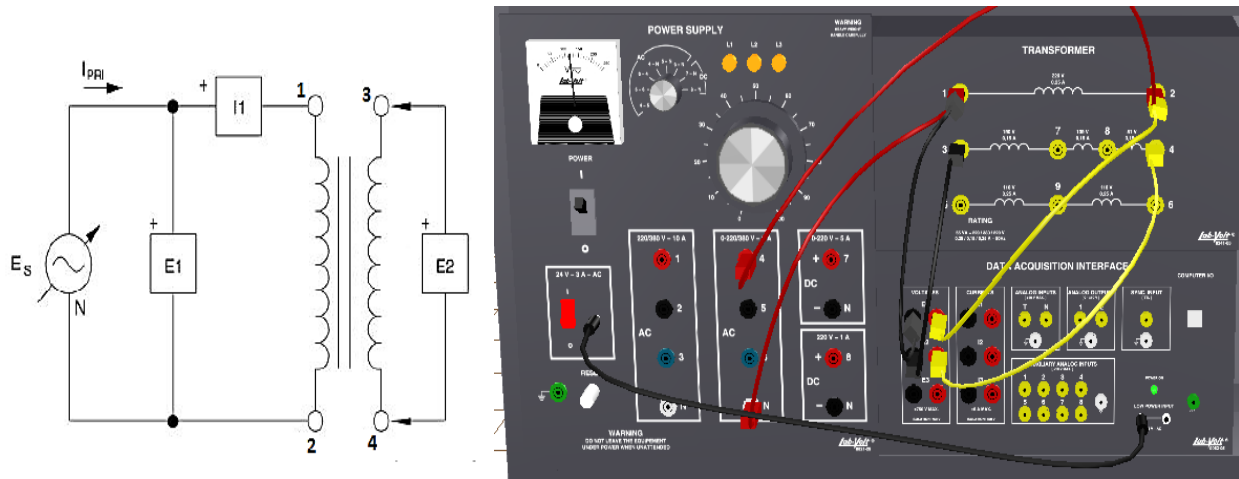


Figure 31 Determine the turn's ratio using voltage ratio

- 2- Open data table window and record data step by 10% from 0% - 100%

|    | E1<br>(V) | E2<br>(V) |
|----|-----------|-----------|
| 0  | 0         | 0         |
| 1  | 22.56     | 38.57     |
| 2  | 46.8      | 79.99     |
| 3  | 68.16     | 116.49    |
| 4  | 92.24     | 157.63    |
| 5  | 114.88    | 196.3     |
| 6  | 137.5     | 234.94    |
| 7  | 160.7     | 274.58    |
| 8  | 184.6     | 315.42    |
| 9  | 207.87    | 355.2     |
| 10 | 229.79    | 392.69    |

Figure 32 Data table for voltage ratio

- 3- Open graph window from data table to find slope of the line between E1 at Y-axis and E2 at X-axis.

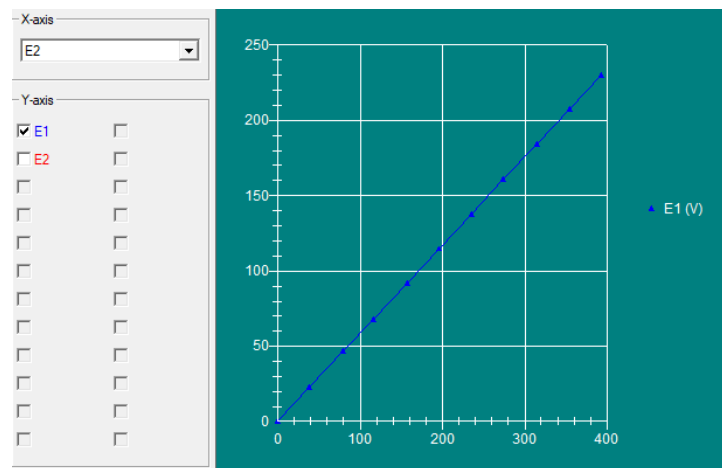


Figure 33 Graph window for voltage ratio

- 4- Find slope of the line from figure above.

$$a = \frac{\Delta E1}{\Delta E2} = \frac{175-120}{300-200} = 0.55$$

### Determine the turn's ratio using current ratio

- 1- Connect the circuit as shown in figure below.

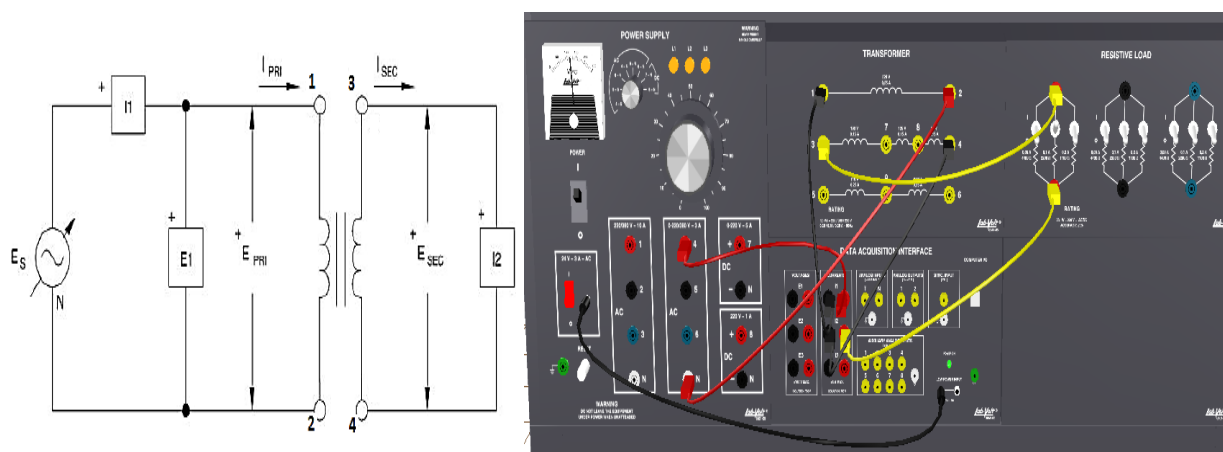


Figure 34 Determine the turn's ratio using current ratio

- 2- Open data table window and record data step by 10% from 0% - 100%

|    | I1<br>(A) | I2<br>(A) |
|----|-----------|-----------|
| 0  | 0         | 0         |
| 1  | 0.052     | 0.029     |
| 2  | 0.101     | 0.057     |
| 3  | 0.151     | 0.085     |
| 4  | 0.197     | 0.111     |
| 5  | 0.247     | 0.139     |
| 6  | 0.292     | 0.165     |
| 7  | 0.34      | 0.192     |
| 8  | 0.387     | 0.219     |
| 9  | 0.431     | 0.244     |
| 10 | 0.479     | 0.272     |

Figure 35 Data table for current ratio

- 3- Open graph window from data table to find slope of the line between I2 at Y-axis and I1 at X-axis.

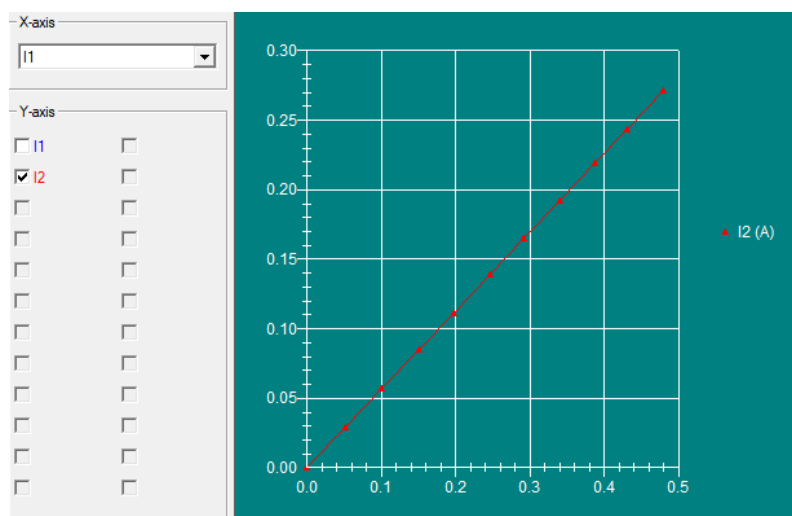


Figure 36 Graph window for current ratio

- 4- Find slope of the line from figure above.

$$a = \frac{\Delta I_2}{\Delta I_1} = \frac{0.15 - 0.1}{0.26 - 0.17} = 0.55$$

∞ Determine the turn's ratio using impedance ratio.

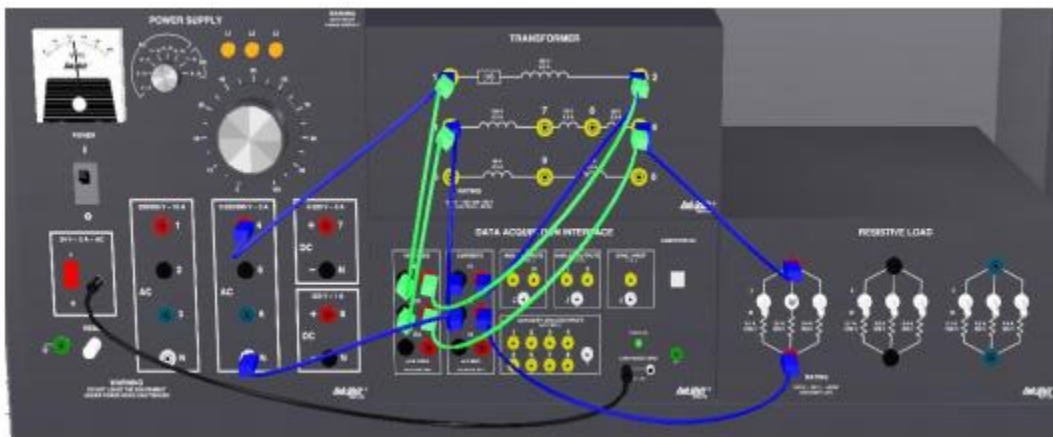
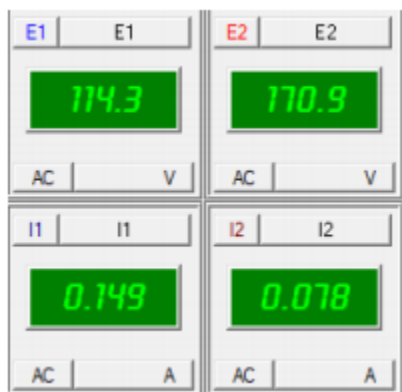


Figure 2 Determine the turn's ratio using impedance ratio



$$E1/I1 = Z1 = 778.2312$$

$$E2/I2 = Z2 = 2191.025$$

$$a = \sqrt{\frac{Z1}{Z2}} = 0.59$$

Figure 38 Primary and secondary Currents and voltages

### ✚ Exercise:

1- Repeat the above two methods to find transformer ratio (a) between:

- Primary side 1,2 and secondary side 5,6
- Primary side 7,8 and secondary side 5,6

## Experiment7

### 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.

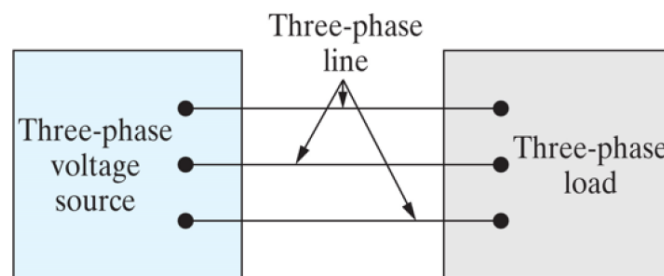


Figure39 Three phase system

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  $120^\circ$  as shown in Figure2.

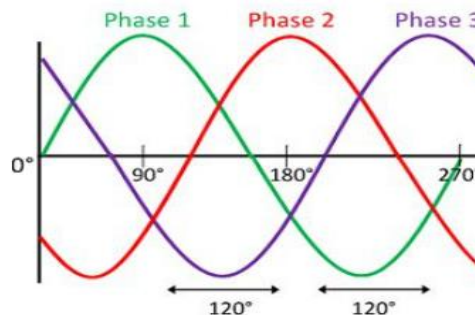


Figure 40 Waves of three phase

### 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).

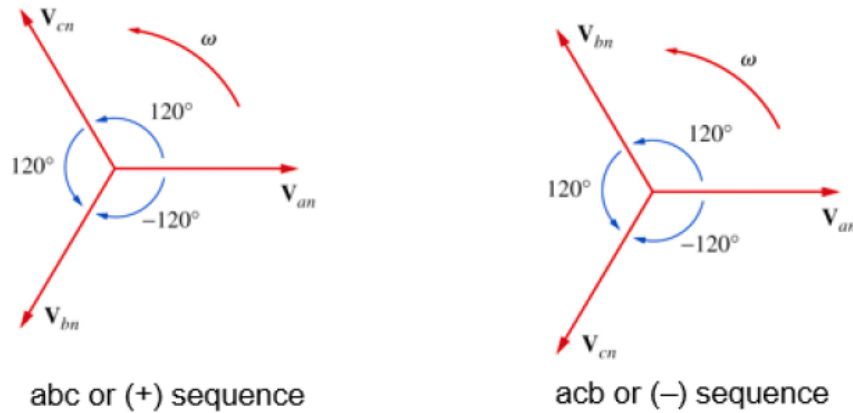


Figure 41 Phase sequences

There are two ways to connect three phase system:

- Star(Y) connection.
- Delta ( $\Delta$ ) 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.

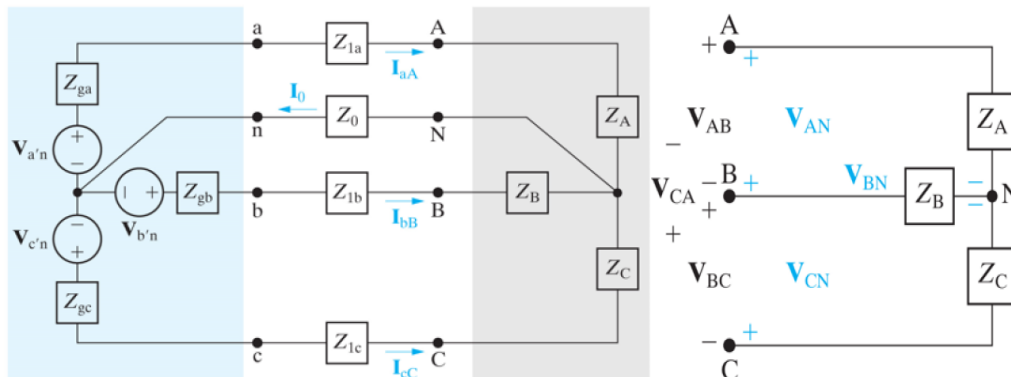


Figure 32 Connection of three phase Y-Y

The current flowing through each phase is called **Phase current  $I_{ph}$** , and the current flowing through each line conductor is called **Line Current  $I_L$** . Similarly, the voltage across each phase is called **Phase Voltage  $V_{ph}$** , and the voltage across two line conductors is known as the **Line Voltage  $V_L$** .

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

$$V_{AN} = V \angle 0^\circ$$

$$V_{BN} = V \angle -120^\circ$$

$$V_{CN} = V \angle +120^\circ$$

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

$$V_{AB} = V_{AN} - V_{BN} = \sqrt{3} V_{ph} \angle +30^\circ$$

$$V_{BC} = V_{BN} - V_{CN} = \sqrt{3} V_{ph} \angle -90^\circ$$

$$V_{CA} = V_{CN} - V_{AN} = \sqrt{3} V_{ph} \angle +150^\circ$$

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

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

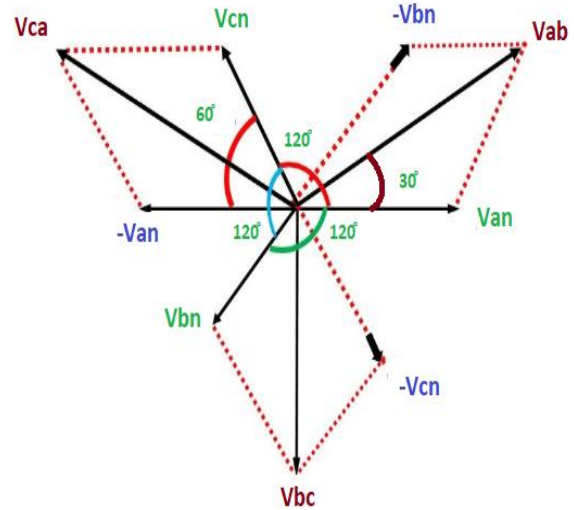


Figure 43 Phasor diagram between phase and line voltage in Y-connected with positive sequence

### Power in 3 Phase Circuits:

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

$$P_{ph} = |V_{ph}| |I_{ph}| \cos \theta, \quad (\theta = \theta_{V_{ph}} - \theta_{I_{ph}})$$

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

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

$$P_{total} = \sqrt{3} |V_L| |I_L| \cos \theta$$

$$P_{total} = P_{ph_1} + P_{ph_2} + P_{ph_3} = 3P_{ph}$$

### 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.

$$P_{total} = 3 * \text{wattmeter reading}$$

- 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:

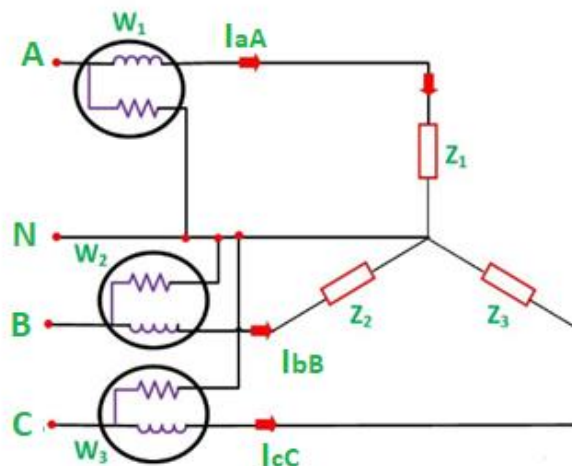


Figure 44 Three wattmeter method

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.

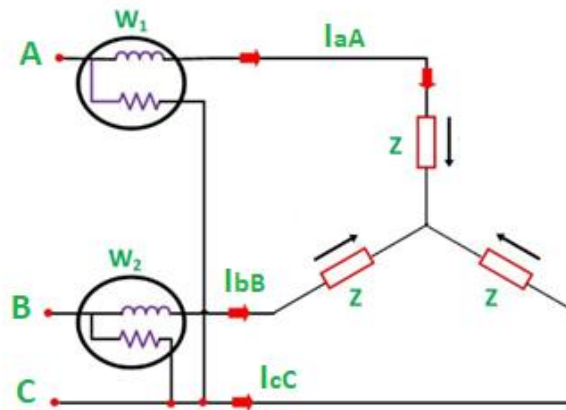


Figure 45 Two wattmeter method

The power measured by the Wattmeters,  $W_1$  and  $W_2$  are:

$$W_1 = I_{aA} * V_{ab} * \cos(\theta_{V_{ab}} - \theta_{I_{aA}})$$

$$W_2 = I_{cC} * V_{cb} * \cos(\theta_{V_{cb}} - \theta_{I_{cC}})$$

OR

$$W_1 = I_{aA} * V_{ab} * \cos(\theta + 30)$$

$$W_2 = I_{cC} * V_{cb} * \cos(\theta - 30)$$

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

### Secondly// Delta ( $\Delta$ ) connection:

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

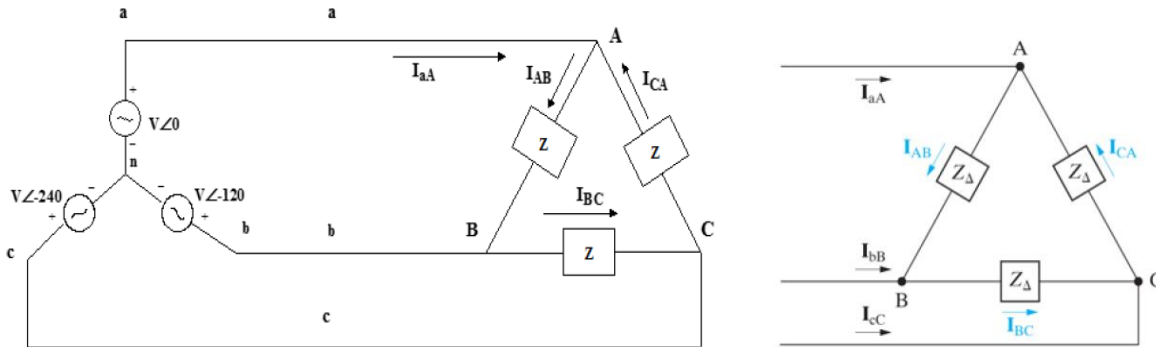


Figure 46 Connection of three phase Y -  $\Delta$

$I_{AB}, I_{BC}, I_{CA} \rightarrow$  Phase Currents

$$I_{AB} = I_L \angle 0^\circ$$

$$I_{BC} = I_L \angle -120^\circ$$

$$I_{CA} = I_L \angle +120^\circ$$

$I_{aA}, I_{bB}, I_{cC} \rightarrow$  Line Currents

$$I_{aA} = I_{AB} - I_{CA} = \sqrt{3} I_{ph} \angle -30^\circ$$

$$I_{bB} = I_{BC} - I_{AB} = \sqrt{3} I_{ph} \angle +90^\circ$$

$$I_{cC} = I_{CA} - I_{BC} = \sqrt{3} I_{ph} \angle -150^\circ$$

$V_{AB}, V_{BC}, V_{CA}, V_{aA}, V_{bB}, V_{cC} \rightarrow$  Line and phase Voltages.

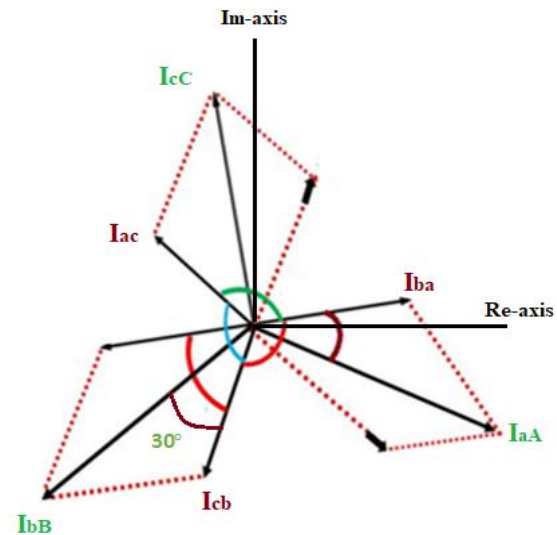


Figure 47 Phasor diagram between phase and line current in  $\Delta$  connected with positive sequence

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

$$V_{ph} = 220 \text{ V} \text{ , , , } V_L = 380 \text{ V}$$

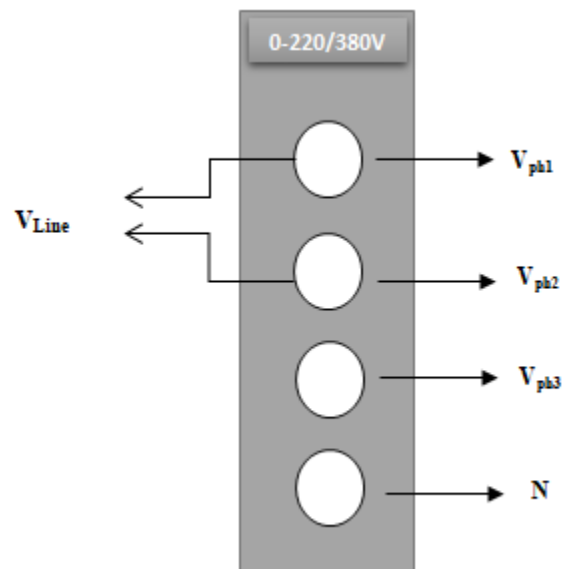


Figure 48 Clarification of voltage source

- 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%).

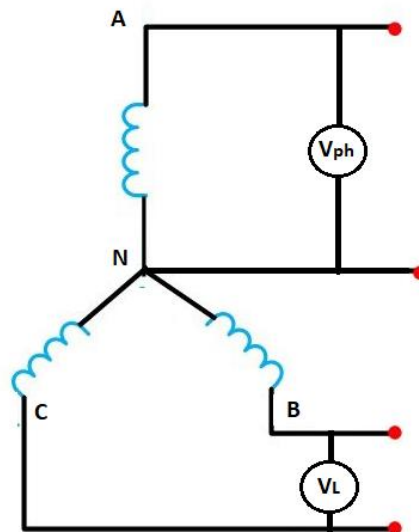


Figure 49 Y-connected generator

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:

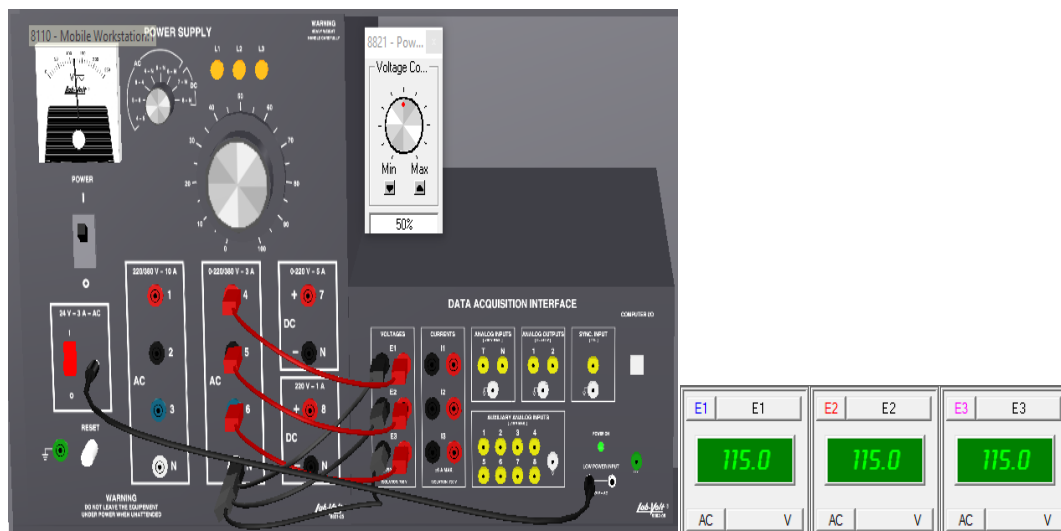


Figure 50 Phase voltages in Y-connection

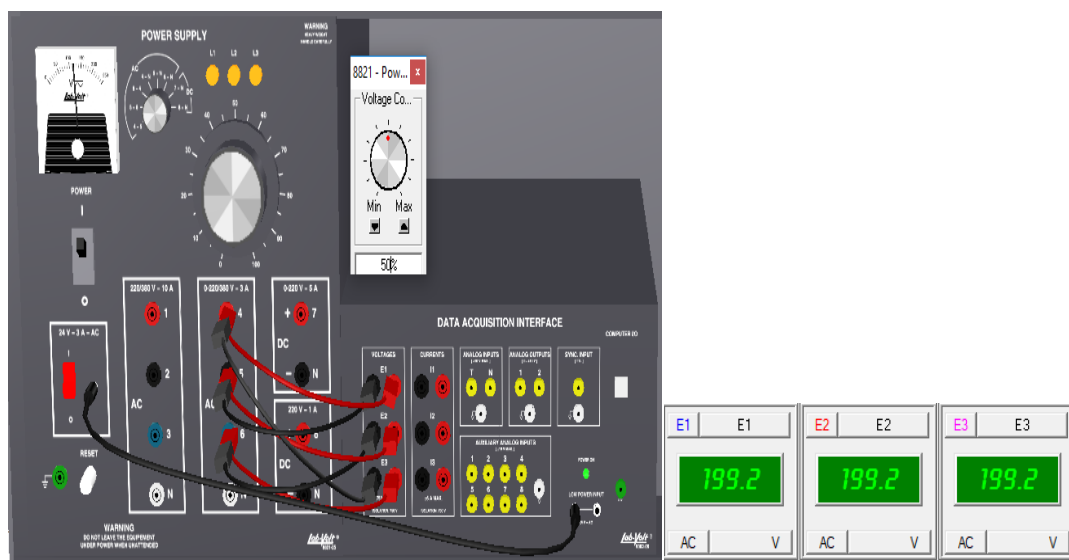


Figure 51 Line voltages in Y-connection

- 3- Use Phasor and oscilloscope window to prove that phase differences between each phase voltage is equal 120.

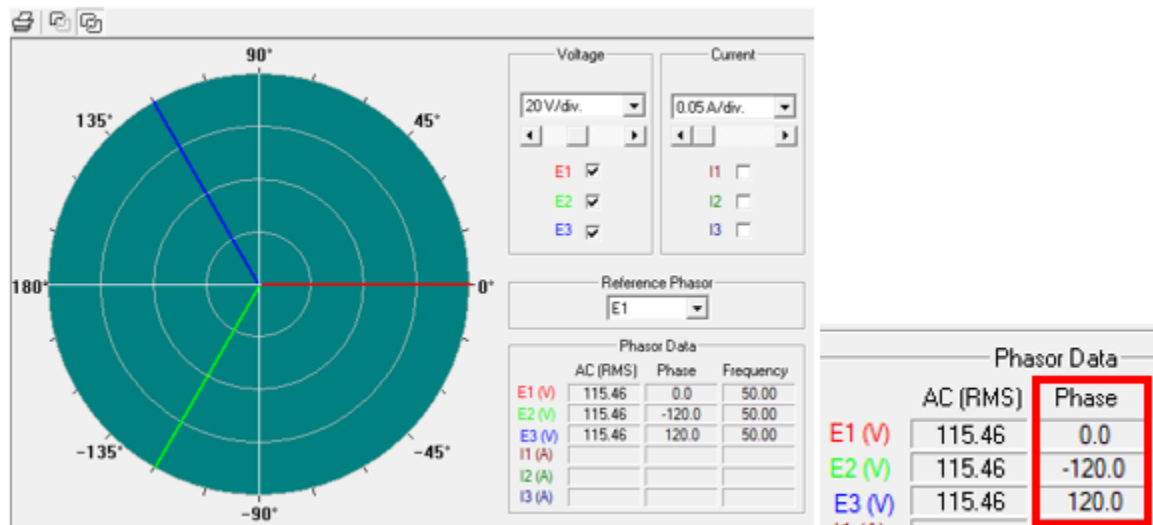


Figure 52 Phasor diagram between phase voltages in Y-connection

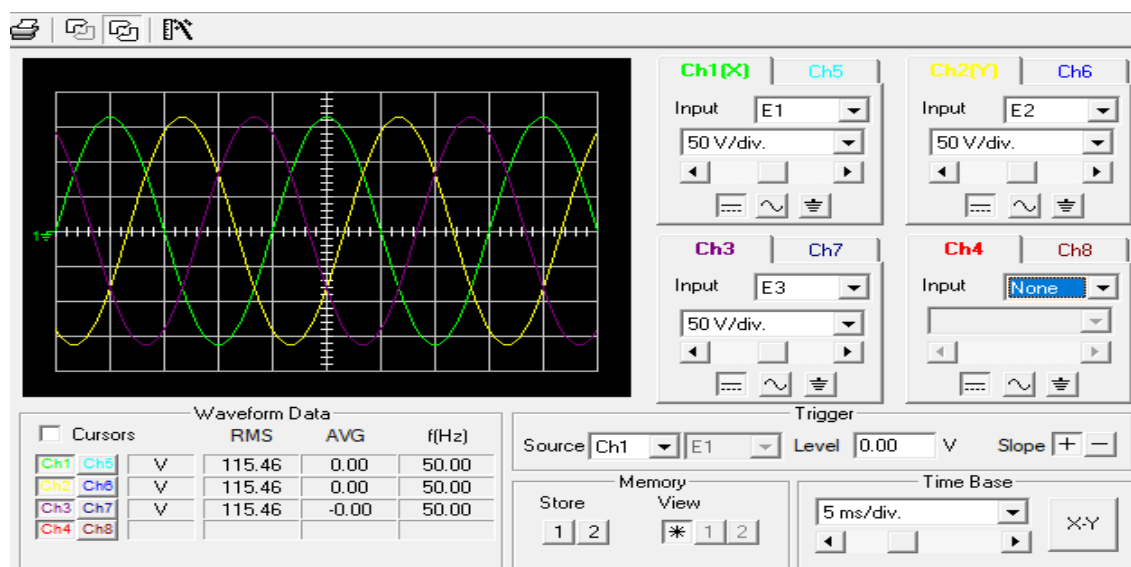


Figure 53 AC signals in Y-connection

### 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%).

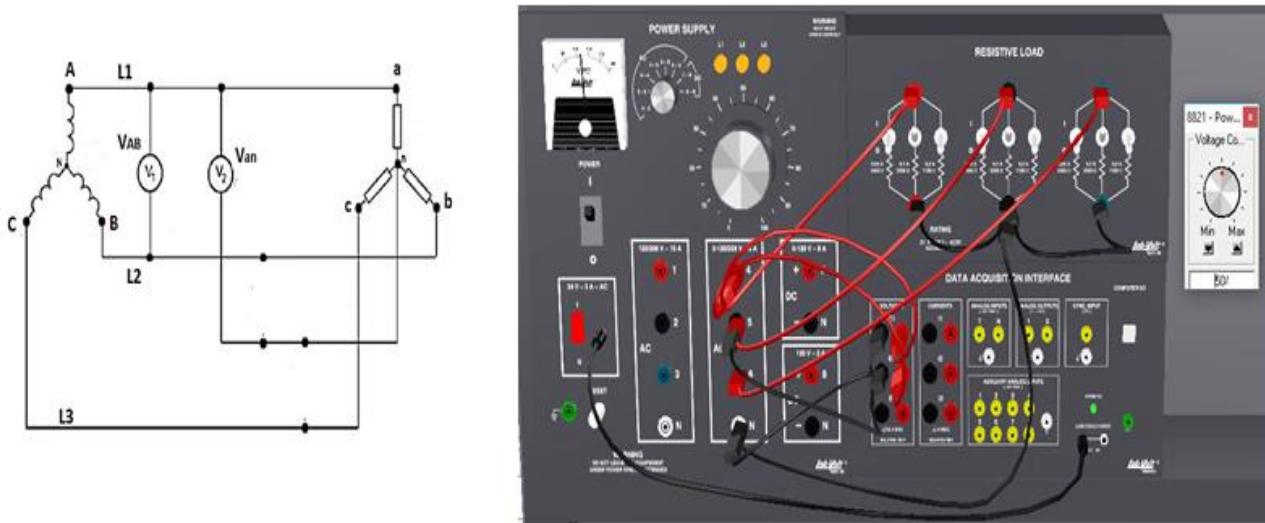


Figure 54 The circuit of 3-phase Y-Y connection

- 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:

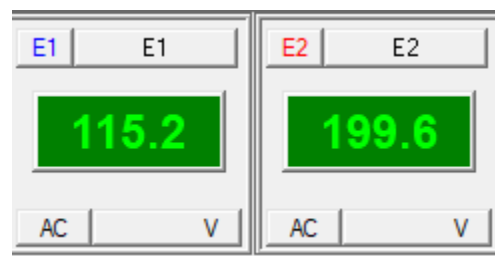


Figure 55 Phase and line voltage in Y-Y connection

- 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.

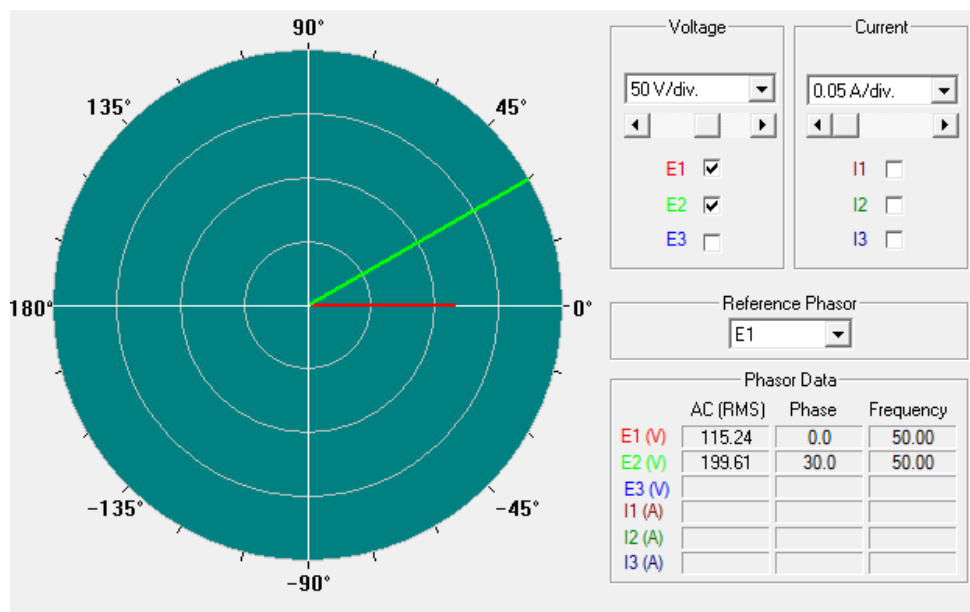


Figure 56 Phasor diagram between phase and line voltage in Y- Y connection

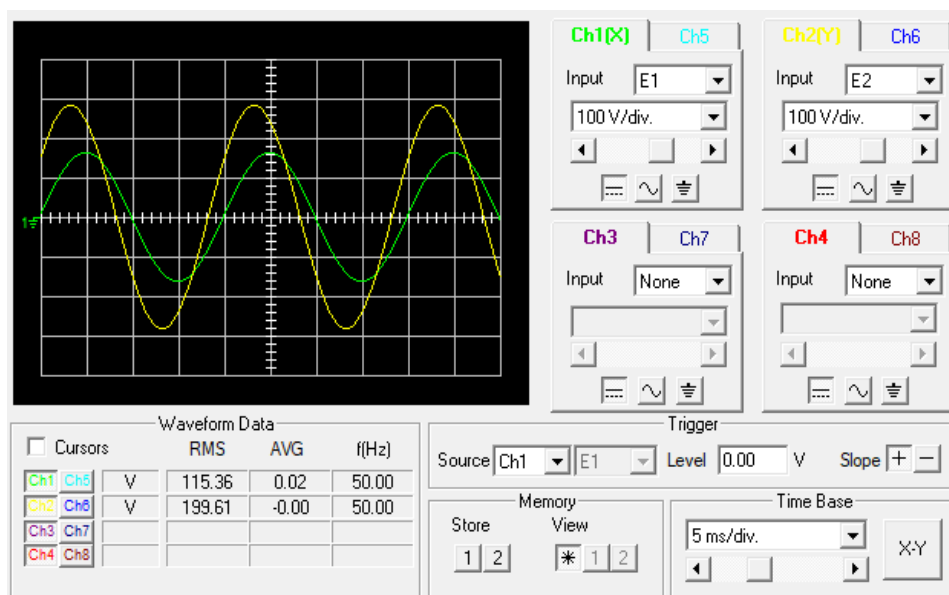


Figure 57 AC signals for phase and line voltage in Y-Y connection

6- To measure power : You can use two method:

➤ One wattmeter :

1. Make the appropriate connection as you can show in figure6.
2. Switch on the resistive load to get the resistor value  $2200\Omega$ .
3. Measure phase voltage and current for one phase.

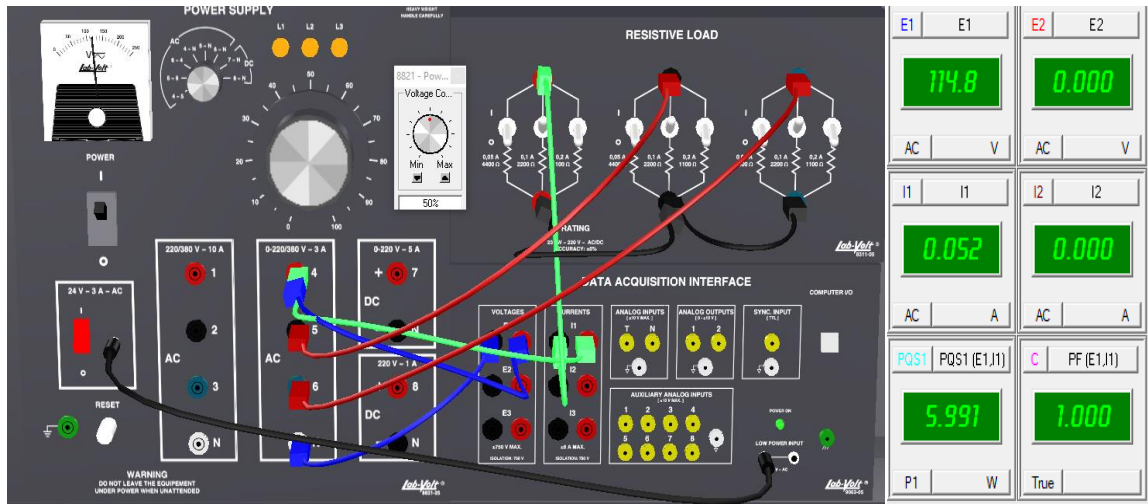


Figure 58 The first method for Power measurement in Y-Y connection

As you can see :  $E1 = V_{ph} = 114.8V$  ,  $I1 = I_{ph} = 0.052A$  , So  $P_{ph} = 114.8 * 0.052 * 3 = 5.991W$  ,  $P_{3ph} = 3 * 5.991 = 17.8W$ .

➤ Two wattmeter :

1. Make the appropriate connection as you can show in figure7.
2. Switch on the resistive load to get the resistor value  $2200\Omega$ .
3. Measure Line voltage and current for two phases.

As you can see :  $P_{3ph} = 8.98 + 8.98 = 17.8W$ .

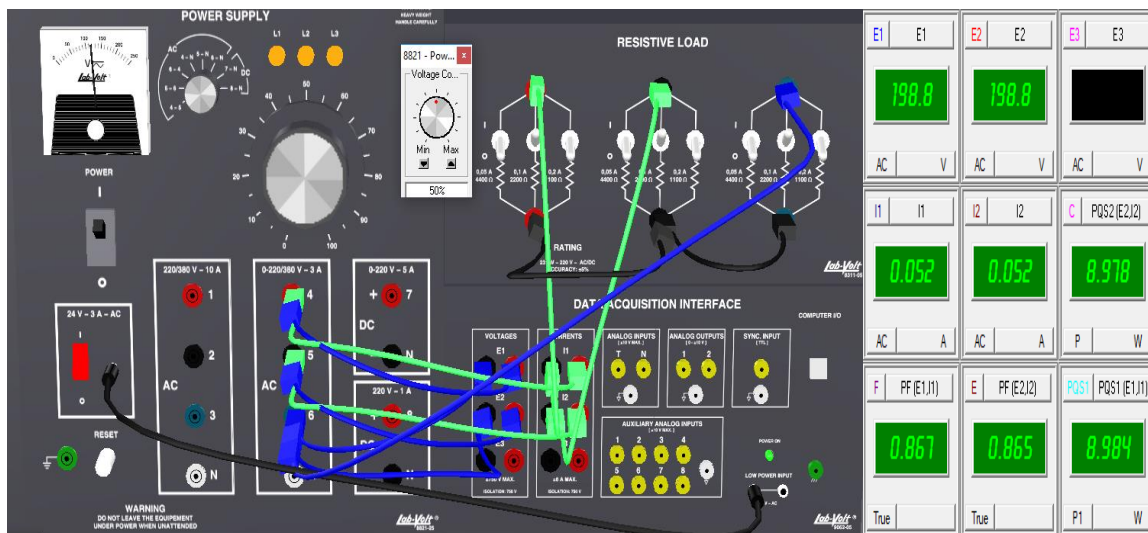


Figure 59 The second method for Power measurement in Y-Y connection

### The Second case: $\Delta$ 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- $\Delta$  connection.
- 2-Switch on the switch in the resistive load to get the resistor value  $2200\Omega$ .
- 3-Switch on the power then use the indicator to set phase voltage at 110V (by put the voltage control Knob 50%).

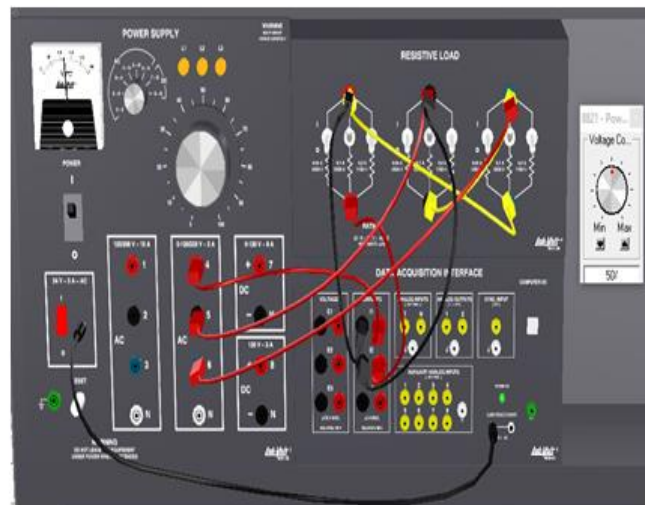
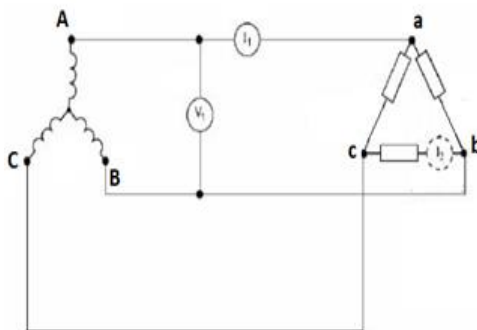


Figure 60 The circuit of 3-phase Y- $\Delta$  connection

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

$$I_L = \sqrt{3}I_{ph} = \sqrt{3} * 0.090 = 0.157A$$

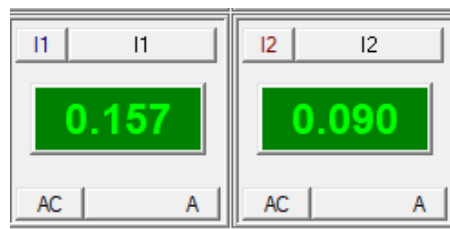


Figure 61 Phase and line currents in Y- $\Delta$  connection

5-Using phasor and oscilloscope window to prove that line currents lags the phase currents by 30 in in abc(+) sequence.

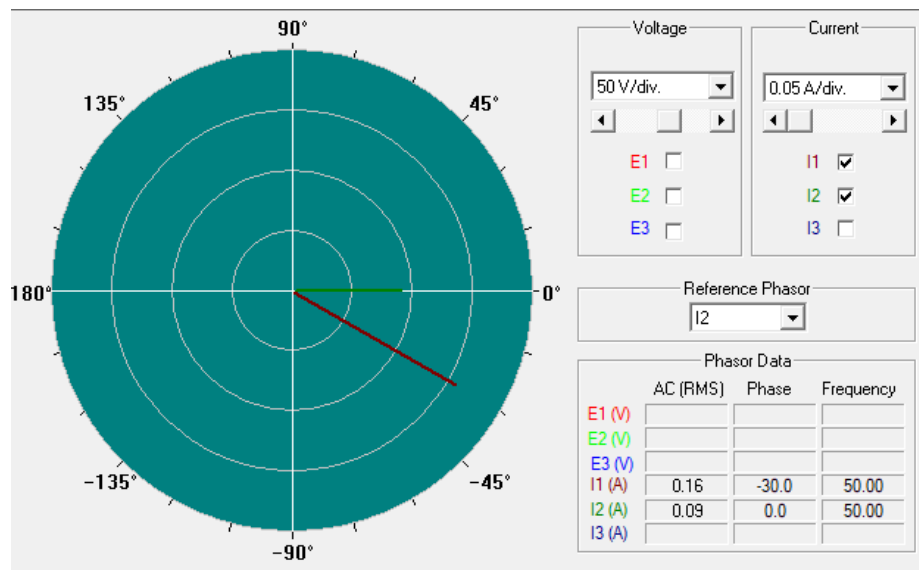


Figure 62 Phasor diagram between phase and line current in Y- Δ connection

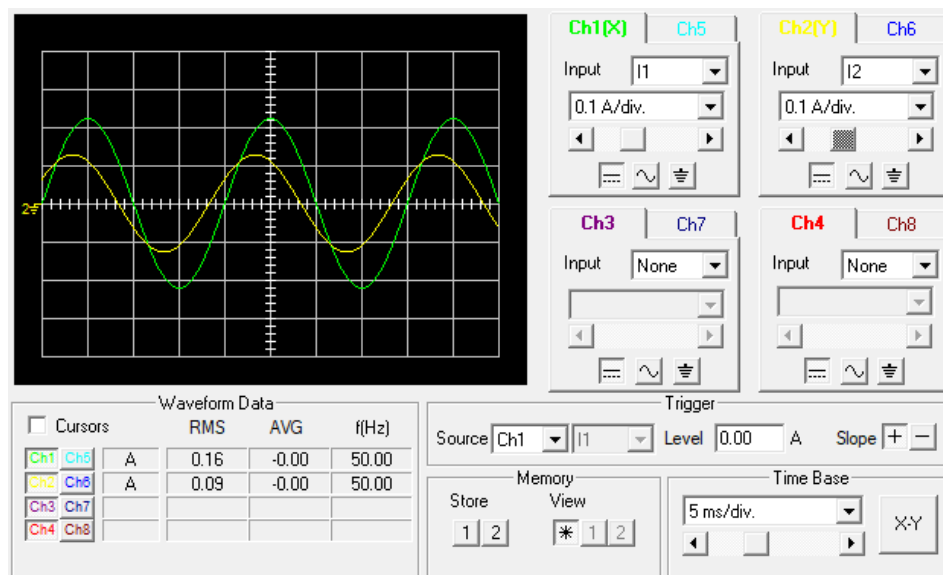


Figure 63 AC signals for phase and line current in Y-Δ connection

 **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- $\Delta$  connection circuit that consist of:  
 $V_L = 50\text{ V}$  ,, Load:  $1100\Omega$  .
- 3- For a  $174\text{ V}$  three-phase Y-Y ideally balanced system , Find mathematically and practically: (Load:  $885\Omega$  )
  - 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  $\Delta$ - $\Delta$  connection and draw phasor diagram using LVVL program.

## Experiment 8

### Filters

#### Objectives:

- To study the filter concept and its functions
- To know and study types of Active Filters
- To be able to design and dealing with Active filters

#### Theory :

Filters are an electric circuit that can control the input signals depending on its frequencies the circuit can allow it to pass or block it. That means any filter has two cases (frequency regions), case for allowing to pass wanted signals and the other for blocking unwanted signals.

Filters can be divided into two distinct types: active filters and passive filters. Active filters contain amplifying devices to increase signal strength while passive do not contain amplifying devices to strengthen the signal. As there are two passive components within a passive filter design the output signal has a smaller amplitude than its corresponding input signal, therefore passive RC filters attenuate the signal and have a gain of less than one, (unity).

Passive filters are made up of passive components such as resistors, capacitors and inductors and have no amplifying elements (transistors, op-amps, etc) so have no signal gain, therefore their output level is always less than the input.

Filters are so named according to the frequency range of signals that they allow to pass through them, while blocking or “attenuating” the rest. The most commonly used filter designs are the:

- **Low Pass Filter** : the low pass filter only allows low frequency signals from 0Hz to its cut-off frequency,  $f_c$  point to pass while blocking those any higher.
- **High Pass Filter** : the high pass filter only allows high frequency signals from its cut-off frequency,  $f_c$  point and higher to infinity to pass through while blocking those any lower.
- **Band Pass Filter** : the band pass filter allows signals falling within a certain frequency band setup between two points to pass through while blocking both the lower and higher frequencies either side of this frequency band.
- **Band Reject(Stop) Filter**: the band reject filter blocking signals falling within a certain frequency band setup between two points to pass through while allow both the lower and higher frequencies either side of this frequency band.

As the function of any filter is to allow signals of a given band of frequencies to pass unaltered while attenuating or weakening all others that are not wanted, we can define the amplitude response characteristics of an ideal filter by using an ideal frequency response curve of the four basic filter types as shown.

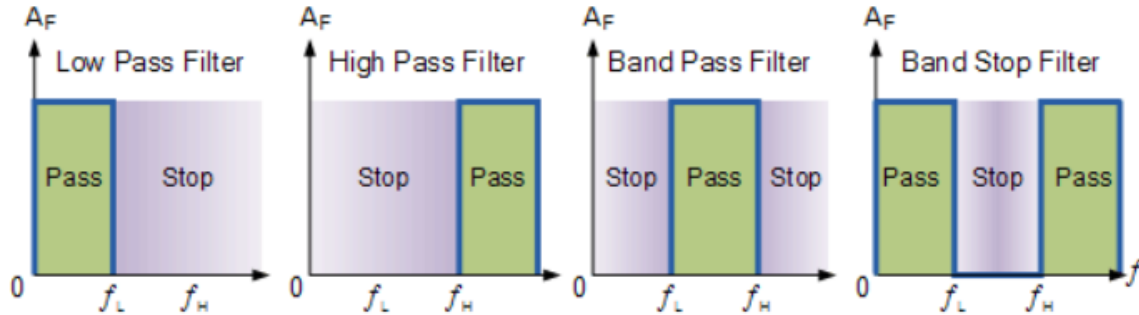


Figure 64 Ideal Filter Response Curves

### ➤ The Low Pass Filter

A Low Pass Filter is a circuit that can be designed to modify, reshape or reject all unwanted high frequencies of an electrical signal and accept or pass only those signals wanted by the circuits designer.

A simple passive RC Low Pass Filter or LPF, can be easily made by connecting together in series a single Resistor with a single Capacitor as shown below. In this type of filter arrangement the input signal (  $V_{in}$  ) is applied to the series combination (both the Resistor and Capacitor together) but the output signal (  $V_{out}$  ) is taken across the capacitor only.

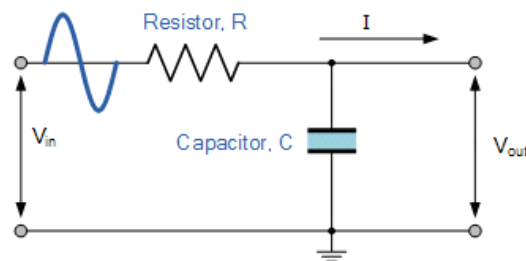


Figure 65 Passive Low Pass Filter

$$X_C = \frac{1}{2\pi fC}$$

$$Z = \sqrt{R^2 + X_C^2}$$

$$V_{out} = V_{in} * \frac{X_C}{\sqrt{R^2 + X_C^2}} = V_{in} \frac{X_C}{Z}$$

$$f_C = \frac{1}{2\pi RC}$$

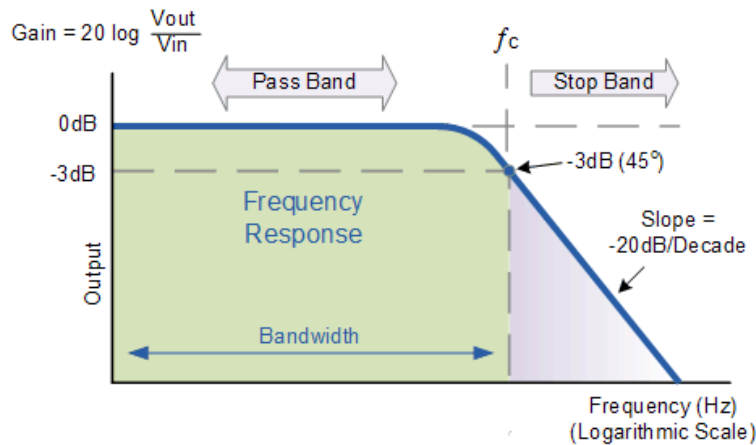


Figure 66 Frequency Response of a 1st-order Low Pass Filter

### ➤ The high Pass Filter

A High Pass Filter is the exact opposite to the low pass filter circuit as the two components have been interchanged with the filters output signal now being taken from across the resistor

In this circuit arrangement, the reactance of the capacitor is very high at low frequencies so the capacitor acts like an open circuit and blocks any input signals at  $V_{in}$  until the cut-off frequency point ( $f_C$ ) is reached. Above this cut-off frequency point the reactance of the capacitor has reduced sufficiently as to now act more like a short circuit allowing all of the input signal to pass directly to the output as shown below in the filters response curve.

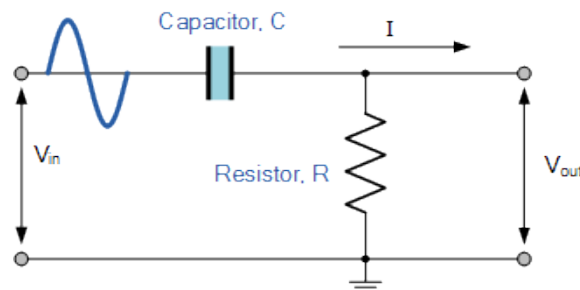


Figure 67 High Pass Filter Circuit

$$A_V = \frac{V_{out}}{V_{in}} = \frac{R}{\sqrt{R^2 + X_C^2}} = \frac{R}{Z}$$

At Low  $f$  :  $X_C \rightarrow \infty$  ,  $V_{out} = 0$

At High  $f$  :  $X_C \rightarrow 0$  ,  $V_{out} = V_{in}$

$$f_c = \frac{1}{2\pi RC}$$

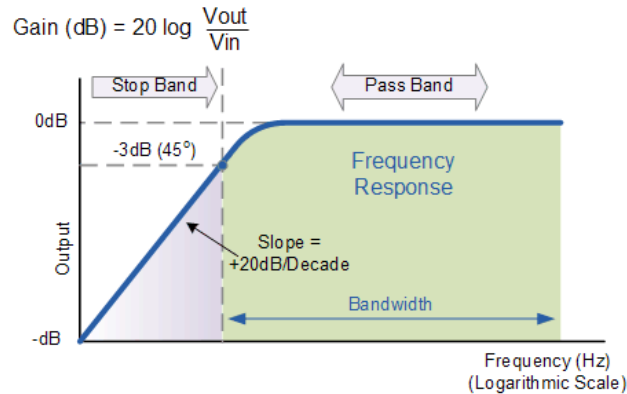


Figure 68 Frequency Response of a 1st Order High Pass Filter

### ➤ Passive Band Pass Filter

Band Pass Filters can be used to isolate or filter out certain frequencies that lie within a particular band or range of frequencies. The cut-off frequency or  $f_c$  point in a simple RC passive filter can be accurately controlled using just a single resistor in series with a non-polarized capacitor, and depending upon which way around they are connected, we have seen that either a Low Pass or a High Pass filter is obtained.

One simple use for these types of passive filters is in audio amplifier applications or circuits such as in loudspeaker crossover filters or pre-amplifier tone controls. Sometimes it is necessary to only pass a certain range of frequencies that do not begin at 0Hz, (DC) or end at some upper high frequency point but are within a certain range or band of frequencies, either narrow or wide.

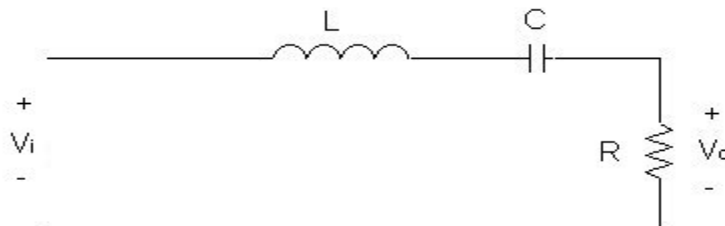


Figure 69 Passive Band Pass Filter

$$\begin{aligned}
 T(j\omega) &= \frac{V_R(j\omega)}{V_S(j\omega)} = \frac{R}{L} \frac{j\omega}{[(j\omega)^2 + (\frac{R}{L})j\omega + \frac{1}{LC}]} \\
 &= \frac{R}{L} \frac{j\omega}{[(\frac{1}{LC} - \omega^2) + (\frac{R}{L})j\omega]} \\
 Z &= \omega L, Z = \frac{1}{\omega C}
 \end{aligned}$$

Hence if the frequency is zero (i.e. D.C.) the impedance of the inductor is zero (i.e. a short circuit) and the impedance of the capacitor is infinite (i.e. an open circuit), this is shown in the circuit below.

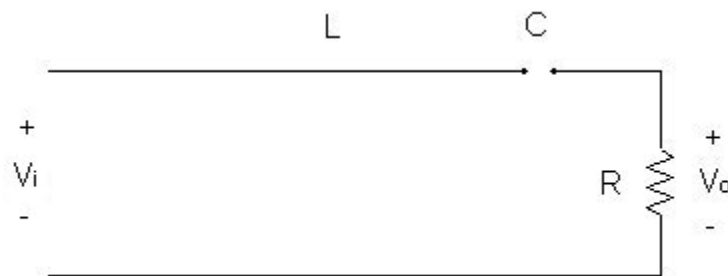


Figure 70 When inductor is short and capacitor is open

Now if the frequency is infinite, the impedance of the inductor is infinite (i.e. an open circuit) and the impedance of the capacitor is zero (i.e. a short circuit), this is shown in the circuit below:

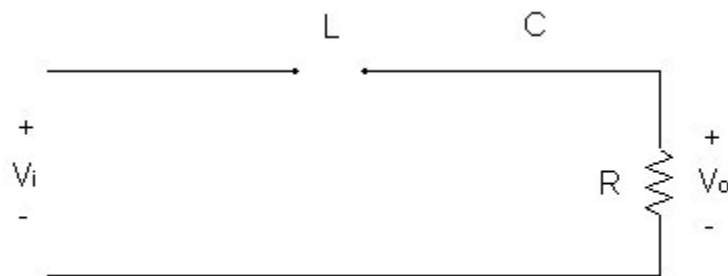


Figure 71 When capacitor is short and inductor is open

- Center Frequency ( $\omega_o$ )

This is the frequency at which the transfer function is at a maximum:

$$\omega_o = \sqrt{\frac{1}{LC}}$$

- Cut off frequency ( $\omega_{C1}, \omega_{C2}$ )

This is the frequency at which the transfer function equals (0.707) of the maximum value:

$$\omega_{C1} = -\frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \left(\frac{1}{LC}\right)}$$

$$\omega_{C2} = \frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \left(\frac{1}{LC}\right)}$$

- Bandwidth ( $\beta$ )

This variable is the width of the pass band. (see graph below):

$$\begin{aligned} \beta &= \omega_{C2} - \omega_{C1} \\ &= \left[ \frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \left(\frac{1}{LC}\right)} \right] - \left[ -\frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \left(\frac{1}{LC}\right)} \right] = \frac{R}{L} \end{aligned}$$

- Quality factor ( $Q$ )

This parameter is the ratio of the center frequency to the bandwidth. This gives a measure of the pass band and can be used to describe the shape of the transfer function graph.

$$Q = \frac{\omega_o}{\beta} = \frac{\sqrt{\frac{1}{LC}}}{\frac{R}{L}} = \sqrt{\frac{L}{CR^2}}$$

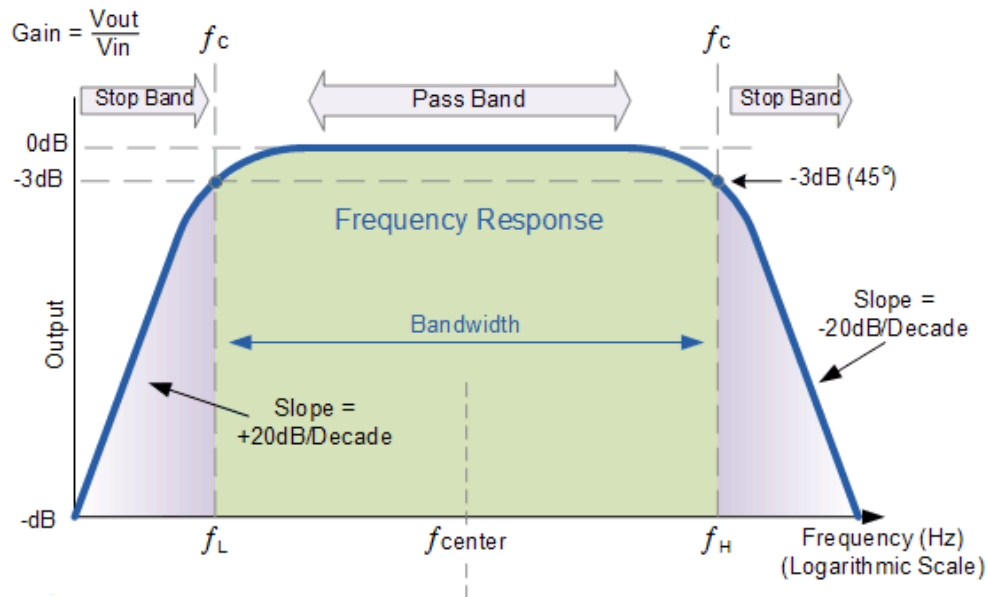


Figure 72 Frequency Response of a Band Pass Filter

### ➤ Band Stop Filter

The Band Stop Filter, (BSF) is another type of frequency selective circuit that functions in exactly the opposite way to the Band Pass Filter we looked at before. The band stop filter, also known as a band reject filter, passes all frequencies with the exception of those within a specified stop band which are greatly attenuated.

If this stop band is very narrow and highly attenuated over a few hertz, then the band stop filter is more commonly referred to as a notch filter, as its frequency response shows that of a deep notch with high selectivity (a steep-side curve) rather than a flattened wider band.

Also, just like the band pass filter, the band stop (band reject or notch) filter is a second-order (two-pole) filter having two cut-off frequencies, commonly known as the -3dB or half-power points producing a wide stop band bandwidth between these two -3dB points.

Then the function of a band stop filter is to pass all those frequencies from zero (DC) up to its first (lower) cut-off frequency point  $f_L$ , and pass all those frequencies above its second (upper) cut-off frequency  $f_H$ , but block or reject all those frequencies in-between. Then the filter's bandwidth, BW is defined as:  $(f_H - f_L)$ .

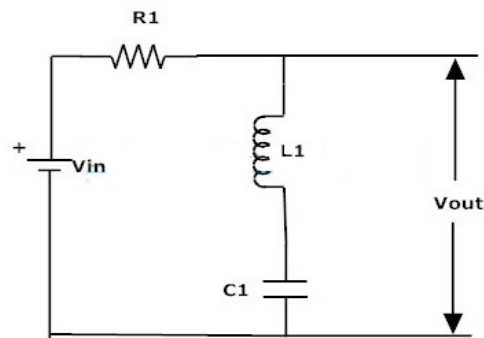


Figure 73 Band Stop Filter

$$H(w) = \frac{j(wL - \frac{1}{wC})}{R + j(wL - \frac{1}{wC})}$$

So for a wide-band band stop filter, the filters actual stop band lies between its lower and upper -3dB points as it attenuates, or rejects any frequency between these two cut-off frequencies. The frequency response curve of an ideal band stop filter is therefore given as:

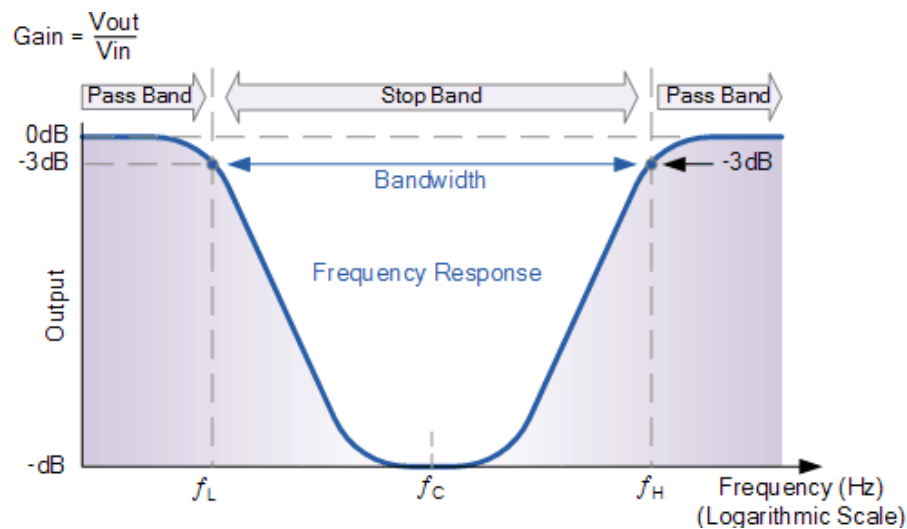


Figure 74 Band Stop Filter Response

## Practical Part:

To Draw frequency response for each type of filter

### Low Pass Filter

Procedures: (R=1K,C=1 $\mu$ ,L=10m)

- 16- Construct the circuit of LPF.
- 17- Adjust the source at max volt.
- 18- Change the frequency as shown in the table.
- 19- In each value measure  $V_{in}$  and  $V_{out}$  then write them down in the table.
- 20- Plot the relation between  $H(w)$  and frequency and determine the cutoff frequency
- 21- Write your comment.

| Frequency(Hz) | $V_{in}$ | $V_{out}$ | $TF=V_{out}/V_{in}$ |
|---------------|----------|-----------|---------------------|
| 30            |          |           |                     |
| 40            |          |           |                     |
| 50            |          |           |                     |
| 100           |          |           |                     |
| 200           |          |           |                     |
| 400           |          |           |                     |
| 600           |          |           |                     |
| 800           |          |           |                     |
| 1000          |          |           |                     |

### High Pass Filter

Procedures: (R=1K,C=1 $\mu$ ,L=10m)

- 1- Construct the circuit of HPF.
- 2- Adjust the source at max volt.
- 3- Change the frequency as shown in the table.
- 4- In each value measure  $V_{in}$  and  $V_{out}$  then write them down in the table.
- 5- Plot the relation between  $H(w)$  and frequency and determine the cutoff frequency
- 6- Write your comment.

| Frequency(Hz) | $V_{in}$ | $V_{out}$ | $TF=V_{out}/V_{in}$ |
|---------------|----------|-----------|---------------------|
| 20            |          |           |                     |
| 40            |          |           |                     |
| 50            |          |           |                     |
| 100           |          |           |                     |
| 200           |          |           |                     |
| 500           |          |           |                     |
| 1000          |          |           |                     |

**Band Pass Filter**Procedures: (R=1K,C=1 $\mu$ ,L=10m)

- 1- Construct the circuit of BPF.
- 2- Adjust the source at max volt.
- 3- Change the frequency as shown in the table.
- 4- In each value measure  $V_{in}$  and  $V_{out}$  then write them down in the table.
- 5- Plot the relation between  $H(w)$  and frequency and determine the cutoff frequency
- 6- Write your comment.

| Frequency(Hz) | $V_{in}$ | $V_{out}$ | $TF=V_{out}/V_{in}$ |
|---------------|----------|-----------|---------------------|
| 3             |          |           |                     |
| 500           |          |           |                     |
| 1000          |          |           |                     |
| 1500          |          |           |                     |
| 2500          |          |           |                     |
| 3000          |          |           |                     |
| 40k           |          |           |                     |

**Band Reject Filter**Procedures: (R=1K,C=1 $\mu$ ,L=10m)

- 1- Construct the circuit of BRF.
- 2- Adjust the source at max volt.
- 3- Change the frequency as shown in the table.
- 4- In each value measure  $V_{in}$  and  $V_{out}$  then write them down in the table.
- 5- Plot the relation between  $H(w)$  and frequency and determine the cutoff frequency
- 6- Write your comment.

| Frequency(Hz) | $V_{in}$ | $V_{out}$ | $TF=V_{out}/V_{in}$ |
|---------------|----------|-----------|---------------------|
| 3             |          |           |                     |
| 500           |          |           |                     |
| 1000          |          |           |                     |
| 1500          |          |           |                     |
| 2000          |          |           |                     |
| 2500          |          |           |                     |
| 3000          |          |           |                     |
| 40k           |          |           |                     |