Ahsanullah University of Science and Technology

Department of Electrical and Electronic Engineering

LABORATORY MANUAL

FOR

ELECTRICAL AND ELECTRONIC SESSIONAL COURSE

Student Name :

Student ID :

Course no : EEE 1202

Course Title : ELECTRICAL CIRCUIT-II LAB

For the students of

Department of Electrical and Electronic Engineering

1st Year, 2nd Semester

Experiment No. 1

FUNDAMENTALS OF AC CIRCUIT - FAMILIARIZATION WITH WAVESHAPE AND MEASUREMENT OF R.M.S. VALUE, FREQUENCY AND PHASE DIFFERENCE.

Part A: Familiarization with alternating current (AC) waves

OBJECTIVE

In this experiment, we will observe voltage waveshapes across different ac circuit elements, such as resistor, inductor and capacitor and establish the relationships between these waveshapes. We will also measure different parameters associated with these wave shapes, such as peak value, peak-to-peak value, r.m.s value, time period, frequency, and phase difference. Finally, we will make a comparison between the theoretical values and the experimental results.

INTRODUCTION

Any periodic variation of current or voltage where the current (or voltage), when measured along any particular direction goes positive as well as negative, is defined to be an AC quantity. Sinusoidal AC wave shapes are the ones where the variation (current or voltage) is a sine function of time.

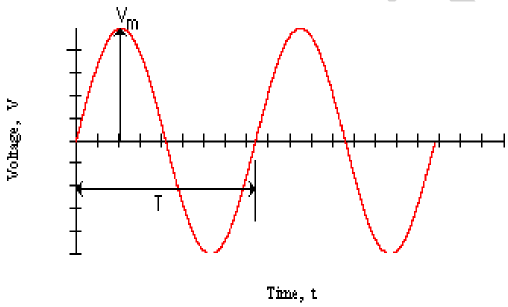


Figure 1: AC voltage waveform

Here, Time period = T, Frequency $f = \dfrac{1}{T}$

$v(t) = V_m \sin(2\pi f.t)$, V_m or V_p = peak value = $\dfrac{V_{p-p}}{2}$

Effective value

The general equation of rms value of any function (voltage, current or any other physical quantity for which rms calculation is meaningful) is given by the equation

$$V = \sqrt{\frac{1}{T}\int_0^T v^2 dt}\ .$$

Now, for sinusoidal functions, using the above equation we get the rms value by dividing the peak value (V_m) by square root of 2. That is

$$V = \sqrt{\frac{1}{T}\int_0^T (V_m \sin(2\pi f.t))^2\, dt}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{2\pi} (V_m \sin\theta)^2\, d\theta} = \frac{V_m}{\sqrt{2}}$$

Similarly, for currents, $I = \dfrac{I_m}{\sqrt{2}}$. These rms values can be used directly for power calculation. The formula for average power is given by $P_{avg} = \dfrac{1}{T}\int_0^T (vi)dt$. And for sinusoids this leads to $P_{avg} = VI\cos(\theta)$. Here, V and I are rms values and θ is the phase angle between voltage wave and current wave. The phase angle is explained in the next section.

Phase Angle

Phase difference between two ac sinusoidal waveforms is the difference in electrical angle between two identical points of the two waves. In figure 2, the voltage and current equations are given as:

$$v = V_m Sin(2\pi f.t)$$

$$i = I_m Sin(2\pi f.t - \theta)$$

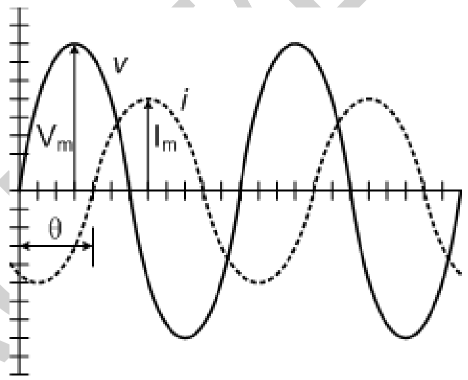


Figure 2: Phase difference between a voltage and a current waveform.

Impedance

For, ac circuit analysis, impedance plays the same role as resistance plays in dc circuit analysis. It, can be stated fairly safely that, the concept of impedance is the most important thing, that makes the ac analysis, so much popular to the engineers. As you will see in your latter courses, any other periodic forms of time varying voltages or currents, are converted into an equivalent series consisting of sines and cosines (much like any function can be expanded by the power series of the independent variable using the Taylor series), only because the analysis of sinusoidal voltages are very much simple due to the impedance technique.

What is the impedance anyway? Putting it simply, it is just the ratio of rms voltage across the device to the rms current through it. That is

$Z = \dfrac{V}{I\angle\theta} = \dfrac{V_m}{I_m\angle\theta}$. Its unit is ohms.

CIRCUIT DIAGRAM

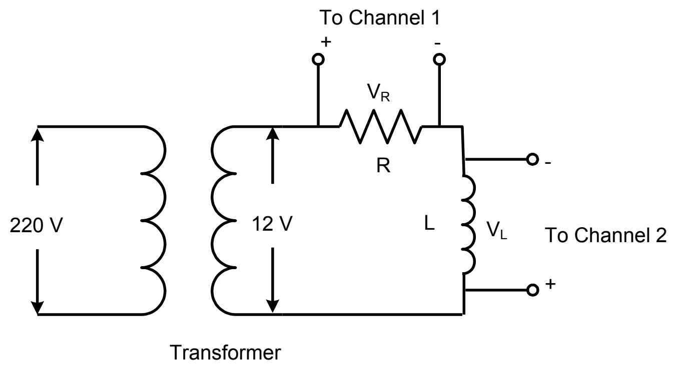


Figure 3: Experimental setup for R-L circuit

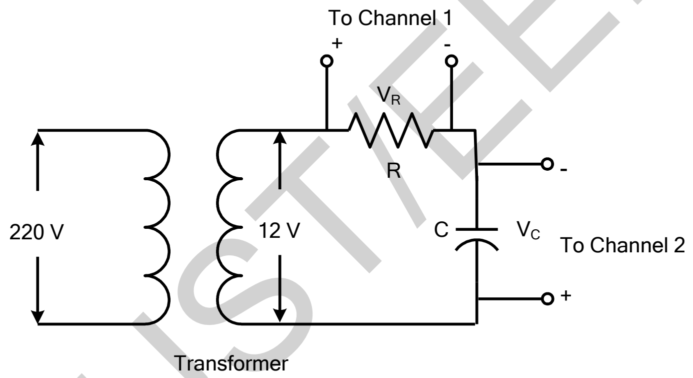


Figure 4: Experimental setup for R-C circuit

APPARATUS

- Dual-beam Oscilloscope
- Digital Multimeter
- Bread Board
- Transformer: 220V/12V - 1 Piece
- Resistor: 100Ω- 1 Piece
- Inductor-1 piece
- Capacitor: 100µF - 1 piece

PROCEDURE

1. Make the circuit connection for the R-L circuit, (Fig.3). Connect the oscilloscope probes properly as shown.
2. Observe the voltage waveshapes obtained in different modes of the oscilloscope. Channel 1 shows the voltage waveform across the resistance (V_R), channel 2 shows the voltage waveform across the inductor (V_L), and dual mode shows the above two waves simultaneously. Note that V_R is in phase with the current flowing in the circuit.
3. Sketch the waveshapes approximately in dual mode on a graph paper. For each waveform, indicate the volts/division and time/division used.
4. Measure the peak-to-peak (p-p) values for both voltage wave shapes. Also measure the time period T and the phase difference Δt (in seconds) between the two voltage wave shapes. Note down the lagging/leading voltage. Record these readings in Table 1.
5. Now calculate the peak and r.m.s. (root mean square) values for both voltage wave shapes. Also calculate the frequency and the phase difference θ (in degrees) between the two waveshapes. . The phase difference θ is given by $\frac{\Delta t}{T} \times 360^0$ degree, where Δt is the time delay between the two waves.
6. Measure the r.m.s voltages by multimeter. Compare the results with that obtained from the oscilloscope.
   <u>**Note:**</u> When in ac mode, the multimeter gives the r.m.s. value of the voltage being measured, and when in dc mode, it shows the dc or average value (taken over a complete cycle) of the measured voltage. The above ac voltages are purely sinusoidal and have no dc value; you should verity it by measuring the voltages by a multimeter set in the dc mode.
7. Measure the input voltage with multimeter with AC voltage mode. The ratio between the voltage to the current gives the magnitude of the impedance Z.
8. Make connections for the R-C circuit shown in Fig. 4 and repeat steps 2 to 7 for the R-C circuit. Record the readings in Table 2.

Table 1 Data for R-L circuit

p-p Values		Peak Values		r.m.s. values				T	f	Phase Difference		
				From peak values		From Multimeter				Δt	θ	Lagging / Leading Voltage
V_R	V_L	V_R	V_L	V_R	V_L	V_R	V_L				In deg	

Table 2 Data for R-C circuit

p-p Values		Peak Values		r.m.s. values				T	f	Phase Difference		
				From peak values		From Multimeter				Δt	θ	Lagging / Leading Voltage
V_R	V_C	V_R	V_C	V_R	V_C	V_R	V_C				In deg	

REPORT

1. Sketch neat diagrams of different waveshapes on graph paper for both the R-L and R-C circuits.
2. What will happen if the oscilloscope probes of Fig.3 are connected as shown in Fig.6? Explain.

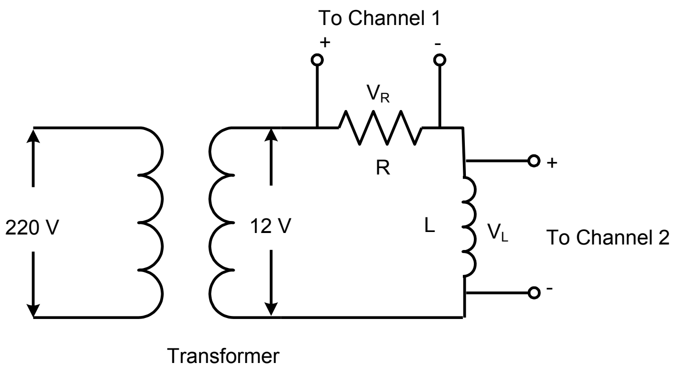


Figure 6

3. To correct the circuit of Fig. 6, the probes arc connected as shown in Fig.3 (with the ground probes at the same node). In this case, we do not obtain the actual waveshapes. Why? What measure should he taken in the oscilloscope to obtain the actual wave shapes?

4. Calculate the magnitude and phase angle of the circuit impedance from the readings taken in step 5, 6 and 7.

5. Can the oscilloscope be used directly to observe current waveshapes?

Part B: Verification of KVL and KCL in AC Circuits

OBJECTIVE

The objective of this experiment is to study RLC series and series parallel circuits when energized by an ac source and to construct phasor diagrams. KVL and KCL in phasor form will also be verified.

APPARATUS

1. Multimeter
2. Ac ammeter
3. Rheostat / Lamp board (2)
4. Capacitor board (one)
5. Switches : SPST (3)
6. Inductor board (1)

CIRCUIT DIAGRAM

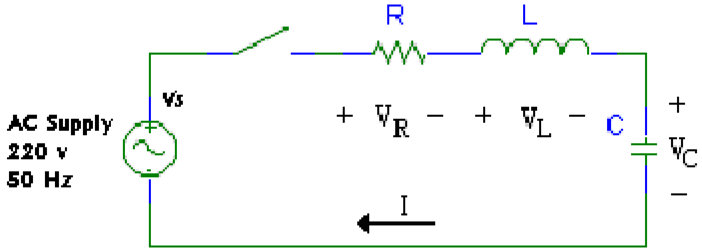


Figure 1 :

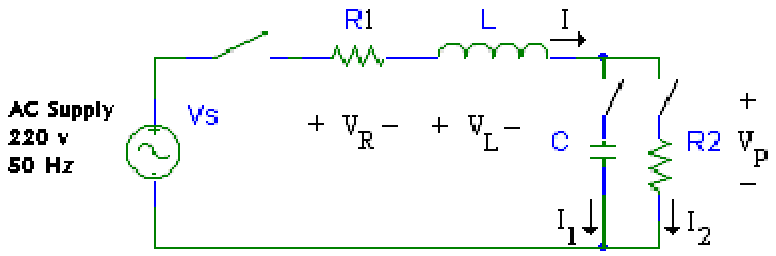


Figure 2 :

PROCEDURE

1. Construct the circuit as shown in Figure 1.
2. Measure the voltage V_R , V_L and V_C and the current I with the help of ac meters.
3. Change the magnitude of R and C and repeat step 2.
4. Construct the circuit of Figure 2.
5. Measure the voltage V_R, V_L and V_P and the currents I , I_1 and I_2.
6. Change the magnitude of R1 and C and repeat step 5.

REPORT

1. Determine the magnitude of circuit components (R, L, C) used in the experiment.
2. Comment on the relative magnitudes of I , I_1 and I_2 in the circuit of Figure 2.
3. Assuming the circuit elements to be ideal, draw the phasor diagram for both the circuits using the experimental data. The diagrams should be drawn to scale on graph paper. Choose I as the reference for figure 1 and I_1 as the reference for figure 2.
4. From the phasor diagrams, express the voltages and the currents as phasors and compare those with the values calculated in step 1. Comment on the observed discrepancies between these.
5. Show that the voltage and the current phasors obtained for figure 1 and 2 satisfies KCL and KVL.

Experiment No. 2

MEASUREMENT OF POWER AND POWER FACTOR CORRECTION

Part A: AC Power measurement using wattmeter

OBJECTIVE

The objective of this experiment is to learn the use of wattmeter for measuring power in ac circuits.

APPARATUS

1. Lamp board (2)
2. Capacitor bank (1)
3. Multimeter (1)
4. AC ammeter (1)
5. Wattmeter (1)
6. SPST switches (3)

Circuit Diagram

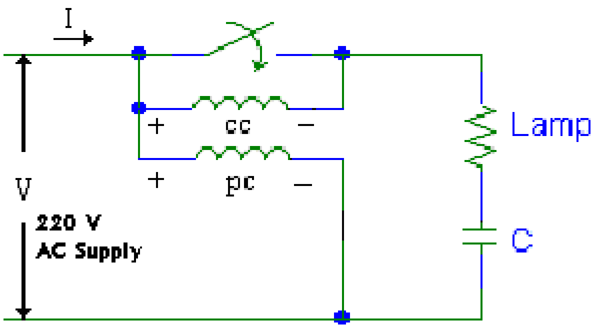


Figure 1:

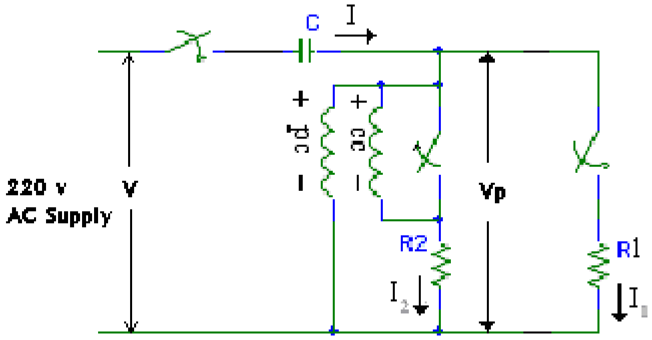


Figure 2:

PROCEDURE

1. Connect the circuit in Figure 1 without the wattmeter. Measure V and I.
2. Connect the wattmeter as shown and measure the power W.
3. Put the potential coil of the wattmeter across the lamp-board. Measure the power W′.
4. Repeat steps 2, 3 for a different combination of lamp and capacitance.
5. Connect the circuit in Fig. 2 without the wattmeter. Measure V, I, I_1 , I_2 and Vp.
6. Connect the wattmeter to measure the total power (W) into the circuit.

7. Connect wattmeter to measure power consumption (W_1 and W_2 respectively) in the two parallel branches.

REPORT

1. Compare/relate the wattmeter readings (W and W′ or W, W_1 and W_2) for both circuits. Give your comments.
2. Use your results to find out of individual circuit components and also the power factors of each circuit.
3. Compare the values of W obtained in step 8 with those obtained in step 2 and 6.

Part B: Power factor correction

INTRODUCTION

In all manufacturing plant (large or small) power factor is usually low and lagging (due to usage of induction motors). This low power factor causes extra line loss which is not registered at consumers meter. For this reason power system authority penalizes the consumer if power is consumed below a certain power factor (normally if less than 0.85). So it is the consumer’s duty to improve the power factor. Lagging power factor (usually industrial loads are lagging) is improved by adding capacitors parallel to the load. In this experiment we shall study how power factor can be corrected by varying the parallel capacitance.

EQUIPMENT

1. One rheostat (120Ω)
2. Decade capacitor box
3. Decade inductance box
4. Oscilloscope
5. Ammeter
6. Signal generator

CIRCUIT DIAGRAM

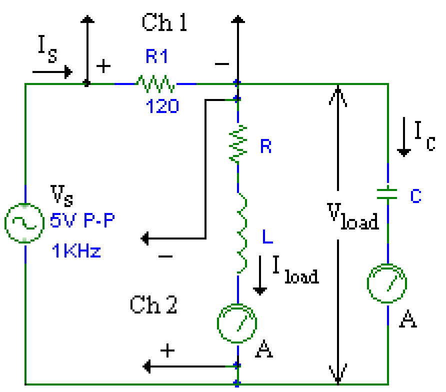


Figure 1:

PROCEDURE

1. Complete the RL circuit by setting R = 500Ω resistance and L = 100mH inductance. Keep capacitance at zero.

2. Connect channel 1 and channel 2 of the oscilloscope, as shown in the diagram. **Remember to connect the grounds of both oscilloscope probes to the same point and to pull the inverter knob of channel 2.**

3. With capacitance zero, observe the wave shapes in both channels separately and in dual mode. Measure the value of current I_s (by dividing the voltage of channel 1 by the value of 120 Ω resistor) and voltage V_{load}, and phase difference between V_{load} and I_s. *Also* note which wave leads.

4. Set the capacitor to 10nF. Then repeat measurements of step 3. Also measure currents I_{load} and I_c from the ammeter.

5. Increase the capacitance gradually until unity pf between V_{load} and I_s is obtained.

6. Continue to increase the capacitance gradually until a leading pf of about 45 degree is obtained. Repeat all measurements in each step.

REPORT

1. Plot the pf vs. C curve and show the capacitance for which the f is unity.
2. Draw the vector diagram for 45° lag, unity and 45° lead pf.
3. Sketch the wave shapes of V_{load} and I_s for the three cases mentioned above.
4. Discuss the overall system performance, power absorbed without and with pf correction.

Experiment No. 3

STUDY OF RESONANCE BEHAVIOUR OF A SERIES RLC CIRCUIT WITH VARIABLE CAPACITANCE

INTRODUCTION

Resonance is a particular situation that may occur in an electric circuit containing both inductive and capacitive elements. In a series RLC circuit this resonance occurs when,

Inductive Impedance = Capacitive Impedance

=> $X_L = X_C$

=> $2\pi f L = 1 / 2\pi f C$……………………………………………………………………(Equation 1)

At resonant condition for a series circuit the following should be observed :

1. The resultant impedance of the circuit is purely resistive in nature :
   $Z_T = R + j (X_L - X_C) = R + j . 0 = R$
2. Since the impedance is minimum the current in the series circuit will be maximum and given as :
   $I_{max} = V_S / R$
3. The circuit yields an unity power factor since the impedance is purely resistive
4. The average power absorbed by the circuit is maximum at this resonance ; $P_{max} = I_{max}{}^2 R$

How can resonance be achieved?

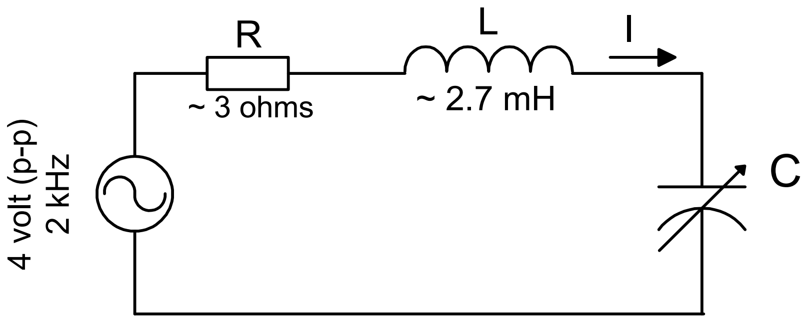
We can obtain the resonance situation by satisfying equation 1 for the series RLC circuit. Our options are to vary any of the three parameters – L,C or f or any combination of them. In this experiment we shall try to achieve resonance point by varying 'C' keeping 'L' and 'f' constant.

Practical Considerations to be taken for the experiment :

- Practical inductor has some resistance of its own. So make sure that this resistance R_L doesn't hamper your calculation significantly.
- It is always better to predict or calculate the probable resonant point in advance using the formula $C = 1 / (4 \pi 2 f L)$.
- Due to loading effect the amplitude of the source voltage changes when we use different capacitors. So one should check the amplitude every time a new capacitor is used and make adjustment if necessary. Remember that we should keep same amplitude value throughout the experiment.
- Since at resonance point the circuit current is maximum , the watt dissipation of the resistor R must be checked against its wattage rating. It should be applicable also for the inductor current rating. Besides, the signal generator we are using must be capable of delivering the maximum current.
- In a series circuit containing R,L and C the voltage across the C can raise beyond the supply voltage. So other circuit equipment those are subjected to V_C must be able to withstand that voltage.
- When measuring the phase angle between voltage and current we should check the connection of the oscilloscope probes carefully. Each of the black crocodile clip represents the ground of respective oscilloscope channel. But inside the oscilloscope these two grounds are shorted. So when we use

both the probes there is a great chance that we short-circuit some parts of the circuit. We should always avoid this situation.

CIRCUIT DIAGRAM



APPARATUS

1. Resistance : 2.2 Ω (or any in the range of 2 ~ 4 Ω) ………………1 *pc*
2. Inductor : 2.7 mH (typical resistance 8 Ω)………………………..1 *pc*
3. Capacitor : 0.1uf (104K), 0.22uf, 1uf, 2.2uf, 4.7uf, 10uf………………1 *pc* each

4. Oscilloscope
5. Oscilloscope Probe ……………………………………………………2 *pc*
6. Signal Generator ………………………………………………………1 *pc*
7. Signal Generator Probe ……………………………………………….1 *pc*
8. Multi-meter ……………………………………………………………1 *pc*
9. Bread Board ……………………………………………………………1 *pc*
10. Wires for connection

PROCEDURE

<u>Step : 1</u>

Measure and note the following values :

R = R_L = L =

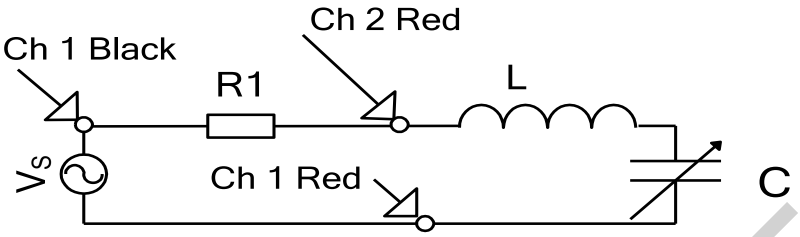
<u>Step : 2</u>
Setup the circuit with C = 0.1 μf

<u>Step : 3</u>
Adjust the signal generator at 4 volt (p-p) & 2 kHz (*f*).
Calculate the value of C for which resonance is expected : $C = 1 / (4 \pi^2 f L)$ =

Step : 4

Measure / Determine the following quantities and fill up the table below :

1. Find I : Measure V_R using multi-meter in AC voltage mode. Then $I = V_R / R$.
2. Measure V_L & V_C using multi-meter.
3. Measure the phase difference θ between Vs and I using Oscilloscope in dual mode (connect the oscilloscope probes as shown below). Note down the relative lag/lead position of the voltage and current wave.



Step : 5
Repeat step 4 for each of the capacitors.
Note : Adjust the amplitude of source each time to 4 volt (p-p).

Table :

No	C (µf)	V_R (mV)	I (mA)	V_L (volt)	V_C (volt)	θ (deg.)	Power Factor	Lag/Lead
1	0.1							
2	0.22							
3	1.0							
4	1.5 (2.2 + 4.7)							
5	2.2							
6	3.2 (4.7+ 10)							
7	4.7							
8	6.9 (4.7 ‖ 2.2)							
9	10							

REPORT

Plot the following curves:

1. I versus C
2. P.f. versus C
3. V_L and V_C versus C

- Plot #1
  1. Maximum Current Value I_{max} =
  2. Resonance Point C =
  3. Mark the resonance point in the graph.

- Plot #2
  1. Mark the resonance point in the graph.
  2. Mark the lagging p.f. region on the graph.
  3. Mark the leading p.f region graph.

- Plot #3
  1. Mark resonance point on the graph.
  2. Observe the peak of V_L & V_C with respect to resonance point.
  3. Note that $(V_C)_{max}$ > supply voltage.

- Draw the vector diagram at resonance.

Experiment No. 4

STUDY OF RESONANCE BEHAVIOUR OF A PARALLEL RLC CIRCUIT WITH VARIABLE CAPACITANCE.

INTRODUCTION

Resonance is a particular situation that occurs in an electric circuit when the resultant impedance is resistive. For the parallel RLC circuit, resonance occurs when susceptance of the inductive branch is equal to the susceptance of the capacitive branch, i.e.

$$b_L = b_C$$

In this experiment, we will vary C to obtain the resonance condition.

At resonant condition for a parallel circuit the following should be observed:

1. The resultant impedance of the circuit is purely resistive in nature and is maximum. Since the impedance is maximum the current from the source is minimum at resonance.
2. The circuit yields unity power factor since the impedance is purely resistive.

CIRCUIT DIAGRAM

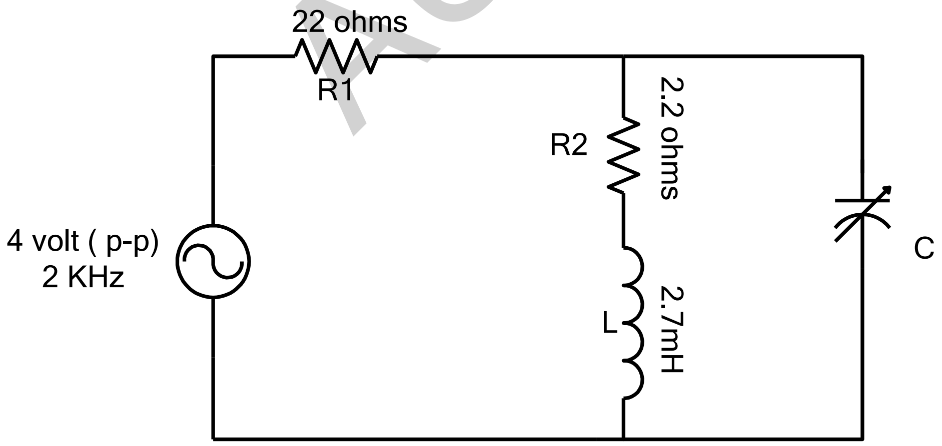


Figure 1

APPARATUS

1. Resistance : 2.2 Ω , 22 Ω ……………………………………………1 *pc* each
2. Inductor : 2.7 mH (typical resistance 8 Ω)………………………..1 *pc*
3. Capacitor : 0.1uf (104K), 0.22uf, 1uf, 2.2uf, 4.7uf, 10uf….…………1 *pc* each

4. Oscilloscope
5. Oscilloscope Probe ………………………………………………….2 *pc*
6. Signal Generator ………………..……………………………..…..1 *pc*
7. Signal Generator Probe ………………………………………………1 *pc*
8. Multi-meter ………………………………………………………….1 *pc*
9. Bread Board ………………………………………………………….1 *pc*
10. Wires for connection

PROCEDURE

Step : 1

Measure and note the following values :

R_1 = ______ R_2 = ______ R_L = ______ L = ______

Step : 2

Setup the circuit with C = 0.1 μf

Step : 3

Adjust the signal generator at 4 volt (p-p) & 2 kHz (*f*).

Step : 4

Measure / determine the following quantities and fill up the table below:

1. Find I : Measure V_{R1} ,V_{R2} using multi-meter in AC voltage mode. Then $I = V_{R1} / R1$ & $I_L = V_{R2} / R2$.
2. Measure V_L & V_C using multi-meter. Then $I_C = V_C / X_C$; $X_C = 1/2\pi fC$.
3. Measure the phase angle θ of the current wave using Oscilloscope in dual mode (connect the oscilloscope probes as shown below). Note down the relative lag/lead position of the voltage and current wave.

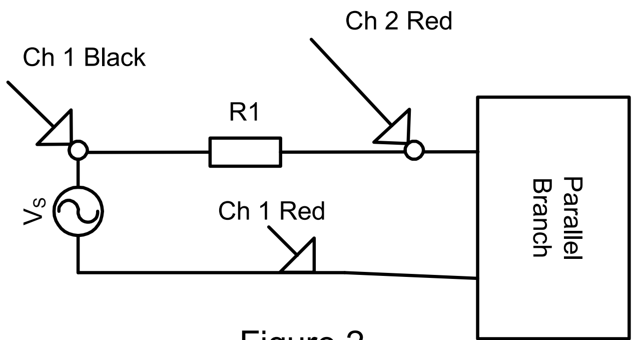


Figure 2

Step : 5

Repeat step 4 for each of the capacitors.

Note : Adjust the amplitude of source each time to 4 volt (p-p).

Table :

C (µf)	V_{R1} (mV)	I (mA)	V_{R2} (mV)	I_L (mA)	V_L (volt)	V_C (volt)	I_C (mA)	θ deg	*Pf*	Lag / Lead
0.1										
0.22										
1.0										
1.5 (2.2 + 4.7)										
2.2										
3.2 (4.7+ 10)										
4.7										
6.9 (4.7 ‖ 2.2)										
10										

REPORT

- Plot the following curves :

  a. Plot # 1 I vs. C

  1. Minimum Current Value I_{min} =
  2. Resonance Point C = $\boxed{}$
  3. Mark the resonance point in the graph.

  b. Plot # 2 power factor vs. C

  1. Mark the resonance point in the graph.
  2. Resonance Point C = $\boxed{}$
  3. Mark the lagging p.f. region on the graph.
  4. Mark the leading p.f region graph.

- Draw the vector diagram of all currents at resonance.

Experiment No. 5

STUDY OF RC FILTER CHARACTERISTICS

INTRODUCTION

Many electrical circuits contain filters, which separate electric signals on the basis of their frequency contents. Filters are characterized by their frequency response as well as phase relation between input and output signals. In this experiment we will study low pass, high pass and band pass filters.

THEORY

An ideal low pass filter passes all signals below a certain frequency which is termed as the *cutoff frequency* for that filter. In other words the output signal amplitude will be zero if we feed the filter with an input signal that has frequency greater than its cutoff frequency. For signals with lower frequency the output signal amplitude will remain unaffected. This is true only for 'ideal filter' and the frequency response curve for ideal filter looks like Fig 1 (a). But for a practical filter the amplitude near the cutoff does not change instantly rather it follows a decreasing nature as shown in Fig 1 (b).Thus for a practical filter we need to define cutoff frequency in different way. Some of the definitions for cutoff frequencies are given below:

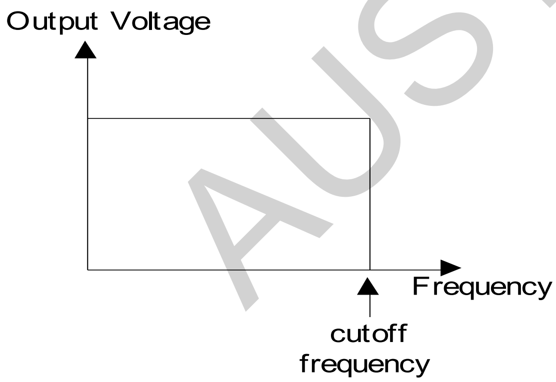


FIg 1. (a) : Ideal Low pass Filter

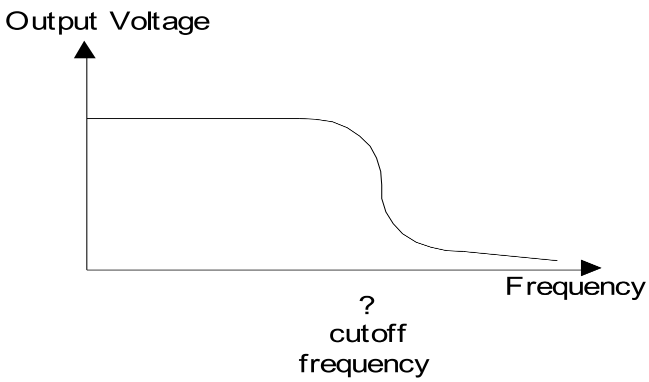


FIg 1. (b) : Practical Low pass Filter

<u>What is cutoff frequency ?</u>

1. When our frequency response curve is given in terms of 'voltage vs. frequency' :

   "cutoff frequency is the point at which the voltage level of the signal falls "1 / √2 or 0.707" times from its maximum value provided that the input signal amplitude remains same for all frequencies."

2. When our frequency response curve is given in terms of ‘signal power vs. frequency’ :

> “cutoff frequency is the point at which the power level of the signal falls “1/2 or 0.5” times from its maximum value.”

3. When our frequency response curve is given in terms of ‘gain vs. frequency’ :

> “cutoff frequency is the point at which the gain of the signal falls “1 / √2 or 0.707” times from its maximum value.”

4. When our frequency response curve is given in terms of ‘gain(in db) vs. frequency’ :

> “cutoff frequency is the point at which the gain(in db) of the signal falls “-3db” from its maximum value.”

A simple first order RC low pass filter is shown in figure 2. Gain of this filter is given by:

$$A_v = \frac{V_o}{V_i} = \frac{1}{j\omega C(R + j\omega C)}$$

where ω_C is the corner or cutoff frequency . For our low pass filter, cut off frequency, $\omega_C = \frac{1}{RC}$.

An ideal high pass filter – blocks all signals below its cutoff frequency but passes all signals above cut off with no attenuation. A simple first order RC high pass filter is shown in figure 3. The gain of this filter is:

$$A_v = \frac{R}{(R + j\omega C)}$$

And its corner frequency ω_C is also $\frac{1}{RC}$. Figure 4 shows a second order band pass filter, which is designed to pass all signals whose frequency lie within a specific band. Therefore it has two cutoff frequencies ω_{CL} below which the filter blocks signals and ω_{CH} above which it again blocks signals. Thus the filter has a pass band between these two frequencies and the frequency ω_O is the mid band frequency where the gain is maximum. The gain of this filter is given by

$$A_v = \frac{\frac{1}{j\omega R_1 C_1}}{1 + \frac{1}{j\omega}\left(\frac{1}{R_1 C_1} + \frac{1}{R_2 C_2} + \frac{1}{R_1 C_2}\right) + \frac{R_1 C_1 R_2 C_2}{(j\omega)^2}}$$

CIRCUIT DIAGRAM

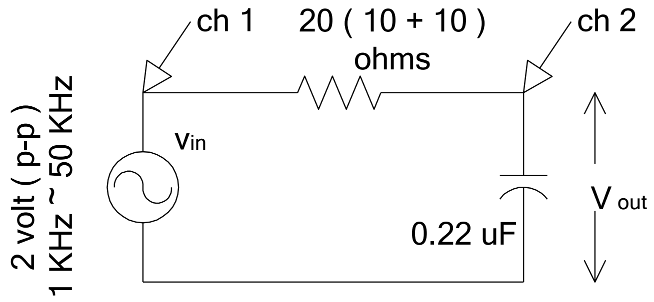


Figure 2 : RC Lowpass Filter

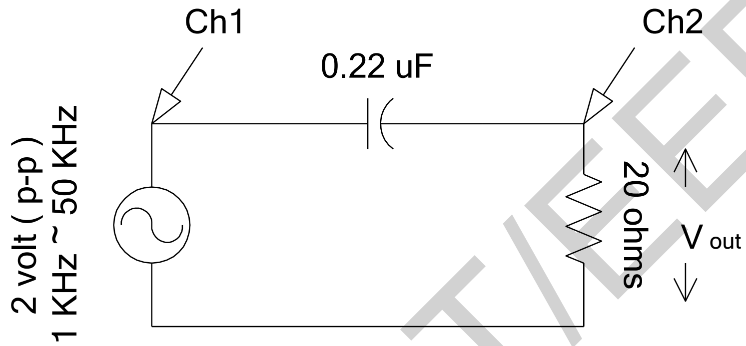


Figure 3: RC High pass Filter

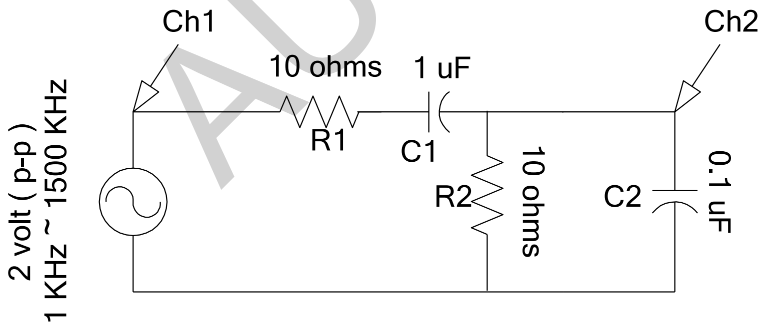


Figure 4 : RC Bandpass Filter

APPARATUS

1. Resistance : 10 Ω ……………………2 *pc*
2. Capacitor : 0.22uf ……………………1 *pc*
   0.1 uf ……………………1 *pc*
   1uf ……………………1 *pc*
   2.2 uf ……………………1 *pc*
3. Oscilloscope
4. Oscilloscope Probe ……………………………………………2 *pc*
5. Signal Generator ……………………………………………1 *pc*
6. Signal Generator Probe ……………………………………………1 *pc*
7. Multi-meter ……………………………………………1 *pc*
8. Bread Board ……………………………………………1 *pc*
9. Wires for connection

PROCEDURE

1. Construct the circuit of figure 2. Connect V_{in} to channel 1 and V_{out} to channel 2 of the oscilloscope.

Adjust the signal generator to 2 volt (p-p) & 100 Hz.

2. Measure V_{in} , V_{out} and phase difference between them using oscilloscope and fill up the table .Repeat for each of the frequencies shown in the table.

***Note* :** Adjust the amplitude of source (channel 1) each time to 2 volt (p-p).

Table : 1

Frequency, *f* (Hz)	Output Voltage, V_{out}	Gain , V_{out} / V_{in}	Phase difference, θ
50 (20ms)			
333 (3ms)			
500 (2ms)			
1000 (1ms)			
5000 (0.2ms)			
20000 (50 us)			
33333 (30 us)			
50000 (20 us)			
100000 (10 us)			

V_o lags V_{in} or V_o leads V_{in}

3. Now construct the circuit of figure 3 and repeat steps 1 and 2 and fill up table 2.

Table 2:

Frequency, *f* (Hz)	Output Voltage, V_{out}	Gain , V_{out} / V_{in}	Phase difference, θ
10000 (0.1ms)			
20000 (50 us)			
40000 (25 us)			
50000 (20 us)			
66666 (15 us)			
400000 (2.5 us)			
666666 (1.5 us)			
1000000 (1 us)			

V_o lags V_{in} or V_o leads V_{in}

4. Now construct the circuit of figure 4 and repeat steps 1 and 2 and fill up table 3.

Table 3:

Frequency, *f* (Hz)	Output Voltage, V_{out}	Gain , V_{out} / V_{in}	Gain in dB, 20 log $_{10}$ (V_{out} / V_{in})
1000 (1ms)			
3333 (0.3 ms)			
8000 (125 us)			
16666 (60 us)			
25000 (40 us)			
50000 (20 us)			
100000 (10 us)			
166666 (6 us)			
250000 (4 us)			
500000 (2 us)			

V_o lags V_{in} or V_o leads V_{in}

REPORT

1. Determine the theoretical corner frequencies of filter 1, 2 and 3 and also the frequency ω_o, at which the gain of filter 4 is maximum.
2. Plot the gain, A_V vs frequency curves for the three filters on separate sheets. Use semi-logarithm graph paper. For the bandpass filter plot the gain (in dB) vs. frequency.
3. Determine the cut-off frequencies from the graphs and compare these with the theoretical values.
4. For filters 1 and 2, plot the phase difference vs. frequency on semi-log graph paper and determine the cut-off frequency.

Experiment No. 6

STUDY OF A 3-Φ SYSTEM WITH BALANCED LOAD

THEORY

A three phase system can be viewed as a combination of three individual sin wave sources those are separated 120 degree in electrical phase. Our distribution system is of this kind where 3 wires are dedicated to three individual phases and the fourth one is the neutral. As for most of the appliances we use single phase 220 volt supply which is in fact one of the three phases those come from distribution lines. We call it the 'phase voltage' or 'line to neutral voltage'. Such a system is schematically drawn in the following figure together with the phasor diagram:

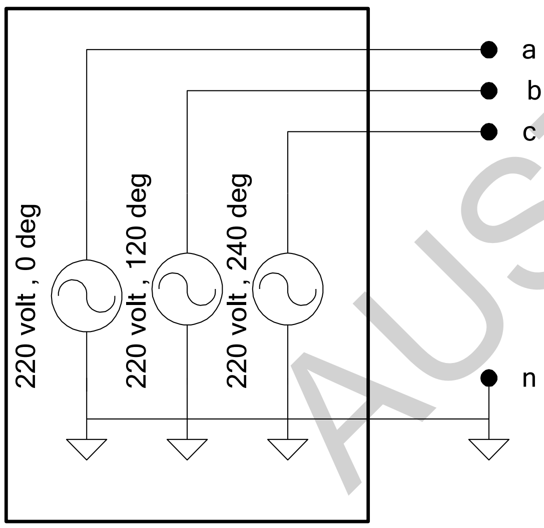


Figure : A 3 - phase system

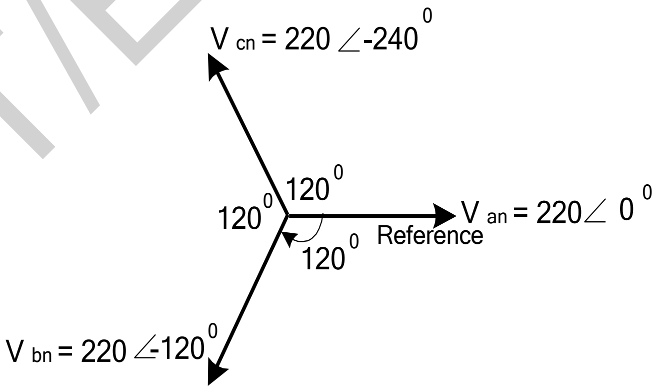


Figure : Phasor diagram of 3-phase system

Three phase system is also represented by the 'line-to-line voltage'. Consider the above system (with sequence 'a-b-c') . The line to line voltage V_{ab} can be expressed as :

$$V_{ab} = V_{an} + V_{nb} = V_{an} - V_{bn} \text{ ………………………………………. Eq. 1}$$

Here , the quantities should be treated as vector. As shown in the following figure the summation of 'V_{an}' and '$-V_{bn}$' gives 'V_{ab}'. Now it should be observed that 'V_{ab}' makes an angle of 30 degree with 'V_{an}' and its magnitude is $\sqrt{3}\,|V_{an}|$. In similar way we can determine the other two line-to-line voltages V_{bc} and V_{ca} . These three line to line voltages are also 120 degree separated. Thus we can define 3 phase system by line to line voltages and chose one of them as reference. The second figure shows the relation of phase and line-to-line quantities taking V_{ab} as reference. Using this representation we can restate the sequence as 'ab-bc-ca'.

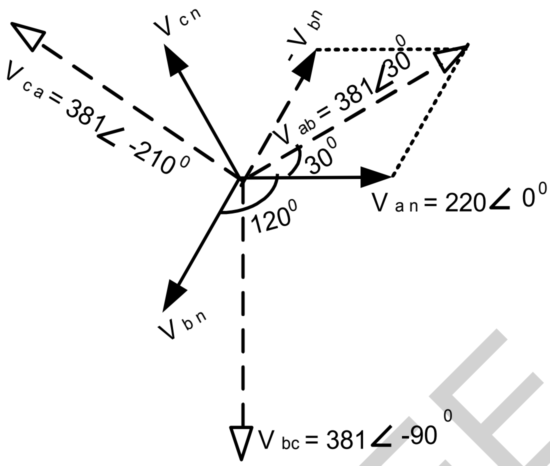


Figure: Line and phase voltages for a-b-c sequence.

Balanced Y- connected and Δ - connected load :

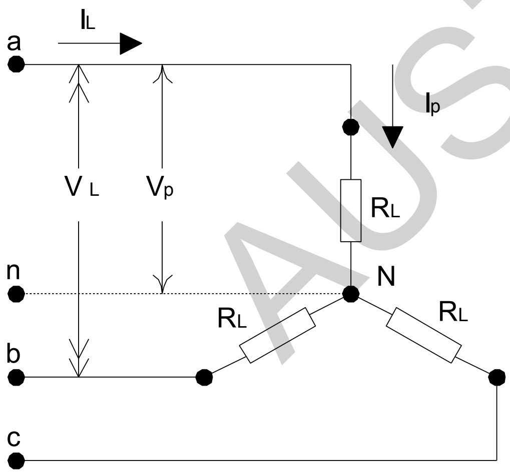


Fig. Balanced Y- connected Load

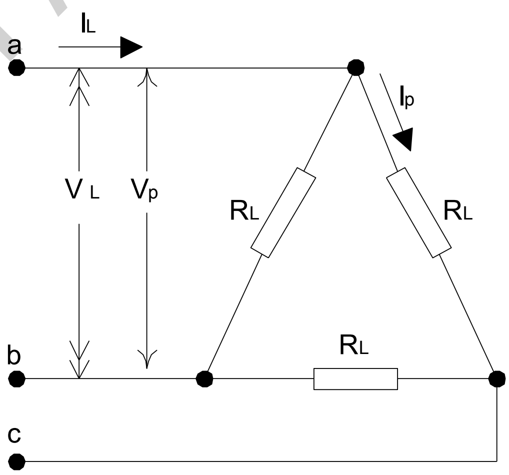


Fig. Balanced △- connected load

Here each of the loads R_L are equal. So the system is balanced.

The following are true for a balanced Y- connected load :

- Each of the loads are subjected to equal phase voltages ; generally 220 volt . The quantities differ only by phase angle.

- The vector summation of line-to-line voltages are zero :

  $V_{ab} + V_{bc} + V_{ca} = 0$
- The vector summation of the phase currents are zero :
  $I_{an} + I_{bn} + I_{cn} = 0$
  This implies that their should be no current flow from node 'n' and 'N'. So for a balanced system there is no need to use the neutral wire.

- The relation between the phase and line quantities are :

  Line current , I_L = phase current , I_P
  Line-to-Line voltage $V_L = \sqrt{3}\, V_P$

The following are true for a balanced Δ- connected load :

- Each of the loads are subjected to equal line-to-line voltages ; generally 381 volt . The quantities differ only by phase angle.

- The vector summation of line-to-line voltages are zero :
  $V_{ab} + V_{bc} + V_{ca} = 0$

- The vector summation of the phase currents are zero :
  $I_{ab} + I_{bc} + I_{ca} = 0$

- The relation between the phase and line quantities are :

  Line current , $I_L = \sqrt{3}$ x phase current = $\sqrt{3}\, I_P$
  Line-to-Line voltage V_L = phase voltage = V_P

Objective of our experiment :

We shall construct a balanced system consisting of Y connected load and Δ connected load . Then we shall measure the line and phase quantities in both cases. We shall verify the above theoretical facts with our findings. In this experiment we shall consider only for resistive loads.

APPARATUS

1. Lamp Holder : ……………………………………………...……………6 *pc*
2. Bulb : 60 Watt ……………………… . ……………………..3 *pc*
   100 Watt ……………………… . ……………………..3 *pc*
3. Oscilloscope ….. …………………..…………………………………..….1 *pc*
4. Oscilloscope Probe ……………………………………………………….. 2 *pc*
5. Multi-meter ………………………………………………………………1 *pc*
6. Wires for connection
7. Power Supply Cord ………………………………………………………..1 *pc*

PROCEDURE

Step : 1

Connect the bulbs (60 Watt) in Y- connection as shown in the following figure :

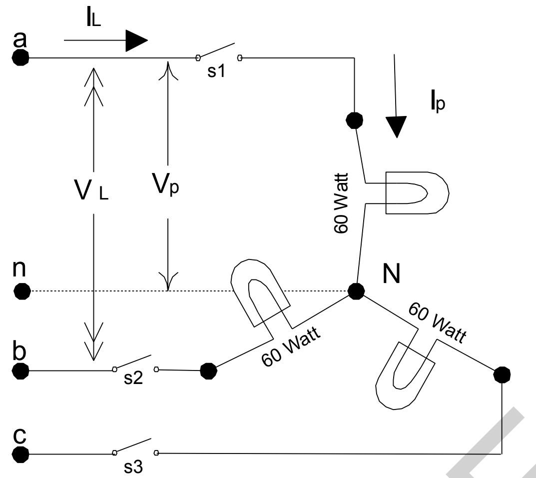


Fig. Balanced Y- connected Load

Measure and note the following values :

Line to Line Voltages : V_{ab} = ……………. , V_{bc} = ……………… , V_{ca} = …………………

Line to Neutral Voltages : V_{an} = ……………. , V_{bn} = ……………… , V_{cn} = …………………

Phase Currents : I_{an} = ……………. , I_{bn} = ……………… , I_{cn} = …………………

Step : 2

Connect the bulbs (60 Watt + 100 Watt) in Δ - connection as shown in the following figure :

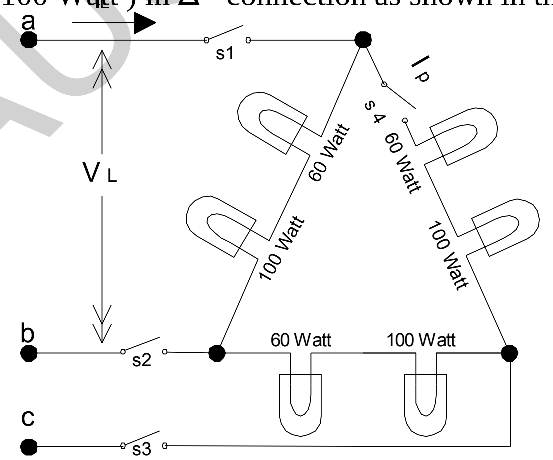


Fig. Balanced delta connected Load

Measure and note the following values :

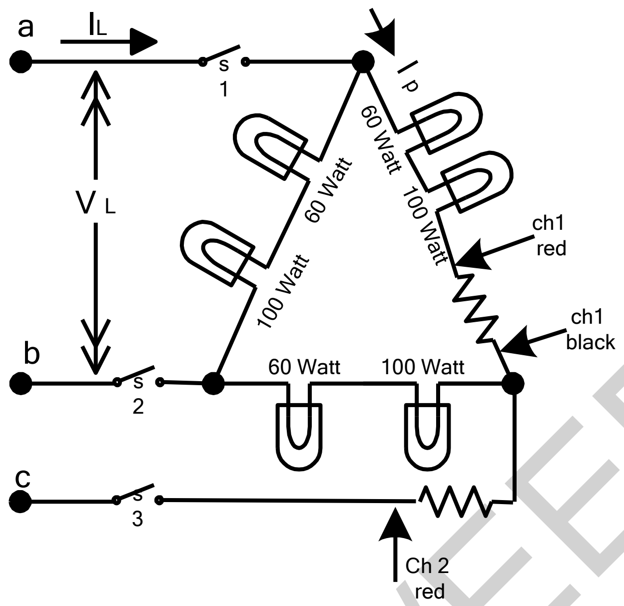
Line to Line Voltages : V_{ab} = ……………. , V_{bc} = ……………… , V_{ca} = …………………

Line Currents : I_a = ……………. , I_b = ……………… , I_c = …………………

Phase Currents : I_{ab} = ……………. , I_{bc} = ……………… , I_{ca} = …………………

Step : 3

Connect the bulbs (60 Watt + 100 Watt) in Δ - connection as shown in the following figure. In one of the branches connect a rheostat (100 ohms ; Set its resistance to 1~3 ohms) as shown.



Observe the wave shapes of I_L and I_p . Take measurement of their phase difference: Which wave is lagging ?

REPORT

1. From data found in Step 1 & Step 2, draw the phasor diagrams showing the relations between phase and line quantities for Y- and Δ-load.

2. For a Balanced Y connected load the neutral wire usually not been used . --- why ?

Experiment No. 7

DETERMINATION OF PHASE SEQUENCE OF A 3-Φ SYSTEM

THEORY

A three phase system can be viewed as a combination of three individual sin wave sources those are separated 120 degree in electrical phase. Such a system is schematically drawn in the following figure :

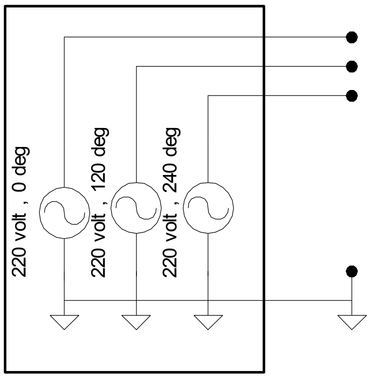


Fig : A 3 - phase system

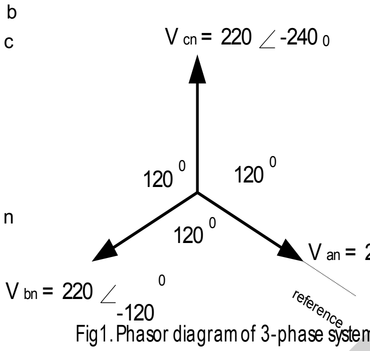


Fig1. Phasor diagram of 3-phase system ('a-b-c') sequence

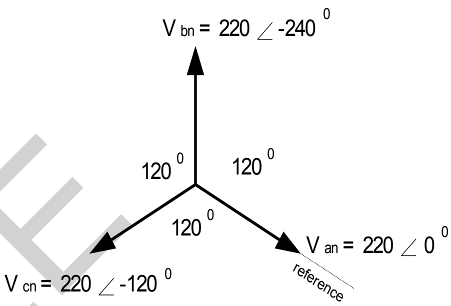


Fig2. Phasor diagram of 3-phase system ('a-c-b') sequence

As from the consumer side we see the four wires only. For our advantage we mark the three phase wires as 'a' , 'b' and 'c' (or sometimes as 'R' , 'Y' and 'B') and the neutral wire as 'n'. We take one of the wires as reference phase and then find the phases of the other two wires with respect to it. In the above 'Fig:1' we take phase 'a' as our reference. As shown in the figure phase 'b' leads phase 'a' by 120 deg and phase 'c' leads phase 'b' by another 120 degree. This sequence is called 'sequence a-b-c' . For three phase system another sequence is possible that is 'sequence a-c-b'. It that case, phase 'c' leads phase 'a' by 120 deg and phase 'b' leads phase 'c' by another 120 degree. The sequence is shown in 'Fig:2'.

Three phase system is also represented by the 'line-to-line voltage'. These three line to line voltages are also 120 degree separated. Using this representation we can restate the sequence 'a-b-c' as 'ab-bc-ca' and 'a-c-b' as 'ab-ca-bc'. The phasor diagram for these two sequences are shown below :

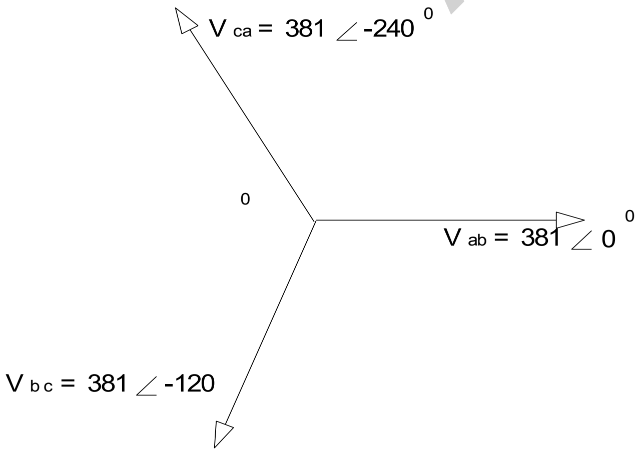


Fig: 4 Line to Line voltages for 'ab-bc-ca' sequence

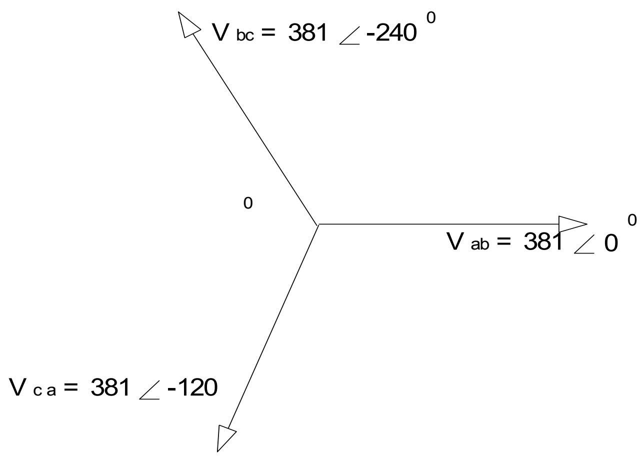


Fig:3 Line to Line voltages for 'ab-ca-bc' sequence

As mentioned earlier, from the consumer side we see the four wires only. For some 3 phase loads we need to know the phases sequences before we connect it to the supply. Taking one of the wires as reference we need to know which of the other two wires leads 120 degree from the reference wire
(or which of the other two wires lags 240 degree from the reference wire). If we mark the reference wire as ‘a’ and find the wire that matches this criterion and mark this wire as ‘b’ and the remaining wire as ‘c’ then we say that we are working with ‘a-b-c’ sequence. It should be observed that when we say about a sequence as ‘a-b-c’ or ‘a-c-b’ we are referring to the three wires that we have already marked. Without this marking the phrase ‘a-b-c sequence’ bears no meaning.

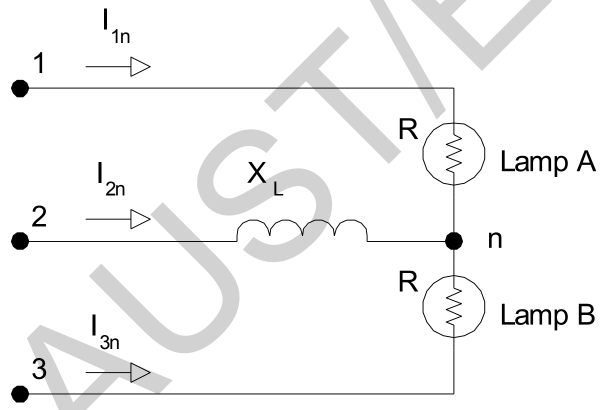
Objective of our experiment :

We are given the three wires of a 3-phase system with neutral connection. We have no idea about the phase sequence of the three wires. We want to mark the three wires as ‘a’ , ‘b’ and ‘c’ so that they represent ‘a-b-c’ sequence (or we may want to mark the three wires as ‘a’, ‘b’ and ‘c’ so that they represent ‘a-c-b’ sequence) .

Methods of determining Phase Sequence :

Method 1 :

Let us connect an unbalanced load to the three wires as show in the figure :



Now it can be shown that the voltage across the Lamp A is equal to ,

$$V_{Lamp\ A} = Z_{1n} \cdot \frac{V_{12}(Z_{1n} + Z_{3n}) + V_{23}Z_{2n}}{Z_{1n}(Z_{2n} + Z_{3n}) + Z_{3n}.Z_{2n}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{eq4}$$

The voltage across the Lamp B is ,

$$V_{Lamp\ B} = V_{31} + Z_{1n}.I_{1n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{eq5}$$

Here Z’s are the impedances of respective phases. For our cases ,

$Z_{1n} = R_1$, the resistance of the bulb connected to line ‘a’

$Z_{3n} = R_2$, the resistance of the bulb connected to line ‘c’

$Z_{2n} = R_L + j\,X_L$, R_L the inductor resistance and X_L reactance of the inductor .
Now, *let us assume* that according to the wire marks, *'1-2-3' represents the 'a-b-c' sequence*. Therefore line to line voltages are,

$V_{12} = V \angle 0^o$ $V_{23} = V \angle -120^o$ $V_{31} = V \angle -240^o$

where 'V' is the rms value of the line to line voltages. If we calculate the voltage across 'Lamp A' and 'Lamp B' using equations 4 and 5 then we find that ,

$$V_{\text{Lamp B}} < V_{\text{Lamp A}} \quad \text{……eq 6}$$

Thus, Lamp A will glow brighter than Lamp B.

But if we had assumed that '1-2-3' represented the 'a-c-b' sequence then our voltage references would be,
$V_{12} = V \angle 0^o$ $V_{23} = V \angle -240^o$ $V_{31} = V \angle -120^o$

Then we would find that,

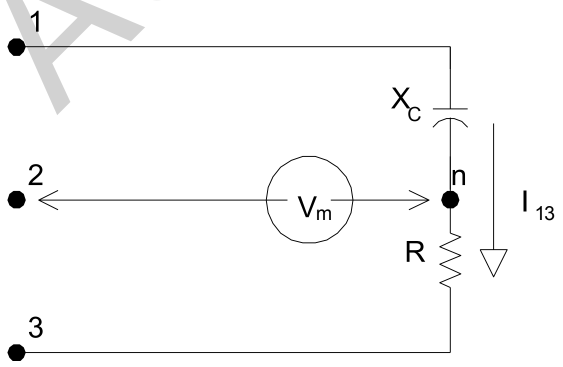
$$V_{\text{Lamp B}} > V_{\text{Lamp A}} \quad \text{……eq 7}$$

In this case Lamp B would glow brighter than Lamp A.

In practice we first arbitrarily mark the three wires as '1' , '2' and '3'. Then we will connect the lamps and the inductor according to the figure. The lamp which glows brighter must be connected to line 'a' the other is connected to 'c' and the middle wire to 'b'. Thus we can mark the three wires as 'a', 'b' and 'c' that will give us the sequence of 'a-b-c'. After determining this sequence of the supply we could either connect a load in 'a-b-c' sequence or in 'a-c-b' sequence as necessary.

Method 2 :

Let us connect an unbalanced load to the three wires as show in the figure :



For this setup it can be shown that , for 'a-b-c' sequence ,

$V_m >$ line-to-line voltage

And for 'a-c-b' sequence ,

$V_m <$ line-to-line voltage

This result can be realized from the phasor diagram shown below :

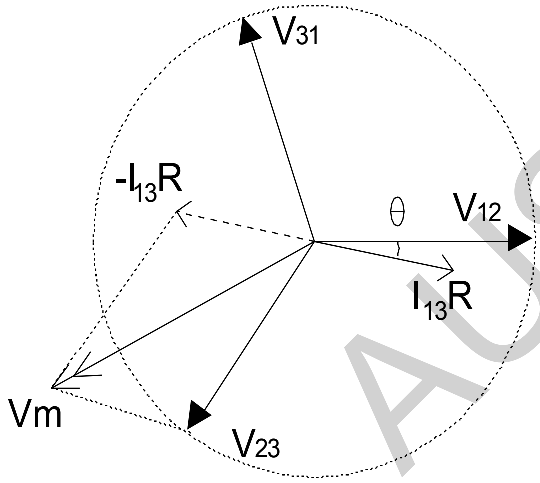
$Z_T = R - j\,X_C$; R = the resistance used in phase connected to line '3'
X_C = impedance of the capacitor connected to line '1'

$$I_{13} = \frac{V_{13}}{Z_T} = \frac{-V_{31}}{R - j\,X_C} = |\,I\,| \angle \theta \quad \text{……eq 8}$$

$$V_m = V_{23} - I_{13}.\,R \quad \text{……eq 9}$$

<u>For 'a-b-c' sequence :</u>

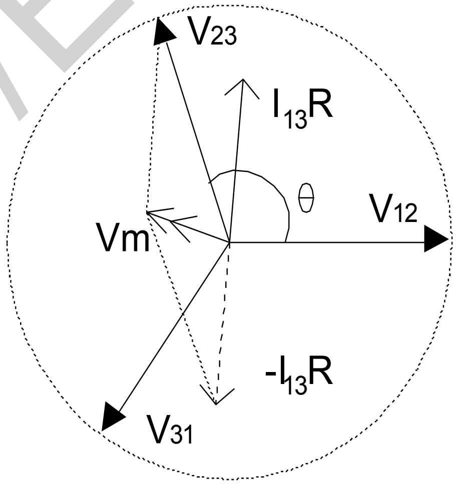
$V_{12} = V \angle 0^{o}$
$V_{23} = V \angle -120^{o}$
$V_{31} = V \angle -240^{o}$



Vm > Line-to-Line voltage

<u>For 'a-c-b' sequence :</u>

$V_{12} = V \angle 0^{o}$
$V_{23} = V \angle -240^{o}$
$V_{31} = V \angle -120^{o}$



Vm < Line-to-Line voltage

Therefore this setup can also be used for determining phase sequence.

EQUIPMENT

1. Lamp Holder : ………………………………………...……………2 *pc*
2. Bulb : 60 Watt …………………… . ………………………2 *pc*
3. Rheostat : 500 ohms (3 Amp.) ……………………………… 1 *pc*
4. Inductor : Ballast ……………………………………………… 1 *pc*
5. Capacitor : 3.4uF , 380 V (fan / motor capacitor) ……………… 1 *pc*
6. SPST switch : ……………………………………………………… .3 *pc*

7. Multi-meter ……………………………………………………… 1 *pc*

8. Wires for connection
9. 3 phase supply cord ……………………………………………… .3 *pc*

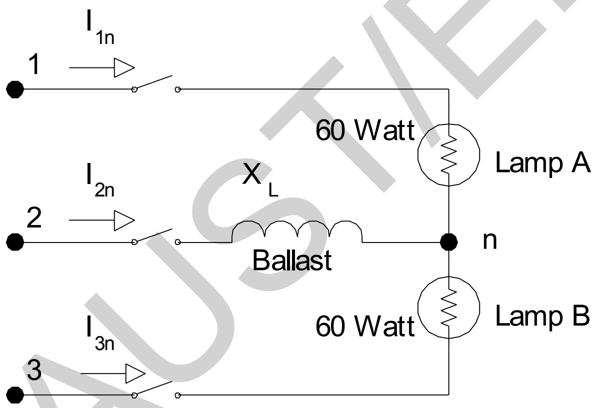
PROCEDURE

<u>Step : 1</u>

First mark the three wires arbitrarily by the notations '1' , '2' and '3'.

<u>Step : 2</u>

Setup the equipments according to the following figure :



Take the following readings :

R_L =					
V_{12} =		V_{23} =		V_{31} =	
V_{1n} =		V_{2n} =		V_{3n} =	
I_{1n} =		I_{2n} =		I_{3n} =	

Note which Lamp glows brighter ?

Calculate the following :

$Z_{1n} = R_1 = V_{1n} / I_{1n} =$ [ ]

$Z_{3n} = R_2 = V_{3n} / I_{3n} =$ [ ]

$Z_{2n} = R_L + j X_L = Z_T \angle\theta = (V_{2n} / I_{2n}) \angle (\tan^{-1} X_L / R_L) =$ [ ]

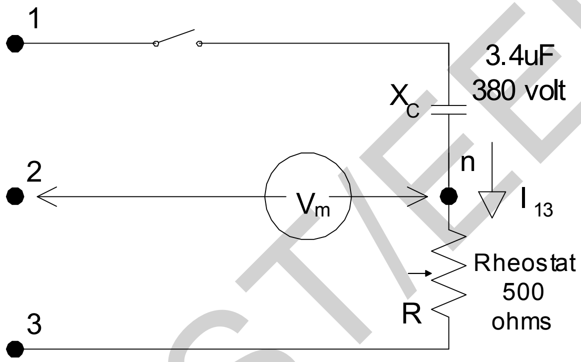
Step : 3

Now interchange the wires at the phases '1' and '3'.

Note which Lamp glows brighter ? [ ]

Step : 4

Adjust the rheostat to its full resistance range and measure its value. Setup the equipments according to the following figure :



Take the following readings :

$R =$ [ ]

$V_{12} =$ [ ] $V_{23} =$ [ ] $V_{31} =$ [ ]

$V_{1n} =$ [ ] $V_m =$ [ ] $V_{3n} =$ [ ]

$I_{1n} =$ [ ]

Note whether the voltage V_m is greater than line voltage or not ? [ ]

Calculate the followings :

$Z_T = R - j X_C =$ [ ] $= Z \angle\theta =$ [ ]

Step : 5

Now interchange the wires at the phases ‘1’ and ‘3’.
Take the following readings :

V_{1n} = [ ] V_m = [ ] V_{3n} = [ ]

I_{1n} = [ ]

Note whether the voltage V_m is greater than line voltage or not ? [ ]

REPORT

1. From data obtained form step 2 calculate the voltage across the Lamps ‘A’ and ‘B’ (use equation 4 and 5). Check your results against the phase sequence found.

2. Using the data found in step 4 and step 5, draw the phasor diagrams for the voltmeter method for both squences.

N.B Discharge capacitor after you switch of the supply by proper method.

Experiment No. 8

MEASUREMENT OF THREE-PHASE POWER BY TWO WATTMETER METHOD

THEORY

The power delivered to a three-phase, three-wire Δ- or Y-connected balanced or unbalanced load can be found by using only two wattmeters if the proper connection is used and if the wattmeter readings are interpreted properly. The basic connection of this two-wattmeter method is shown in the figure below. One end of each potential coil is connected to the same line. The current coils are then placed in the remaining lines.

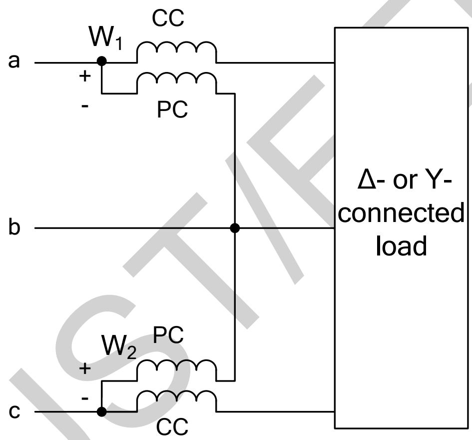


Figure: Two-wattmeter method for Δ- or Y-connected load.

The total power delivered to the load is the algebraic sum of the two wattmeter readings. For a balanced load, we will consider two methods for determining whether the total power is the sum or the difference of the two wattmeter readings.

Method 1:

Open line a. Then all power must be transferred to the load over lines b and c. If the wattmeter W_2 is connected so that it reads "upscale" (i.e. has a positive deflection), it will then be known to have this deflection when the power it reads is going to the load. Next, reconnect line a and open line b. Then connect W_1 so that it reads upscale. Now close line b. If at any time after this, either wattmeter needle shows downscale deflection, power through this wattmeter is of opposite sign to that registered by the other. Either the potential or the current coil will have to be reversed to get an upscale reading.

Method 2:

Connect both wattmeters so that each shows a positive reading. Disconnect the common potential point of the potential coil of the wattmeter which has the smaller reading and connect it to the line containing the current coil of the other wattmeter. If the needle shows downward deflection, the wattmeter reading was negative.

APPARATUS

1. One multimeter.
2. AC ammeter- 1 pc.
3. Wattmeter-2 pc.
4. Lamp 60 W– 3 pc.
5. Inductor (Ballast)- 3 pc.
6. Wires for connection
7. 3 phase supply cord

CIRCUIT DIAGRAM

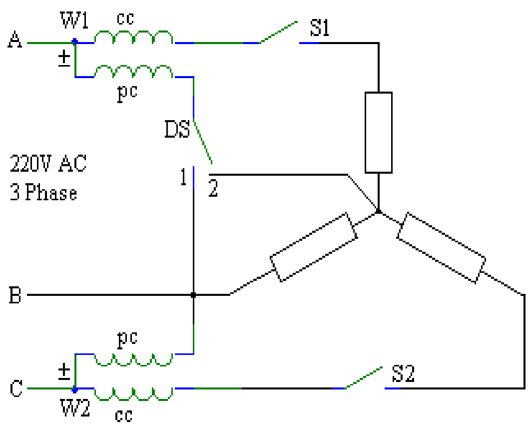


Figure 1: Wye Connected Load

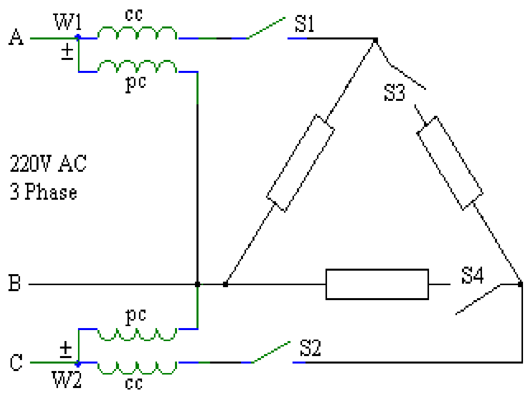


Figure 2: Delta Connection Load

Procedure

1. Connect the lamp in the balanced Wye as shown in figure 1. Make sure the same number of lamps are turned on in each phase.
2. Connect both wattmeters to read upscale. Note readings W_1 ,W_2. Determine whether the total power is the sum or the difference of the two wattmeter readings.
3. Measure the line and phase voltage as well as line current.

Data

Wye Connection

W_1	W_2	$W_T = W_1 \pm W_2$

V_{ab} = ☐ V_{bc} = ☐ V_{ca} = ☐

V_{an} = ☐ V_{bn} = ☐ V_{cn} = ☐

I_a = ☐ I_b = ☐ I_c = ☐

Phase powers:

Pa = ☐

Pb = ☐

Pc = ☐

P_T = Pa+ Pb+ Pc

4. Connect the lamps and the ballasts in balanced delta as shown in figure 2 and repeat steps 2 and 3.

Data

Delta Connection

W_1	W_2	$W_T = W_1 \pm W_2$

V_{ab} = ☐ V_{bc} = ☐ V_{ca} = ☐

I_{ab} = ☐ I_{bc} = ☐ I_{ca} = ☐

I_a = ☐ I_b = ☐ I_c = ☐

Phase powers:

Pa = ☐

Pb = ☐

Pc = ☐ P_T = Pa+ Pb+ Pc

REPORT

1. Theoretically prove that the sum of the two-wattmeter readings gives total three phase real power. Verify with your experimental data for both connections.
2. Draw the complete vector diagram to scale showing the vectors that determine W_1 and W_2.
3. Calculate and compare the power factor of the load as determined from the two wattmeter.
4. Find the total reactive power for both connections.

Experiment No. 9

DETERMINATION OF THE MUTUAL INDUCTANCE OF TWO MAGNETICALLY COUPLED CIRCUITS

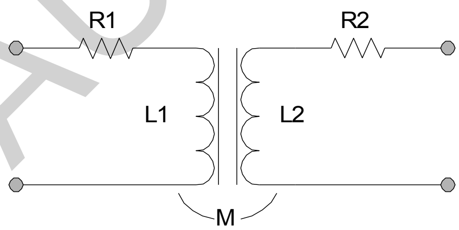
THEORY

When the magnetic flux produced in one circuit links a second circuit, the two circuits are magnetically coupled. The mutual inductance between two circuits determines the coupling between the two circuits and the energy that can be transferred from one circuit to the other. This technique is used in transformers where the primary and secondary coils form the two circuits and the flux produced by one of them is magnetically linked via core material to the other circuit. Thus energy can be transferred from one circuit to the other via magnetic field produced in the core.

Objective of our experiment:

We will use a center tapped transformer to carry out our experiment. As shown in the figure the transformer has self inductances L_1 and L_2 and mutual inductance M between the coils. Moreover both the coils have finite resistances ; R_1 and R_2. We shall try to determine L_1, L_2 and M and co-efficient of coupling 'k' using the formula :

$$k = \frac{M}{\sqrt{(L_1 L_2)}} \quad \text{..........Eq. 1}$$



Methods of finding L_1 (of HT side)and M_{12} :
Let us assume that we use the following setup :

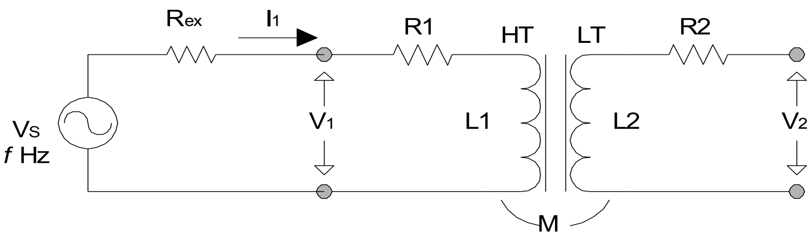


Fig : Primary energized with a source keeping secondary open

From the above circuit we can write ,

$V_1 = I_1 R_1 + j \omega L_1 I_1$ ……………………………………………………………….Eq. 2

and, $V_2 = j \omega M_{12} I_1$ ……………………………………………………………….Eq. 3

where, M_{12} is the mutual inductance of due to current in primary side. Using the above relation we can determine the value of L_1 and M_{12}.

Method of finding L_2 (of LT side)and M_{21} :
Let us assume that we use the following setup :

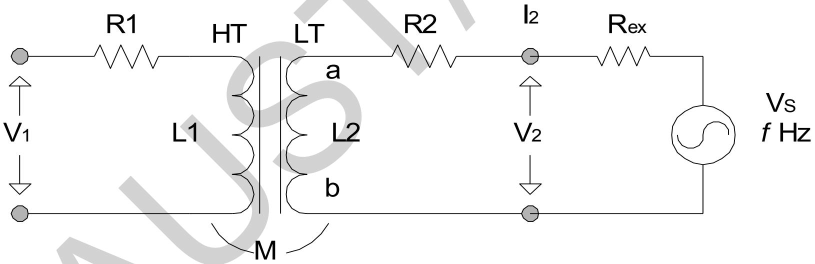


Fig : Secondary energized with a source keeping primary open

From the above circuit we can write ,

$V_2 = I_2 R_2 + j \omega L_2 I_2$ ……………………………………………………………….Eq. 4

and, $V_1 = j \omega M_{21} I_2$ ……………………………………………………………….Eq. 5

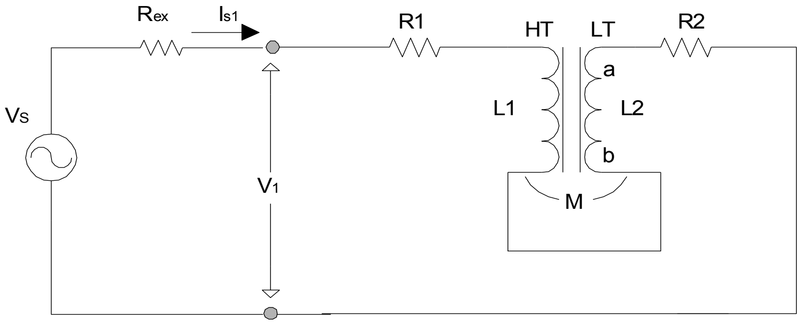
where, M_{21} is the mutual inductance due to current in secondary side.
Using the above relation we can determine the value of L_2 and M_{21}. Now we can determine the mutual inductance using the formula,

$M = \sqrt{(M_{12} M_{21})}$ ………………………………………………..Eq. 6

And using Eq. 1 we can determine the co-efficient of coupling 'k' .

Alternate method for determining M:

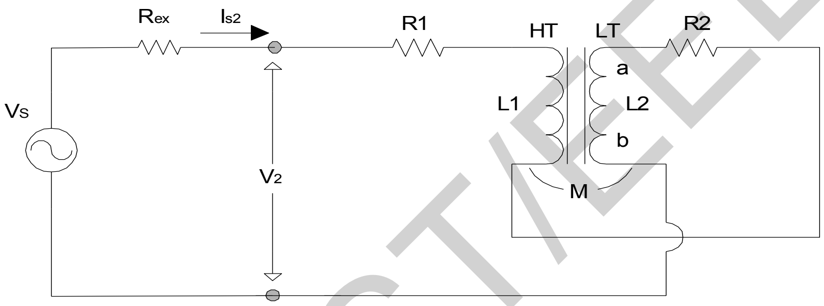
Step 1 :



From the circuit we can write ,

$$V_1 = (R_1 + R_2) I_{S1} + j\omega (L_1 + L_2 \pm 2M) I_{S1} \quad \text{Eq. 7}$$

Step 2 :



From the circuit we can write ,

$$V_2 = (R_1 + R_2) I_{S2} + j\omega (L_1 + L_2 \pm 2M) I_{S2} \quad \text{Eq. 8}$$

Here the mutual inductance 'M' has double effect because the same current flows through each of the coils. The polarity of the voltage drop due to M should be considered as follow :

- When the coils are such connected so that the fluxes produced by them aid each other then they are said to be positively coupled. In this case the sign of 2M in Equation 4 or 5 should be taken positive.
- When the coils are such connected so that the fluxes produced by the coils opposes each other they are said to be negatively coupled. In this case sign of 2M in Equation 5 or 4 should be taken negative.
- One way of determining the polarity of coupling is to observe the value of currents in step 1 and step 2. For positive coupling the overall flux in the core is greater than that of negative coupling. This results in a smaller value of current (I_{S1} or I_{S2}) when the same voltage is applied for both of the setups.

Let us assume the first setup is for positive coupling and the second one is for negative coupling. Therefore the Equation 4 and 5 can be written as ,

$$V_1 = (R_1 + R_2) I_{S1} + j\omega (L_1 + L_2 + 2M) I_{S1} \quad \text{.. Eq. 9}$$

$$V_2 = (R_1 + R_2) I_{S2} + j\omega (L_1 + L_2 - 2M) I_{S2} \quad \text{.. Eq. 10}$$

Now (Eq.7 – Eq 8) gives,

$$V_1 - V_2 = \{ (R_1 + R_2) I_{S1} - (R_1 + R_2) I_{S2} \} + j\omega \{ (L_1 + L_2 + 2M) I_{S1} - (L_1 + L_2 - 2M) I_{S2} \}$$

If we can make $I_{S1} = I_{S2} = I_S$ by adjusting the voltage source then we can write,

$$V_1 - V_2 = j\omega \{ 4M I_S \}$$

From where we can easily calculate the value of M as,

$$M = \frac{V_1 - V_2}{8 \pi f \; I_S} \quad \text{.. Eq 11}$$

APPARATUS

1. Resistance : 2.2 Ω (or any in the range of 2 ~ 4 Ω) ………………1 *pc*
2. Transformer : 220v / 12v-0-12v ………………………..1 *pc*
3. Signal Generator …………………..……………………………..…..1 *pc*
4. Signal Generator Probe …………………………………………………1 *pc*
5. Multi-meter ………………………………………………………….1 *pc*
6. Wires for connection

PROCEDURE

<u>Step : 1</u>

Measure and note the following values :

Resistance of the High Tension (HT) side R_1 = ☐

Resistance of the Low Tension (LT) side R_2 = ☐

External Resistance R_{ex} = ☐

Step : 2

Arrange the circuit as shown below . Use the main supply as your source.

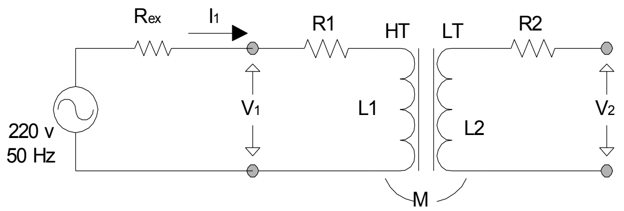


Fig : 1

Measure , V_1 = V_{Rex} =

V_2 = I_1 = V_{Rex} / R_{ex} =

NB: Make sure that you connect the HT side to the supply and measure V_2 across the end terminals of secondary side.

Step : 3

Arrange the circuit as shown below . Adjust the signal generator at 16 volt (p-p) & 50Hz (*f*). Use it as your supply.

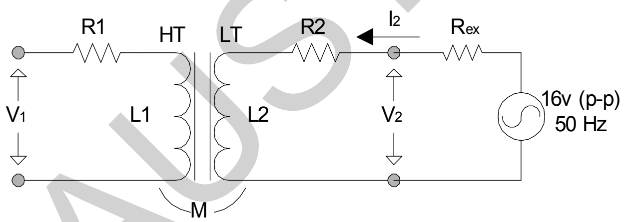


Fig : 2

Measure , V_2 = V_{Rex} =

V_1 = I_2 = V_{Rex} / R_{ex} =

NB: Make sure that you connect the LT side to the supply and measure V_1 across the terminals of primary side.

Step : 4

Arrange the circuit as shown below :

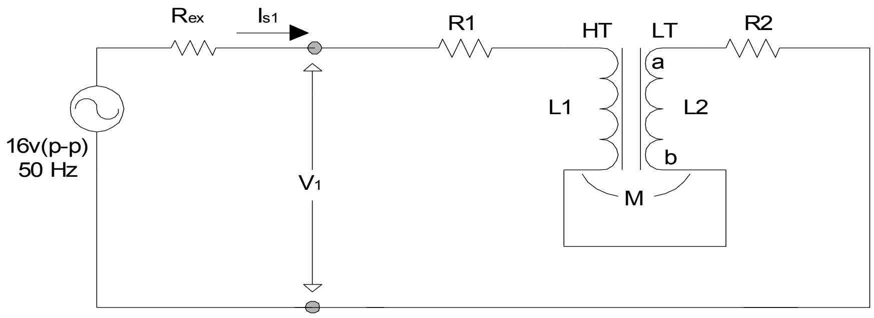


Fig. 3

- Measure the voltage across V_{Rex} = ☐ and V_1 = ☐
- Now reverse the connection at points 'a' & 'b' of the circuit and measure

V_{Rex} = ☐ V_1 = ☐

From these two readings determine which connection is for aiding and which one is for opposing flux. Mark the terminals of the transformer with appropriate dot notations.

Step : 5

From Step 4 we find that at opposing flux condition V_{Rex} = ☐ …… for opposing flux.

Therefore current $I_{S(opp)}$… = V_{Rex} / R_{ex} = ☐

- Now Setup the circuit for aiding flux condition. Adjust the source voltage from 0 ~ 16 v (p-p) , 50 Hz so that we get V_{Rex} equal to that of opposing flux condition. At this stage we make $I_{S1} = I_{S2}$.

Measure V_1 (or V_2) = ☐

REPORT

1. From the data found in Step 1 use Equations 2 & 3 and calculate L_1 and M_{12}.
2. Use Step 2 data and Equations 4 & 5 , calculate L_2 and M_{21}.
3. Calculate M and k using the above data , use Equation 6 & 1 .
4. From Step 4 & 5 data find the value of 'M' using Equation 11. Also find the value of 'k' using this value.