BEE PRACTICAL JOURNAL

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SIGNATURE OF TEACHER :

EXPERIMENT NO. 1

SUPERPOSITION THEOREM

SUPERPOSITION THEOREM

AIM:
To study and verify superposition theorem

APPARATUS:
Digital multimeter, EDKITS Superposition theorem kit, patch cords.

THEORY:
- SUPERPOSITION THEOREM

Many electrical circuits may contain more than one sources of emf in such cases, its more convienient to solve the circuit for the desired current produced by each source of emf acting separately and then combining the results. The theorem is applicable only to linear networks where current is linearly related to voltage as per Ohm's law.

- STATEMENT

In a network of linear resistances containing more than one source of emf, the current which flows at any point is the ~~same~~ sum of all the currents which would flow at that emf point if each source of emf is considered separately and all other sources of emf were replaced for the time being by resistances equal to natural resistances i.e. internal resistances.

- EXPLANATION

To illustrate the theorem, consider the circuit shown find out the current flowing through resistance $R_1 R_2$ & R_3

Let the resultant currents flowing through the resistances R_1, R_2 and R_3 be I_1, I_2 and I_3 respectively.

As per the theorem, let us first solve the above circuit with only E_1 emf acting along, replacing the other

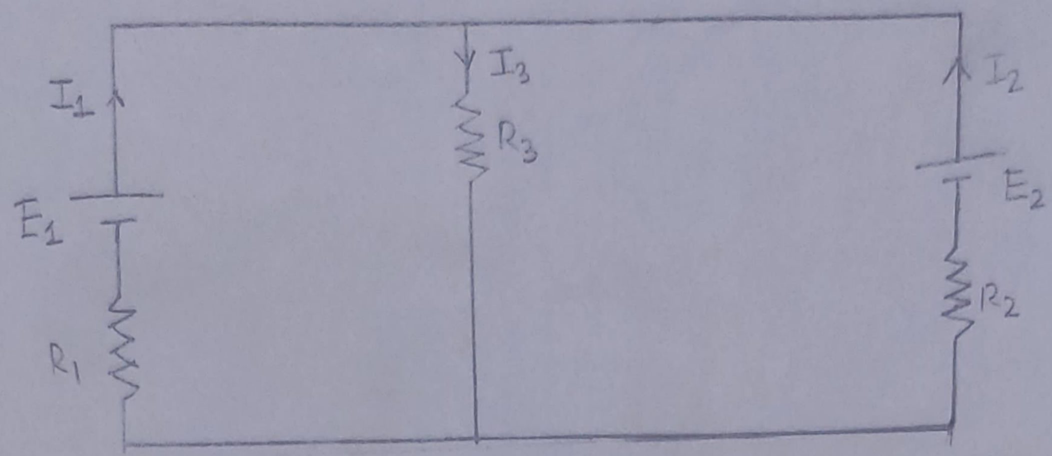
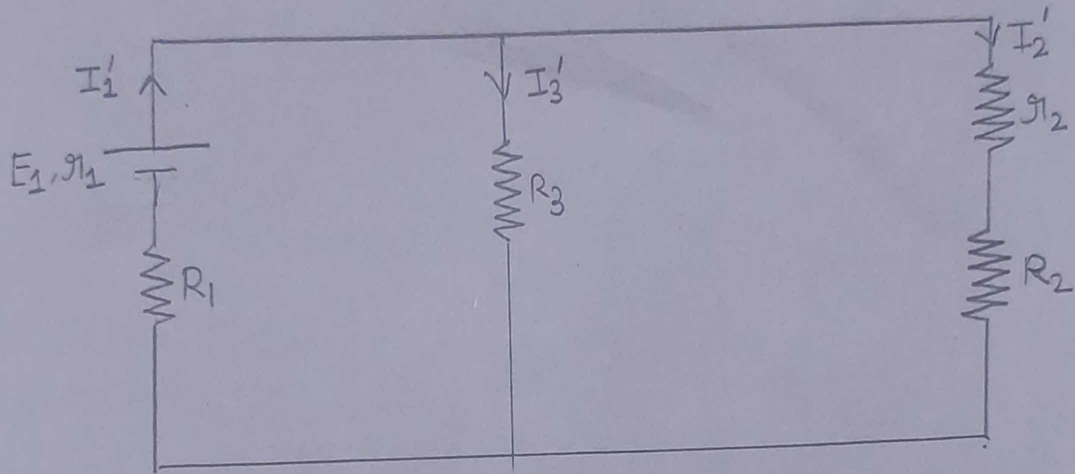
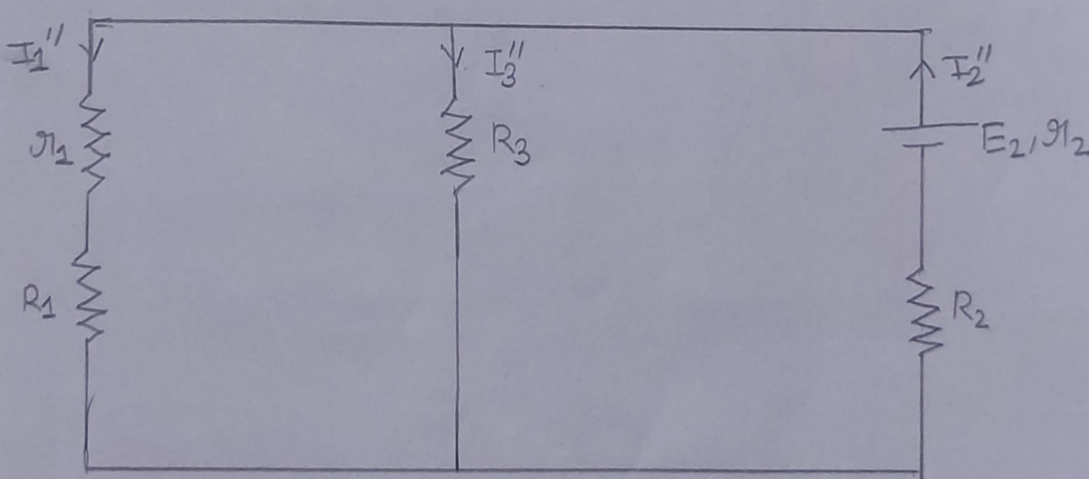


ILLUSTRATION OF SUPERPOSITION THEOREM



CURRENT IN VARIOUS BRANCHES DUE TO E1



CURRENT IN VARIOUS BRANCHES DUE TO E2

sources of emf by their internal resistances as shown. This circuit can be easily solved for I_1', I_2' and I_3'.

Similarly, solve circuit with emf E_2 acting alone replacing emf E by its internal resistance R as shown. The circuit is solved for I_1'', I_2'', I_3''. Now applying superposition theorem to combine resultants in order to find the total current in various branches.

Current in resistor $R_1 \Rightarrow I_1 = I_1' + I_1''$

Current in resistor $R_2 \Rightarrow I_2 = I_2' + I_2''$

Current in resistor $R_3 \Rightarrow I_3 = I_3' + I_3''$

- ADVANTAGES

(i) The advantage of superposition theorem over Kirchoff's law is that circuit can be analysed with one power source at a time, hence circuit is simplified. When Kirchoff's law ~~sur~~ sum at the junction point with all power sources is to be found which makes the analysis harder.

(ii) Superposition theorem is applicable to both DC and AC voltage circuits.

(iii) Voltage or current in entire circuit are added or subtracted arithmetically.

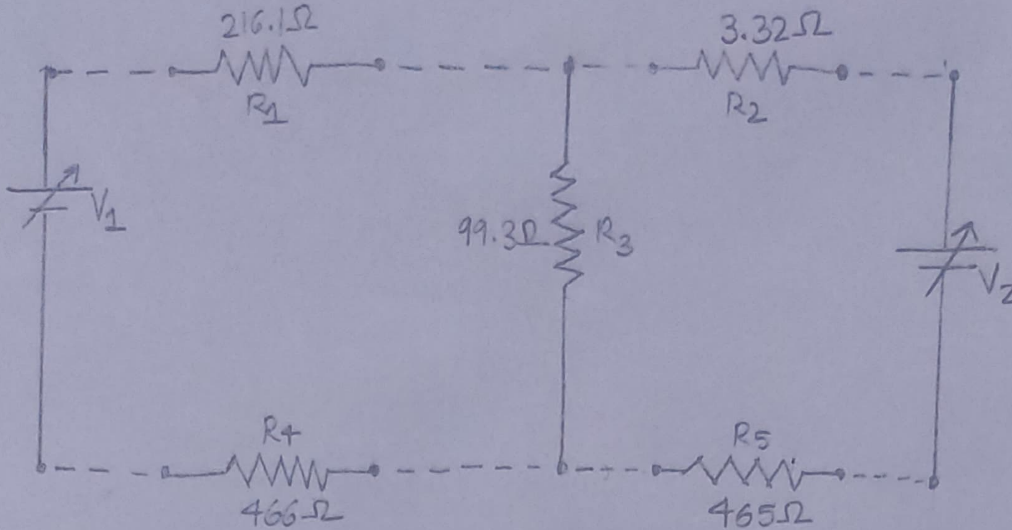
This theorem has the advantage of allowing each source to be taken separately. So that only Ohm's law equation is required in the circuit.

- DISADVANTAGES

(i) If a huge number of sources are involved, use of superposition theorem becomes difficult as final analysis will be more tedious than nodal and mesh analysis.

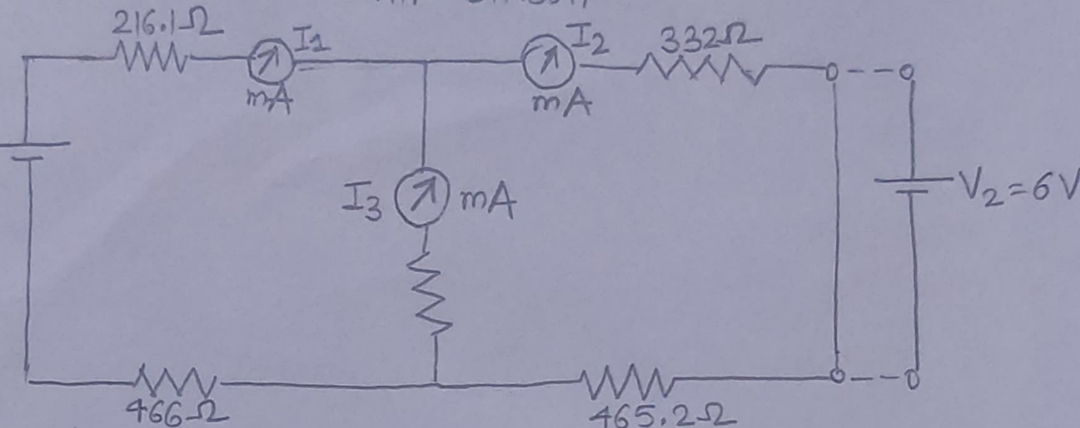
(ii) It can only be applied to linear circuit.

~~CALCULATIONS~~:

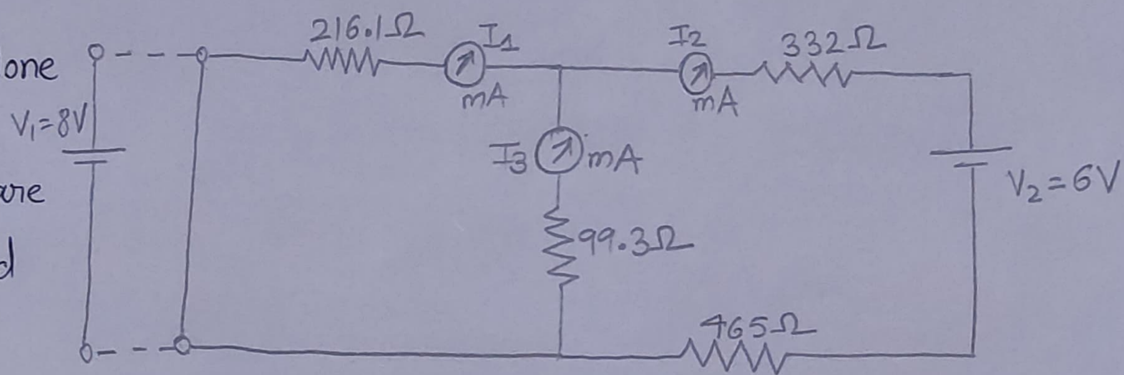


MAIN CIRCUIT

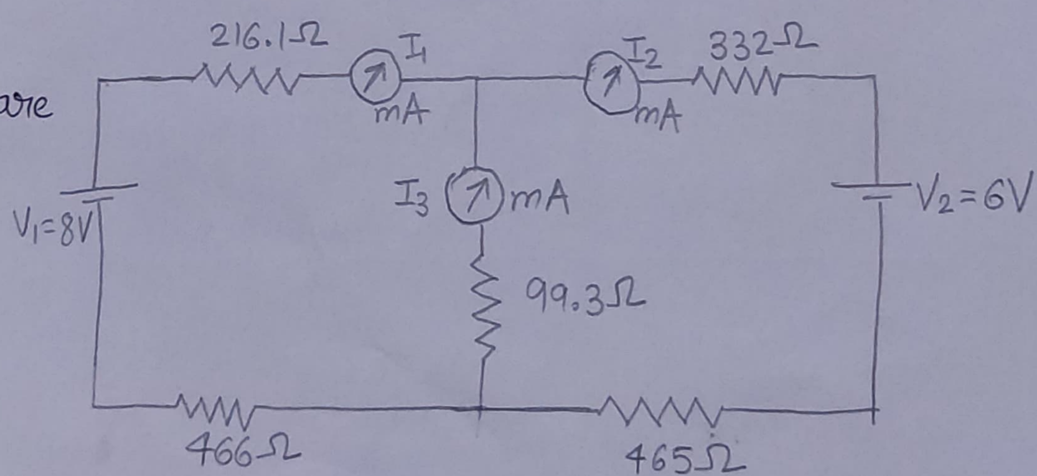
V_1 acting alone therefore R_2 and $V_1=8V$ R_5 are short circuited



V_2 acting alone and therefore R_1 and R_2 are short circuited



V_1 and V_2 are acting together



(iii) Superposition theorem can't be applied for finding the power dissipated in the circuit.

- APPLICATIONS

Superposition theorem can be used in electronics. When relation between V and I is linear when the current (I) or voltage (V) at same point can be found as the sum of current or voltage of each source taken individually.

PROCEDURE:

(i) Adjust $V_1 = 8V$ and measure the resistance in superposition theorem but in OFF condition.
(ii) Switch on the power supply to the kit
(iii) Adjust the $V_1 = 8V$ alone and short circuit V_2 and measure the value of current through R_1, R_2 and R_3.
(iv) Adjust the $V_2 = 6V$ alone and short circuit V_1 to measure the value of current I through R_1, R_2 and R_3
(v) Adjust $V_1 = 8V$ and $V_2 = 6V$ and measure the value of current through R_1, R_2 and R_3.

OBSERVATIONS:

$R_1 = 216.1\Omega$ $R_2 = 332\Omega$ $R_3 = 99.3\Omega$
$R_4 = 466\Omega$ $R_5 = 465\Omega$

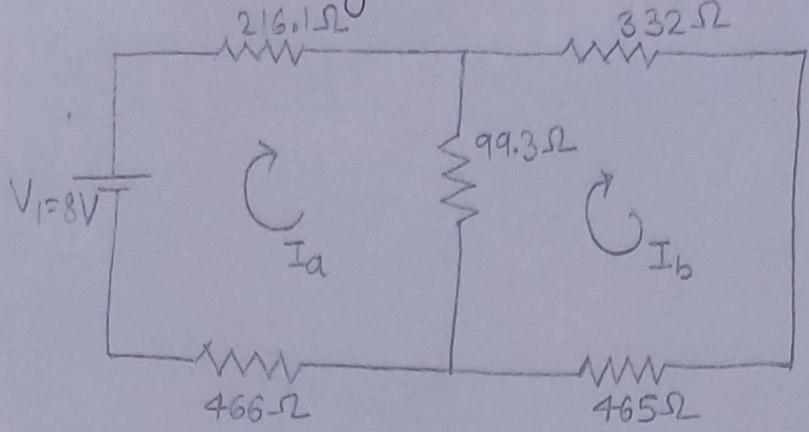
OBSERVATION TABLE:

(a) Practical values

Sr. No.	V_1	V_2			
1	8V	0V	$I_1' = 3.6mA$	$I_2' = 1.093mA$	$I_3' = 8.3mA$
2	0V	6V	$I_1'' = 1.054mA$	$I_2'' = 8.3mA$	$I_3'' = 6.9mA$
3	8V	6V	$I_1 = 10.6mA$	$I_2 = 7.0mA$	$I_3 = 17.5mA$

CALCULATIONS:

CASE 1: When V_1 is acting alone ($V_1 = 8V$, $V_2 = 0V$)



Applying KVL to Mesh 1:

$$8 - (216.1) I_a - 99.3(I_a - I_b) - 466 I_a = 0$$
$$-781.4 I_a + 99.3 I_b = -8$$
$$781.4 I_a - 99.3 I_b = 8 \quad - (1)$$

Applying KVL to Mesh 2:

$$-332 I_b - 465 I_b - 99.3(I_b - I_a) = 0$$
$$99.3 I_a - 896.3 I_b = 0 \quad - (2)$$

$$D = \begin{vmatrix} 781.4 & -99.3 \\ 99.3 & -896.3 \end{vmatrix} = -690508.33$$

$$D_{I_a} = \begin{vmatrix} 8 & -99.3 \\ 0 & -896.3 \end{vmatrix} = -7170.4$$

$$D_{I_b} = \begin{vmatrix} 781.4 & 8 \\ 99.3 & 0 \end{vmatrix} = -794.4$$

$$I_a = \frac{D_{I_a}}{D} = 10.384\,mA \quad , \quad I_b = \frac{D_{I_b}}{D} = 1.150\,mA$$

$\therefore I_1' = 10.384\,mA$

$I_2' = 1.150\,mA$

$I_3' = 9.234\,mA$

(b) Theoretical Values

Sr. no.	V_1	V_2			
1	8V	0V	$I_1' = 10.384mA$	$I_2' = 1.150mA$	$I_3' = 9.234mA$
2	0V	6V	$I_1'' = 0.862mA$	$I_2'' = 6.789mA$	$I_3'' = 5.927mA$
3	8V	6V	$I_1 = 9.621mA$	$I_2 = 5.639mA$	$I_3 = 15.160mA$

RESULT:

(i) Observed and theoretical values of current are almost the same.

(ii) Practical value of current = 10.6 mA, 7.0 mA, 17.5 mA

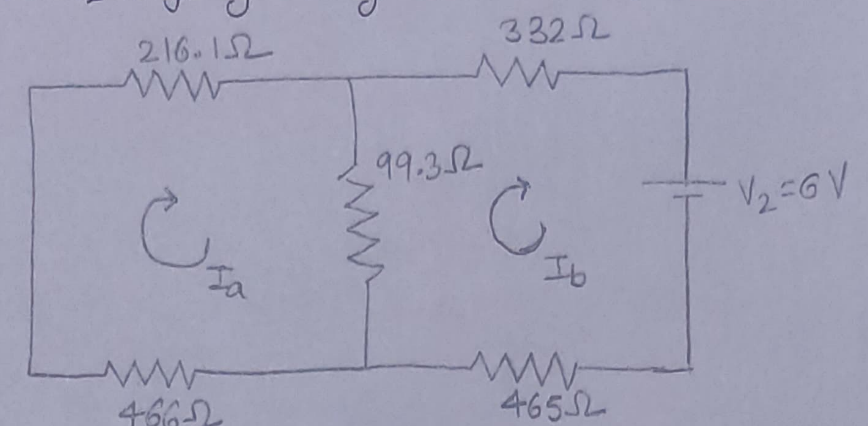
Theoretical value of current = 9.521mA, 5.639mA, 15.160 mA

CONCLUSION:

(i) We have studied and verified superposition theorem.

(ii) It is found that current through a point in a circuit containing multiple sources is the sum of currents through that point when each source acts independently.

CASE 2: When V_2 is ~~going~~ acting alone ($V_1 = 0V$, $V_2 = 6V$)



Applying KVL to Mesh 1:

$$-216.1 I_a - 99.3(I_a - I_b) - 466 I_a = 0$$

$$-781.4 I_a + 99.3 I_b = 0$$

Applying KVL to Mesh 2:

$$-332 I_b - 10 - 465 I_b - 99.3(I_b - I_a) = 0$$

$$99.3 I_a - 896.3 I_b = 10$$

$$D = \begin{vmatrix} -781.4 & 99.3 \\ 99.3 & -896.3 \end{vmatrix} = 690508.33$$

$$D_{I_a} = \begin{vmatrix} 0 & 99.3 \\ 6 & -896.3 \end{vmatrix} = -595.8$$

$$D_{I_b} = \begin{vmatrix} -781.4 & 0 \\ 99.3 & 6 \end{vmatrix} = -4688.4$$

$$I_a = \frac{D_{I_a}}{D} = -0.862\,mA \quad , \quad I_b = \frac{D_{I_b}}{D} = -6.789\,mA$$

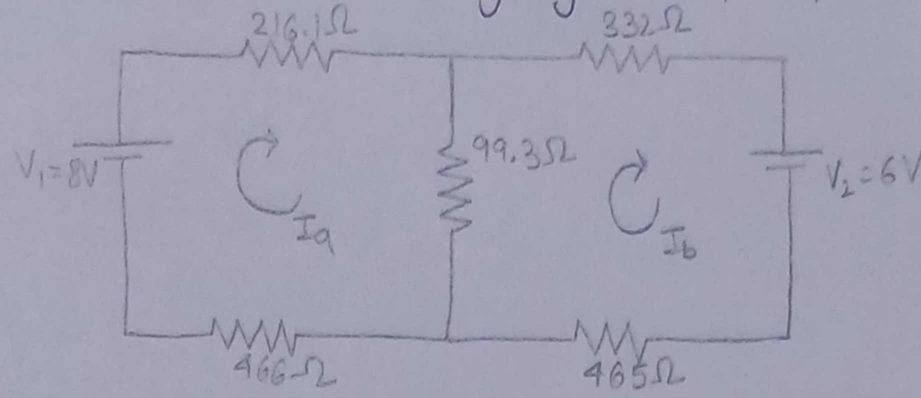
$I_1'' = -0.862\,mA$

$I_2'' = -6.789\,mA$

$I_3'' = -5.927\,mA$

Negative sign indicates that current flows in opposite direction.

CASE 3: Both V_1 and V_2 acting together ($V_1 = 8V$, $V_2 = 6V$)



Applying KVL to Mesh 1:

$$-216.1 I_a - 99.3(I_a - I_b) - 466 I_a + 8 = 0$$

$$-781.4 I_a + 99.3 I_b = -8$$

Applying KVL to Mesh 2:

$$-332 I_b - 6 - 465 I_b - 99.3(I_b - I_a) = 0$$

$$99.3 I_a - 896.3 I_b = 6$$

$$D = \begin{vmatrix} -781.4 & 99.3 \\ 99.3 & -896.3 \end{vmatrix} = 690508.3$$

$$D_{I_a} = \begin{vmatrix} -8 & 99.3 \\ 6 & -896.3 \end{vmatrix} = 6574.6$$

$$D_{I_b} = \begin{vmatrix} -781.4 & -8 \\ 99.3 & 6 \end{vmatrix} = -3894$$

$$I_a = \frac{D_{I_a}}{D} = 9.521mA, \quad I_b = \frac{D_{I_b}}{D} = -5.639mA$$

$I_1 = 9.521mA$

$I_2 = -5.639mA$

$I_3 = 15.16mA$

Negative sign indicates that current flows in opposite direction.

Experiment No. 2

Thevenin's Theorem

THEVENIN THEOREM

AIM:
To study and verify Thevenin's theorem.

APPARATUS:
Digital multimeter (DMM), EDKITS Thevenin's theorem kit, patch cords.

THEORY:
It states that 'Any two terminals of a network can be replaced by an equivalent voltage source and an equivalent series resistance. The voltage source is the voltage across the two terminals with load, if any removed. The series resistance of the network measured between two terminals with load removed and constant voltage being replaced by the its internal resistance (or if it is not given with zero resistance i.e. short circuit) and constant current source replaced by infinite resistance i.e. open circuit.'

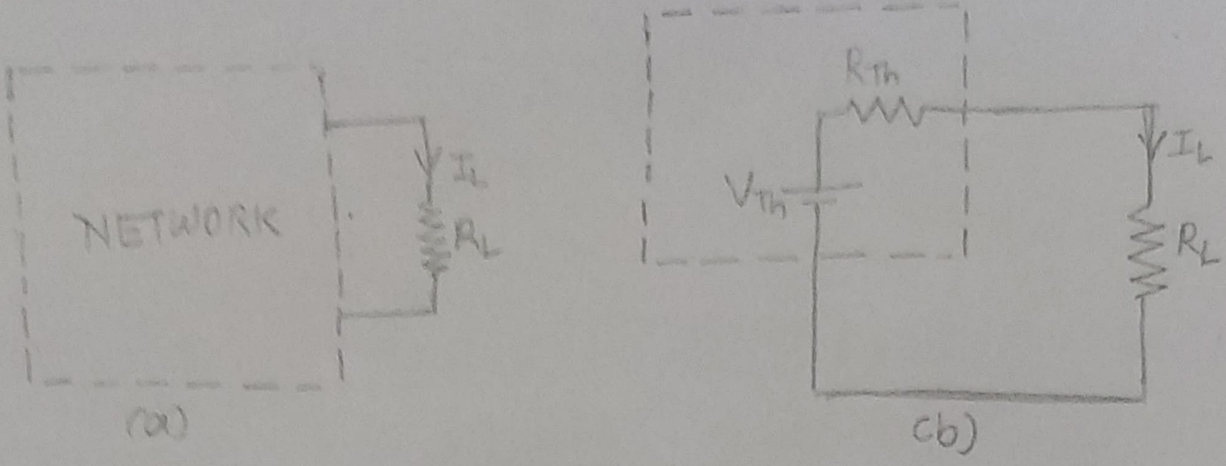
- **EXPLANATION**

The above method of determining the load current through a given load resistance can be explained with the help of given circuits.

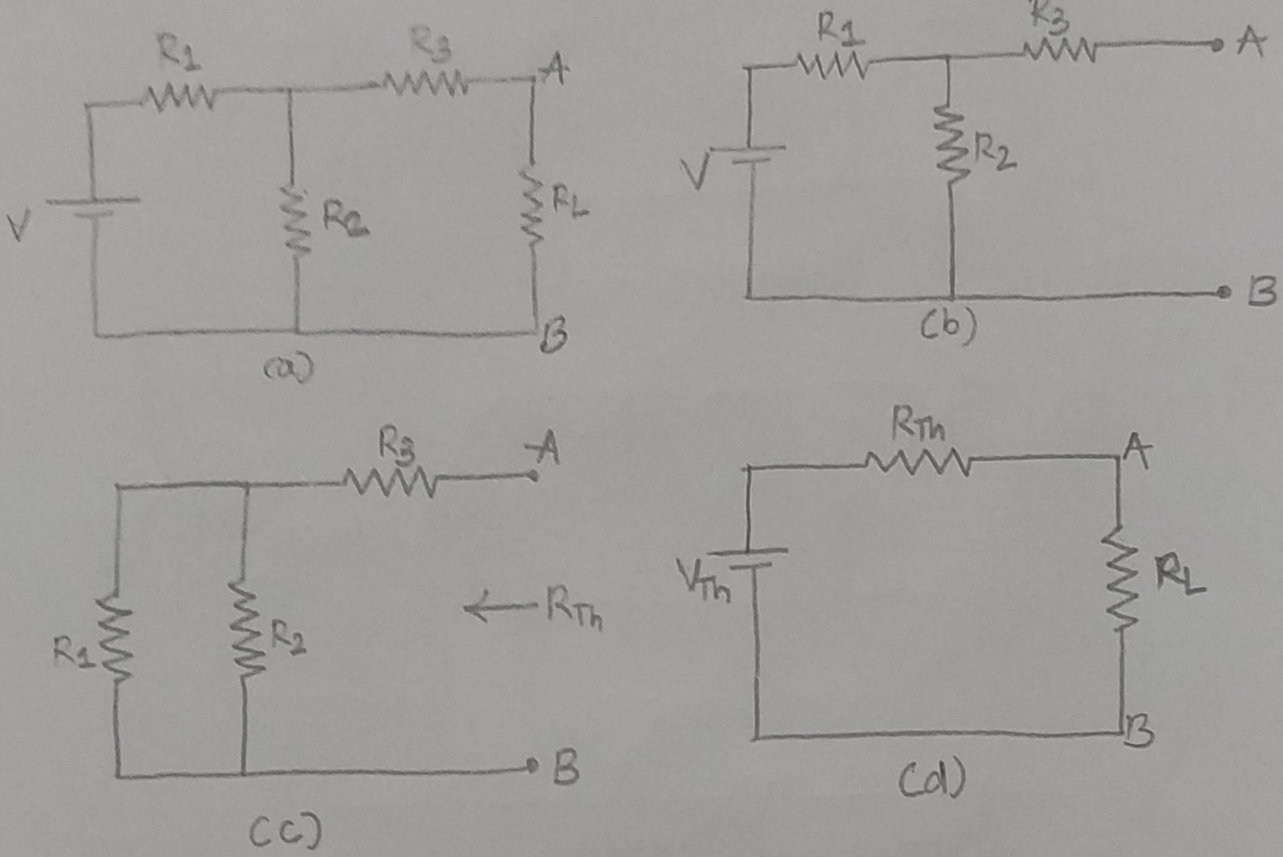
- **STEPS TO BE FOLLOWED IN THEVENIN'S THEOREM**

(i) Remove the load resistance R_L.
(ii) Find the open circuit voltage V_{Th} across points A and B.
(iii) Find the resistance R_{Th} as seen from points A and B with the voltage sources and current sources replaced by internal resistances.
(iv) Replace the network by voltage source V_{Th} in series with resistance R_{Th}.
(v) Find the current through R_L using Ohm's Law,

$$I_L = \frac{V_{Th}}{R_{Th}+R_L}$$



THEVENIN'S THEOREN



STEPS IN THEVENIN'S THEOREM

• ADVANTAGES

(i) Basic advantage of Thevenin's theorem is that it reduces a current circuit into a simple circuit.

(ii) Current through load resistance can be easily calculated.

• DISADVANTAGES

(i) Application of Thevenin's theorem is limited

(ii) Thevenin's theorem is applicable to linear circuits only.

(iii) It is applicable to bilateral network, i.e. networks in which current through element is not affected by polarity change.

PROCEDURE:

(i) Find the resistances in 'OFF' condition.

(ii) Switch on the kit.

(iii) Keep the multimeter in DC, adjust input 'V' to 12 V

(iv) Disconnect R_L and find V_{Th} across 'xy' in 'ON' condition

(v) Short voltage source and find R_{Th} across xy in 'OFF' condition.

(vi) Connect the voltage source in the circuit upto xy.

(vii) Re-insert R_1 in the circuit across ~~R_L~~. xy

(viii) Connect millimeter in series and voltage across R_L.

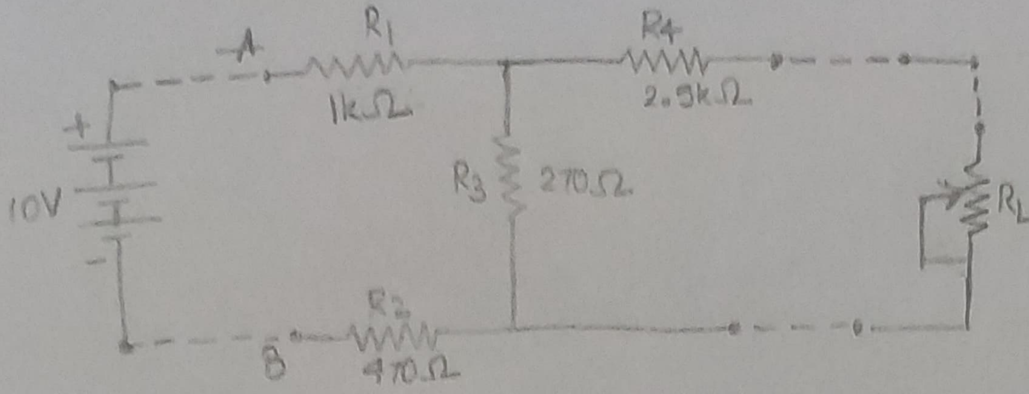
(ix) Observe values of V_L and I_L.

(x) Obtain I_L by formula,

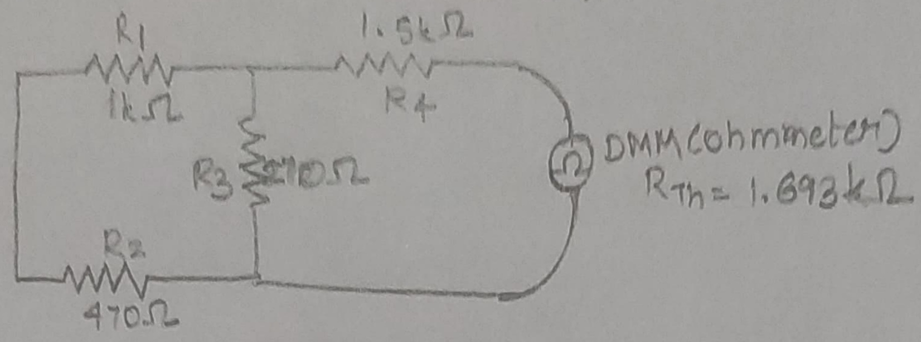
$$I_L = \frac{V_{Th}}{R_{Th} + R_L}$$

$$\text{Where, } R_L = \frac{V_L}{I_L}$$

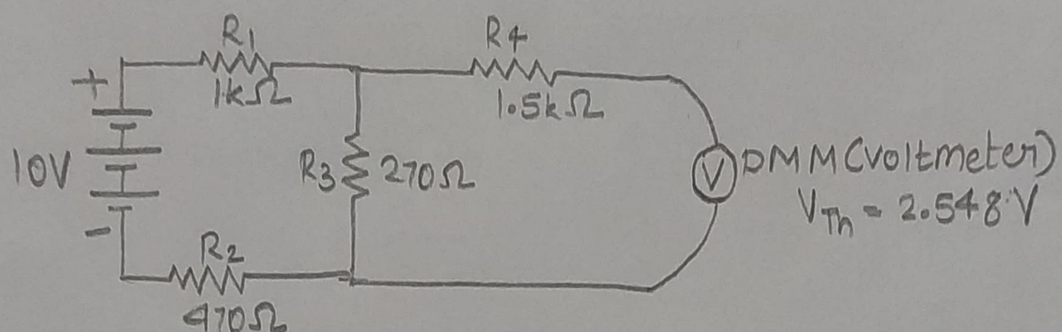
(xi) Compare both R_L and verify Thevenin's theorem.



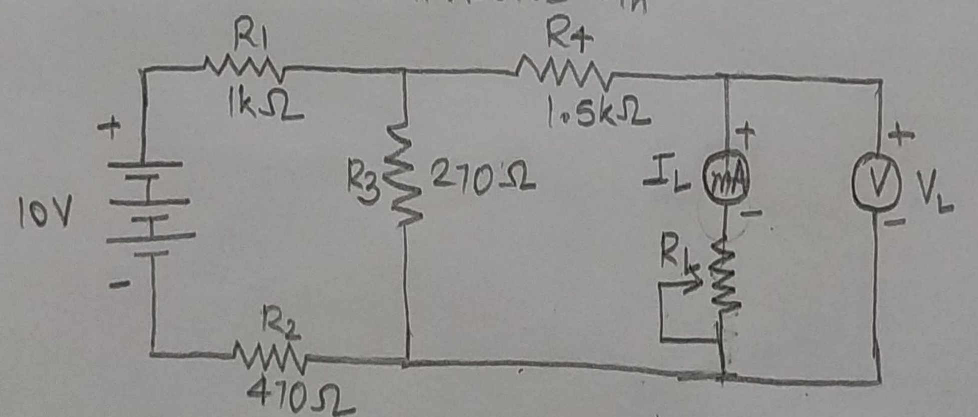
CIRCUIT DIAGRAM



MEASURE R_{Th}



MEASURE V_{Th}



MEASURE V_L and I_L

OBSERVATION TABLE:

Sr. no.	Quantity	Theoretical Value	Practical Value
1	R_1	1kΩ	983Ω
2	R_2	470Ω	468Ω
3	R_3	270Ω	265Ω
4	R_4	1.5kΩ	1471Ω
5	R_{Th}	1.728kΩ	1.693kΩ
6	V_{Th}	1.551 V	1.548V

Sr. no.	V_L (V)	I_L (mA)	$R_L = \frac{V_L}{I_L}$ (Ω)	$I_L = \frac{V_{Th}}{R_{Th}+R_L}$ (mA)
1	0.421	0.569	739	0.636mA
2	0.787	0.433	1817.5	0.440mA
3	0.919	0.357	2576.3	0.362mA
4	1.007	0.307	3280.1	0.311mA
5	1.097	0.256	4285.1	0.258mA
6	1.146	0.228	5026.7	0.2303mA
7	1.183	0.207	5714.9	0.2089mA

RESULT:

For specified value of resistances, the calculated value of I_L is approximately equal to the observed value of I_L.
e.g. for $R_L = 5714.9\Omega$, the calculated value I_L is 0.208mA and the observed value of I_L is 0.207mA.

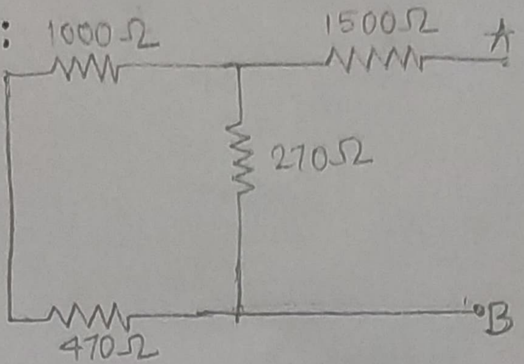
CONCLUSION:

(i) Thevenin's theorem is ~~equal~~ verified and it is found that any network can be replaced by an equivalent voltage source (V_{Th}) and equivalent series resistance (R_{Th})
(ii) Observed and calculated values of I_L (current through load resistance) is approximately equal.

CALCULATIONS:

THEORETICAL CALCULATIONS:

For R_{Th}:



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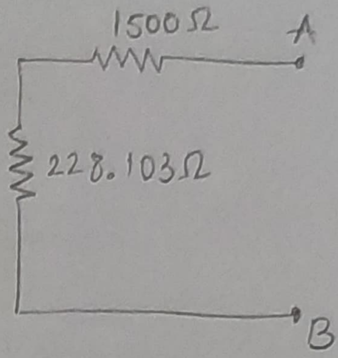
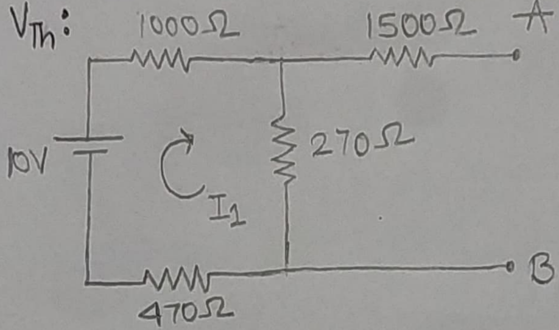


$$R_{AB} = R_{Th} = 1.728k\Omega$$

For V_{Th}:



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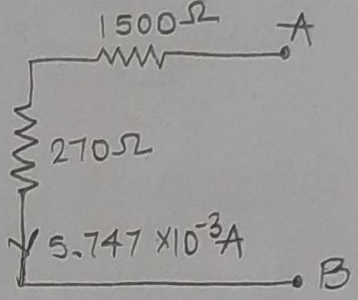


Applying KVL to loop 1:

$$10 - 1000I_1 - 270I_1 - 470I_1 = 0$$

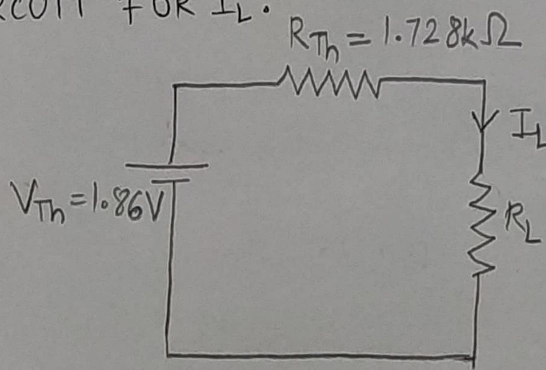
$$\therefore I_1 = 5.747 \times 10^{-3} A$$

Applying KVL to open path from B to A,

$$270 \times 5.747 \times 10^{-3} + 0 = V_{Th}$$

$$V_{Th} = 1.551V$$

CIRCUIT FOR I_L:



PRECAUTIONS:

(i) Connect the patch cords properly.

(ii) Switch off the circuit while connecting the ammeters/ voltages.

(iii) Adjust the value of R_L carefully.

CALCULATIONS FOR 3 READING:

(i) $R_L = \frac{V_L}{I_L} = \frac{0.421}{0.569 \times 10^{-3}} = 739\,\Omega$

$$I_L = \frac{V_{Th}}{R_{Th} + R_L} = \frac{1.548}{1693 + 739} = 0.636\,mA$$

(ii) $R_L = \frac{V_L}{I_L} = \frac{0.787}{0.433 \times 10^{-3}} = 1817.5\,\Omega$

$$I_L = \frac{V_{Th}}{R_{Th} + R_L} = \frac{1.548}{1693 + 1817.5} = 0.440\,mA$$

(iii) $R_L = \frac{V_L}{I_L} = \frac{0.919}{0.357 \times 10^{-3}} = 2576.3\,\Omega$

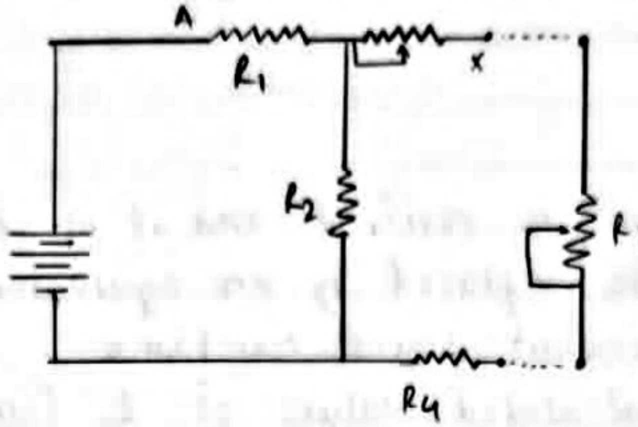
$$I_L = \frac{V_{Th}}{R_{Th} + R_L} = \frac{1.548}{1693 + 2576.3} = 0.362\,mA$$

EXPERIMENT No. 3.

MAXIMUM POWER TRANSFER THEOREM

CIRCUIT DIAGRAM

Maximum Power Transfer Theorem



Observations :-

$R_1 = 0.986\ K\Omega$, $R_2 = 3.35 K\Omega$, $R_3 = 0.08\ K\Omega$, $R_4 = 100\ \Omega$

$R_{TH} = 0.931\ k\Omega$.

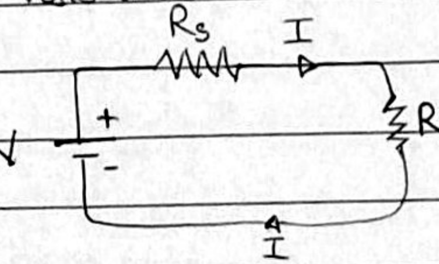
Observation table.

$V_L (V)$	$I_L (mA)$	$R_L = V_L / I_L$	$P_L = V_L \times I_L$.
1.936	6	322.67 Ω	11.616 mW
2.704	5.1	530.19 Ω	13.7904 mW
3.73	4.1	909.75 Ω	15.293 mW
4.7	3.0	1566.67 Ω	14.1 mW
5.3	2.4	2208.34 Ω	12.72 mW
5.66	2.1	2695.23 Ω	11.886 mW

AIM:
To verify maximum power transfer theorem.

APPARATUS:
Maximum power transfer kit, a rheostat, D.C source, multimeter connecting wires.

THEORY:
A resistive load will abstract maximum power from a network when the load resistance is equal to the resistance of the network as viewed from the output terminals, with all energy sources removed, leaving behind their internal resistances.



$$I = \frac{V}{R_s+R_L}$$

Power consumed by the load is $P_L = I^2 R_L = \frac{V^2}{(R_s+R_L)^2} R_L$

$\therefore$ To determine the value of R_L, for maximum power to be transferred to the load $\frac{dP_L}{dR_L} = 0$. $\therefore \frac{d}{dR_L}\left(\frac{V^2 R_L}{(R_s+R_L)^2}\right) = 0$.

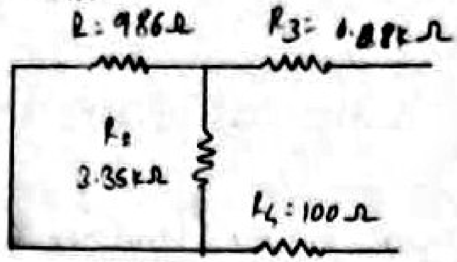
$\therefore V^2\left[\frac{dP_L}{dR_L} \times \frac{1}{(R_s+R_L)^2} + R_L \times \frac{d}{dR_L}\left(\frac{1}{R_s+R_L}\right)^2\right] = 0$. $\therefore V^2\left(\frac{1}{(R_s+R_L)^2} - \frac{2R_L}{(R_s+R_L)^3}\right) = 0$

$\therefore \frac{1}{(R_s+R_L)^2} = \frac{2R_L}{(R_s+R_L)^3}$ $\therefore R_s + R_L = 2R_L$.

$$\boxed{\therefore R_s = R_L}$$

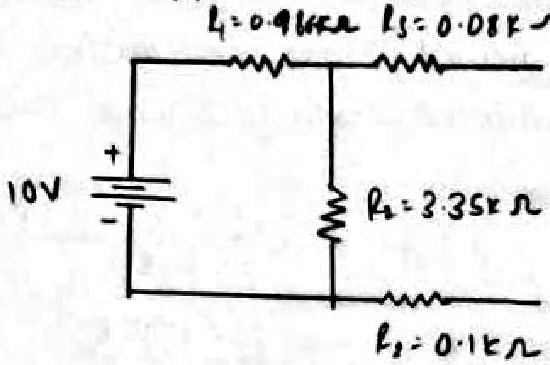
THEORETICAL CALCULATION

To calculate R_{TH}



$$R_{TH} = (R_1 \| R_2) + R_3 + R_4$$
$$= 0.941\,k\Omega$$
$$\therefore R_{TH} = 0.941\,k\Omega$$

To calculate V_{TH}



Applying KVL to loop 1

$$10 - 0.986 \times I - 3.35 \times I = 0$$
$$I = \frac{10}{(0.986 + 3.35)} = 2.30\,mA$$
$$V_{TH} = I \times R_2$$
$$= 2.30 \times 3.35$$
$$V_{TH} = 7.705\,V$$
$$P_{max} = 15.772\,mW$$

∴ So, maximum power will be transferred when $R_s = R_L$.
The theorem has limited applications but, the goal is to observe high efficiency. According to this theorem, the small efficiency of the network supplying maximum power to any branch is 50%.

∴ Resistance is calculated by removing all the energy sources leaving behind their internal resistances.

$$P_{max} = \frac{V^2 R_L}{(R_s + R_L)^2} = \frac{V^2 R_s}{(2R_s)^2} = \frac{V^2}{4R_s} \quad (\because R_s = R_L)$$

If AC source of internal resistance $(R_s + jX_s)$ supplying power to a load $(R_L + jX_L)$ it can be proved that maximum power transfer will have take place when the modulus of load impedence is equal to modulus of source impedence.

$$|Z_L| = |Z_s|$$

Maximum amount of power will be delivered to the load resistan when the load resistance is equal to the thevenin resistance of the network supplying the power of the load resistance is more or less than Thevenin's resistance of the network, then the power delivered to the load is less than maximum.
Increase of electronics & communication, it is of cirrical significance in the operation of transmission lines and antennas. Although applicable to all branches of engineering, this theorem is particularly used for analyzing communication networks.

PROCEDURE :
1) Measure R_1, R_2, R_3, R_4 by multimeter in OFF condition.

2) Disconnect R_L from the circuit.
3) Apply voltage source of 10V and measure open circuit voltage across open terminals X-Y in ON condition.
4) Find R_{TH} by shorting volting source across X-Y.
5) Connect the circuit as shown.
6) Measure V_L and ~~V_{TH}~~ I_L for different values of R_L.
7) Connect milliammeter in series with R_L and voltmeter across R_L.
8) Fill the observation table for $V_L, I_L, R_L = \frac{V_L}{I_L}, P_L = I^2 R_L$

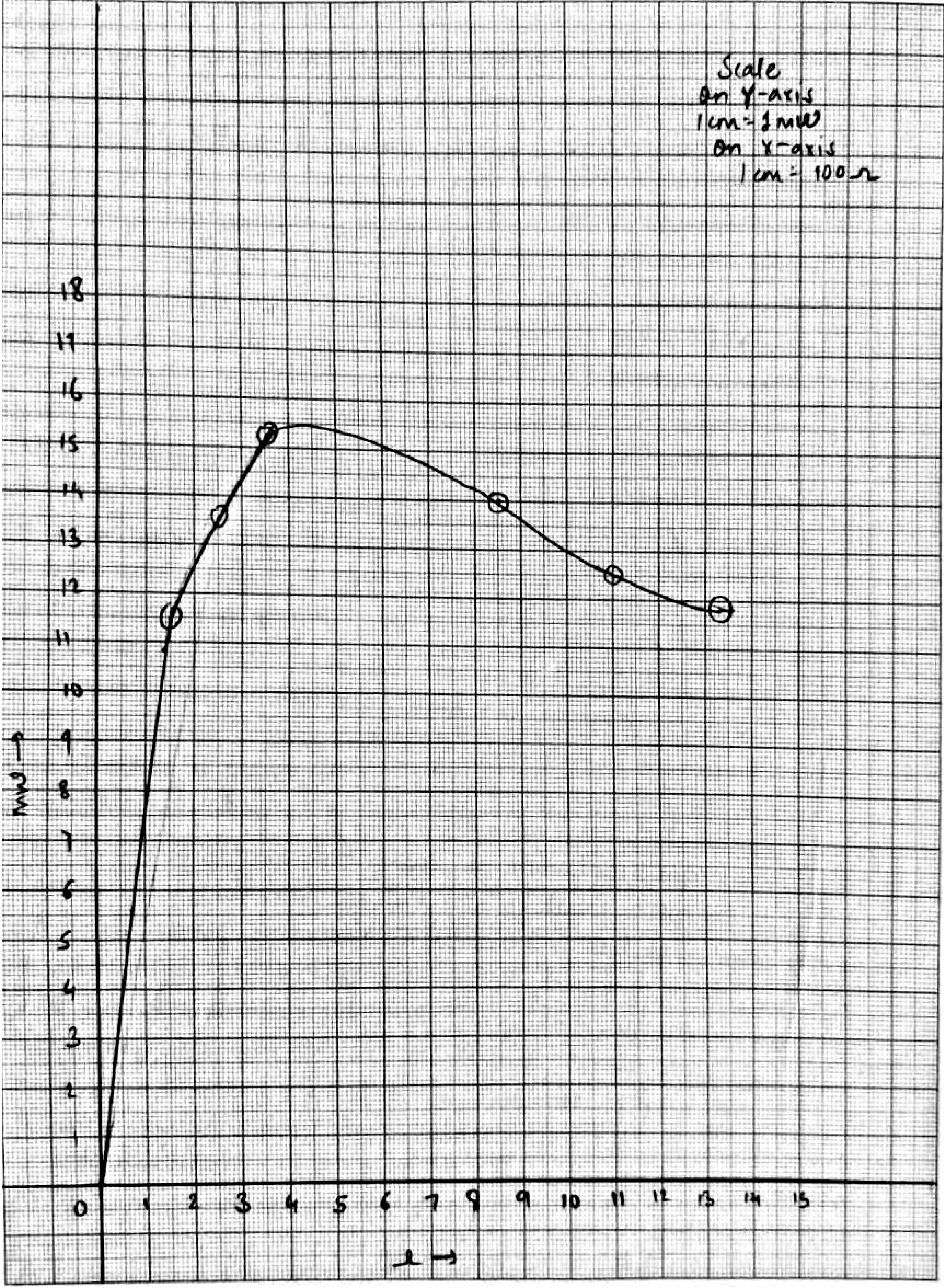
9) Calculate the V_{TH} and R_{TH} respective theoretically.
10) Calculate maximum power theoretically i.e $P_{max} = \frac{V_{TH}^2}{4R_{TH}}$

CONCLUSION :
1) As R_L is increased from small values towards R_S, the power delivered keeps on increasing.
2) As R_L is increased over R_S, power delivered P_L is increasing.
3) The maximum power can only be delivered when $R_L = R_S$, which verifies maximum power theorem.

RESULT :
The experimental value of maximum power is 15.293 mW and theoretical value of maximum power is 15.772 mW.

PRECAUTIONS :

1) Patch cords must be connected properly.
2) Use well insulated wires.
3) Check the circuit connections properly before switching ON.


Scale
On Y-axis
1cm = 1mW
On X-axis
1cm = 100 Ω
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
mW
R

Experiment No. 4
Series Resonant Circuit

SERIES RESONANT CIRCUIT

AIM:
Study of series resonant circuit

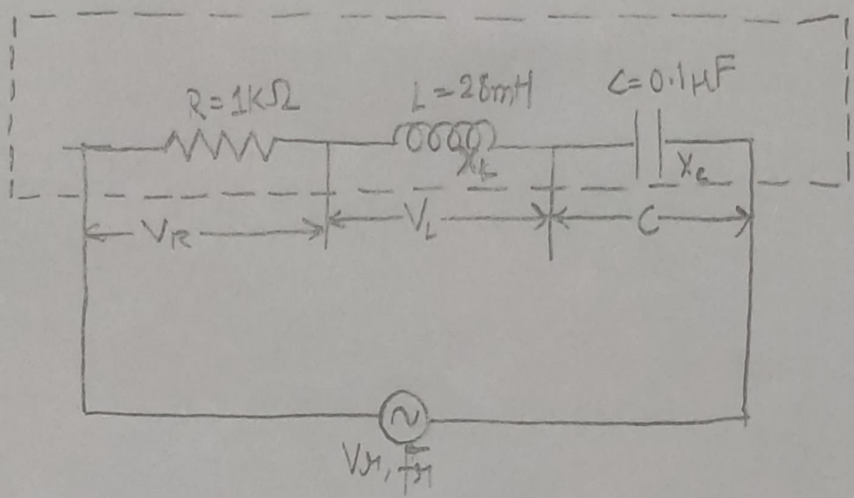
APPARATUS:
Trainer kit of series resonance circuit, signal/function generator, patch cards, multimeter.

THEORY:
Inductive reactance increases as the frequency is increased but capacitive reactance decreases with higher frequency. Because of these opposite characteristics, for any LC combination, there must be a frequency at which X_L equals X_C, as one increases while other decreases. This case of equal and opposite reactance is called resonance and AC circuit is then a resonant circuit.

• SERIES RESONANT CIRCUIT

A series resonant circuit is a frequency sensitive circuit. It consists of a series arrangement of inductance, capacitance of resistance, such resistance are important for selecting or rejecting specific frequencygies or range of frequencies. The frequency applied to a series resonant circuit affects both inductive reactance (X_L) and capacitive reactance (X_C). Thus, at a specific applied frequency, when $X_L = X_C$, the voltages across the inductor and capacitor will be equal, the net resultant of voltages across the inductor and capacitor will be equal, the net resultant of voltages will be zero and also the opposition offered by X_L and X_C will cancel each other at this frequency. Since the net reactance of the circuit ($X_L - X_C$) is zero the impedance (Z) of the network will be equal to the resistance (R)

The frequency which produces the condition described



CIRCUIT DIAGRAM

above is called resonant frequency.

$$f_s = \frac{1}{2\pi\sqrt{LC}} = \frac{0.159}{\sqrt{LC}}$$

$f_s \rightarrow$ series resonant frequency.

Total impedance (Z_r)

$\bar{Z}_r = R + jX_L - jX_C = R + j(X_L - X_C)$ ... (Rectangular form)

$\bar{Z}_r = Z_r < \phi_r$ ... (Polar form)

$Z_r = \sqrt{R^2 + (X_L - X_C)^2}$

& $\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$

As resonance power factor of the circuit should be 1

$\therefore (p.f.)_T = 1$

$\cos\phi_T = 1$

$\phi_T = \cos^{-1}(1) = 0$

i.e. at resonance, angle between total voltage V_T and total current is zero.

$$\phi_T = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$

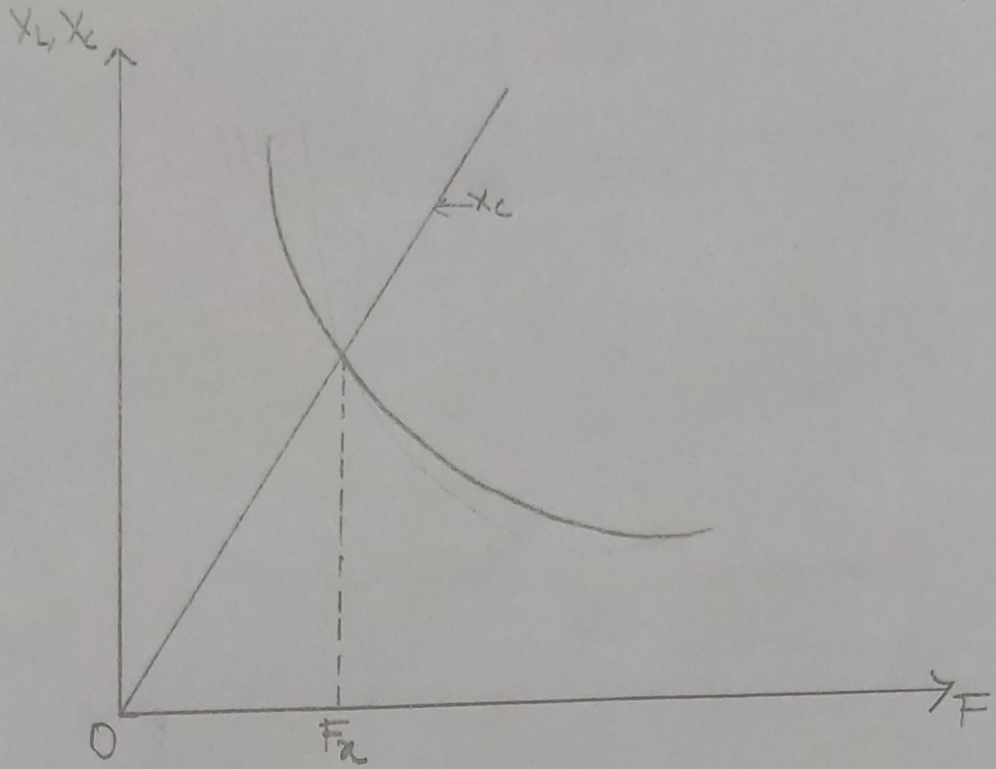
$$0 = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$

$$\frac{X_L - X_C}{R} = 0$$

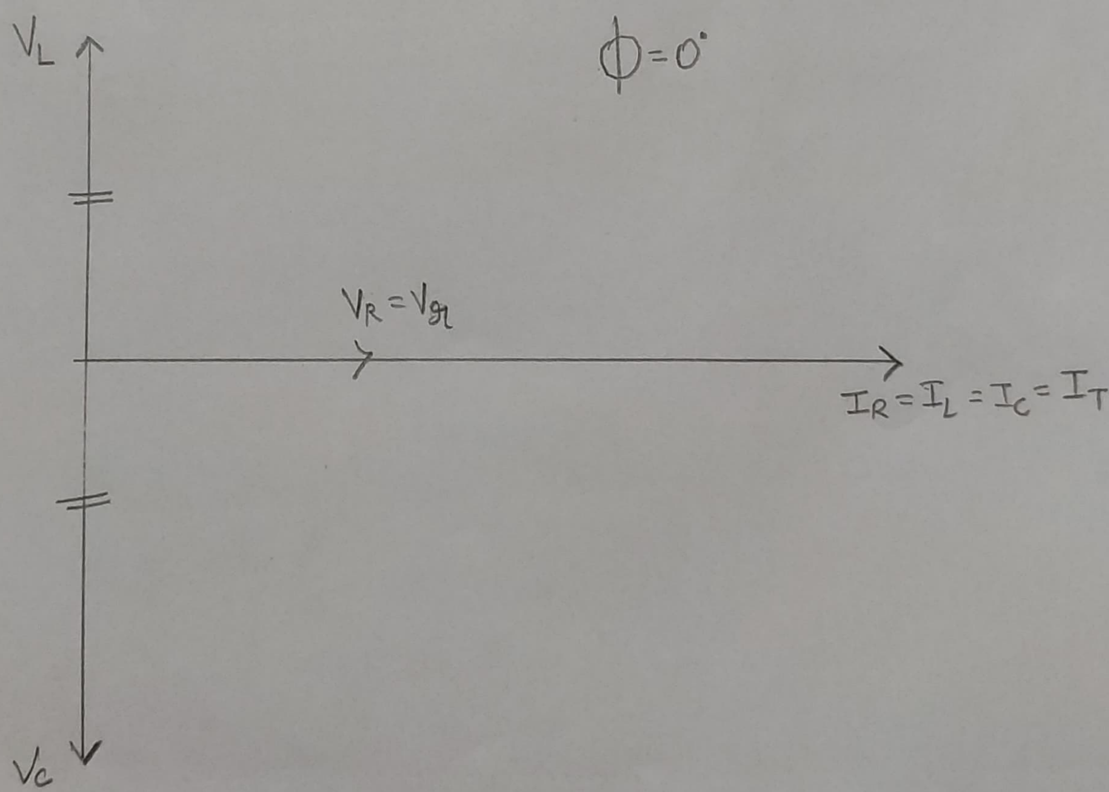
$$\therefore \boxed{X_L = X_C}$$

Impedance, $Z_r = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{R^2 + 0^2} = R$

$$\therefore \boxed{Z_r = R}$$



RESONANT FREQUENCY GRAPH



PHASOR DIAGRAM

- VOLTAGE ACROSS INDUCTOR (V_L) AND ACROSS CAPACITOR (V_C)

Voltage across inductor (V_L) = $I_L X_L$

Voltage across capacitor (V_C) = $I_C X_C$

But, $I_L = I_C$ (Because of series circuit)

& $X_L = X_C$

$$\boxed{V_L = V_C}$$

- EFFECT SERIES RESONANCE

(i) $X_L = X_C$

$\therefore X_L - X_C = 0$ i.e. net reactance of the circuit is zero.

(ii) Because of zero net reactance, impedance of the circuit (Z_r) is $Z_r = R$

It is the lowest value impedance. Since, impedance is minimum, current is maximum at resonance, thus circuit accept more current and such R-L-C circuit under resonance is called ACCEPTOR CIRCUIT.

(iii) Because of equal reactance of equal current $V_L = V_C$

(iv) $V_L = V_R$

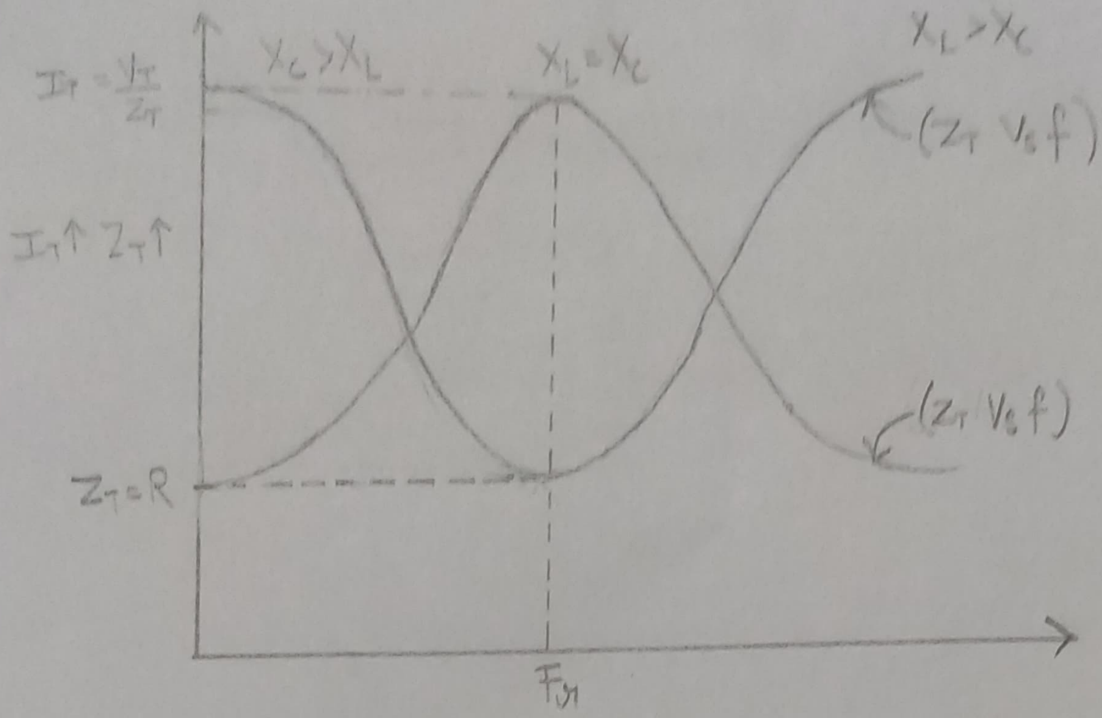
- RESONANCE FREQUENCY (f_r)

The frequency at which $X_L = X_C$ in an R-L-C series circuit is called the resonant frequency (f_r).

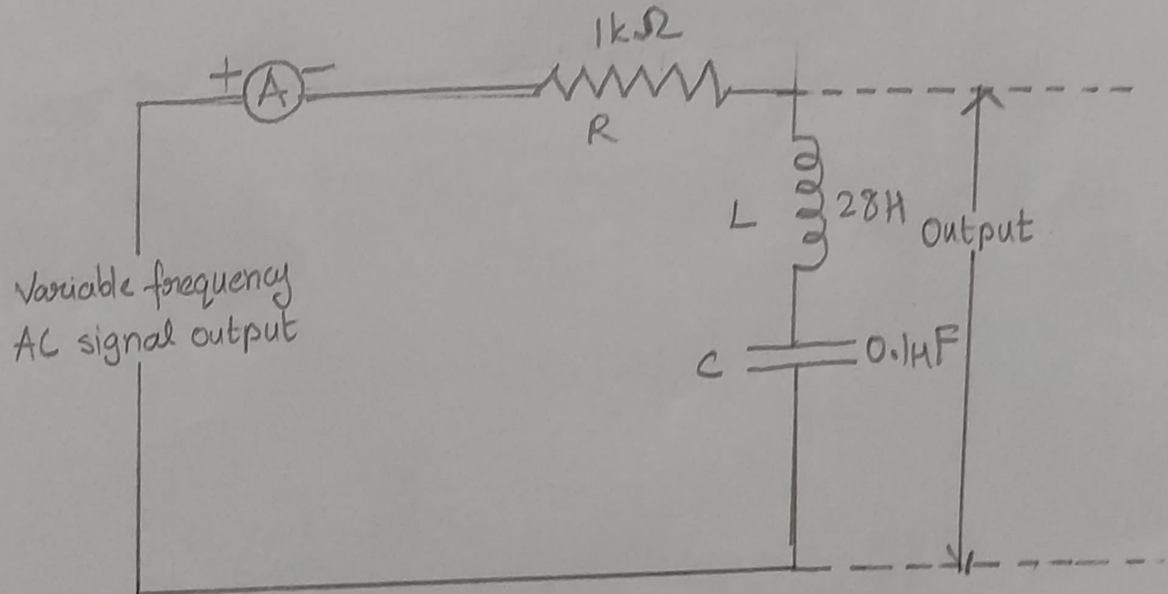
$$X_L = X_C$$

$$2\pi f_r L = \frac{1}{2\pi f_r C}$$

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



RESONANCE CURVE



SERIES RESONANCE CIRCUIT

PROCEDURE:

(i) Select sine wave from the signal generator.

(ii) Set the frequency range of input sine wave at range 306.3 Hz to 30kHz by variable frequency knob.

(iii) Connect the multimeter acting as ammeter in series with function generation and circuit.

(iv) Vary the frequency by frequency variable knob of F.G. and note the value of current.

(v) Again change the range of F.G. from 1 Hz to 10 Hz from frequency, change knob of F.G.

(vi) Vary the frequency by frequency variable knob of F.G. and note the value of current.

(vii) Note the frequency at which current I is max.

(viii) Calculate the Resonant frequency by formula

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

(ix) Compare measured and calculated frequency.

(x) Plot the resonance curve between frequency (f) and current (I)

CALCULATIONS:

Calculated resonant frequency of given apparatus

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{28\times10^{-3}\times10^{-7}}}$$

$$= 3007.75 \text{ Hz}$$

$$= 3.008 \text{ kHz}$$

OBSERVATION TABLE:

Sr. no.	Frequency (Hz)	Current (mA)
1	306.7	0.062
2	569.4	0.111
3	723.2	0.137
4	1000	0.180
5	1508	0.239
6	1902	0.266
7	2000	0.271
8	2500	0.284
9	2800	0.285
10	3200	0.281
11	3600	0.272
12	4000	0.261
13	4500	0.246
14	5000	0.229
15	5500	0.214

RESULT:

In series circuit,

Maximum result = 0.285 mA (frequency = 2800 Hz)
Minimum result = 0.062 mA (frequency = 306.7 Hz)

CONCLUSION:

(i) The characteristic of series resonant circuit when variable frequency is applied on be obtained from practical and theoretical observations.
(ii) At resonance, the current drawn is in phase with the voltage.
(iii) The difference in observed and calculated value is may be due to the internal resistance of the

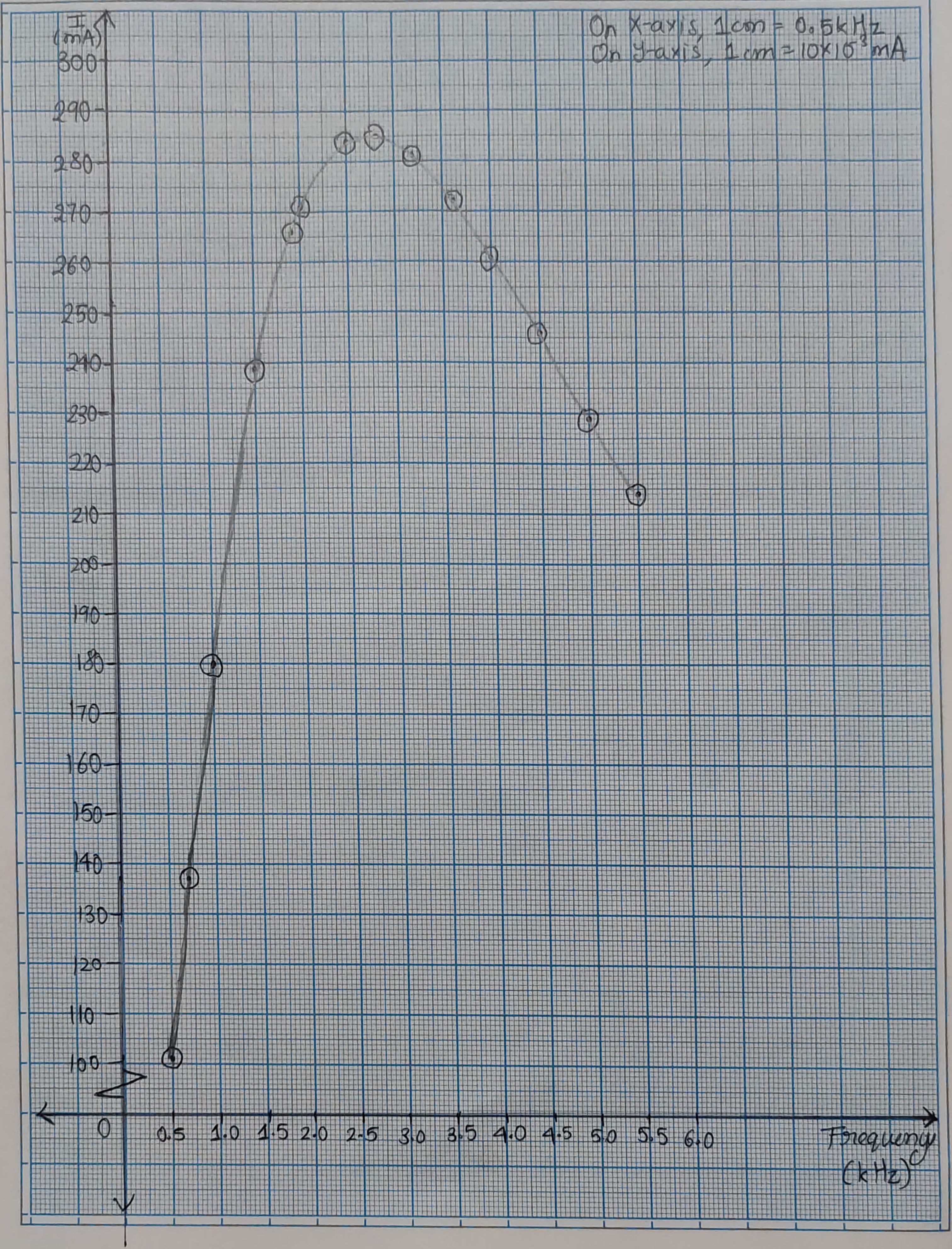
patch chords.

PRECAUTIONS:

(i) Frequency must be increased gradually.

(ii) Voltage must be adjusted properly according to the marking.

(iii) Check the connection before switching on the circuit.



On X-axis, 1cm = 0.5kHz
On y-axis, 1cm = 10×10^{3} mA
I (mA)
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
Frequency (kHz)

EXPERIMENT NO. 5

PARALLEL RESONANT CIRCUIT.

PARRALLEL RESONANT CIRCUIT

AIM:
Study of parallel resonant circuit

APPARATUS:
Trainer kit of parallel resonant circuit, signal generator, patch ~~dor~~ cords, multimeter.

THEORY:
Inductive reactance increases as the frequency is increased but increased capacitive reactance ~~increases~~ decreases with higher frequencies. Because of this opposite characteristics, for any LC combination, there must be a frequency at which X_L equals to X_C, as one increases while other decreases. This case of equal and opposite reactance is called resonance and the AC circuit is then a resonant circuit

• PARALLEL RESONANT CIRCUIT

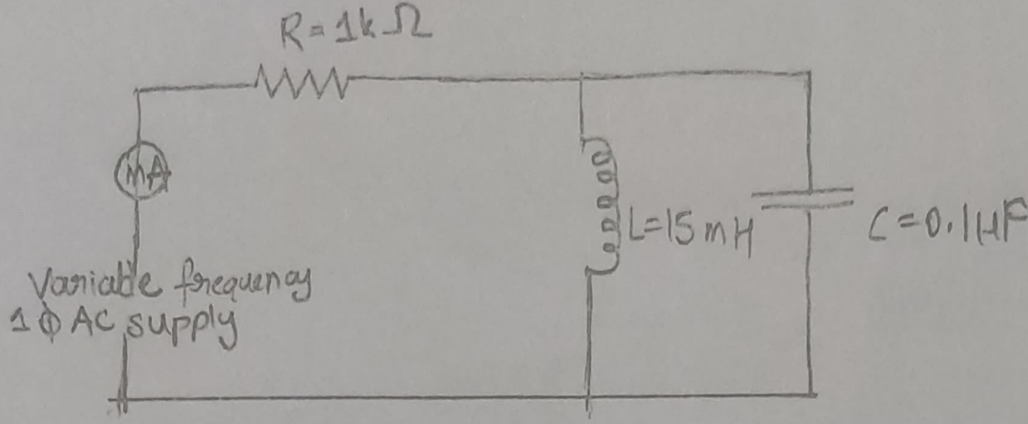
A parallel resonant circuit is another type of frequency sensitive circuit. This type of circuit is similar in function to the series circuit of resonance, however its electrical characteristics are different. The rank circuit is a parallel configuration of L and C, which may be used to select or reject specific frequencies of the circuit when the resonant frequencies is applied to the input of a parallel resonant circuit.

(i) $X_L = X_C$

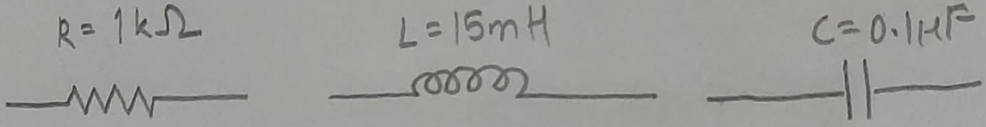
(ii) $I_L = I_C$ and $I_R = 0$

(iii) $Z = R$

(iv) Phase angle $= 0$



CIRCUIT DIAGRAM



RLC FOR EXPERIMENT

- EFFECT OF PARALLEL RESONANCE

(i) Net reaction of the circuit is zero.

$$I_C = I_{coil} \sin \phi_{coil} \quad -①$$

(ii) Active components are equal

$$I_T = I_{coil} \cos \phi_{coil} \quad -②$$

- RESONANT FREQUENCY (f_r)

At parallel resonance,

$$I_C = I_{coil} \sin\phi_{coil},$$

$$V_C = I_C \cdot \cancel{Z} X_C$$

$$V_{coil} = I_{coil} \cdot Z_{coil}$$

$$\therefore \cancel{V_C =} \quad \boxed{I_C = \frac{V_C}{X_C}}$$

- IMPEDANCE TRIANGLE

Put all these values in equation ①,

$$I_C = I_{coil} \sin\phi_{coil}$$

$$\frac{V_C}{X_C} = \frac{V_{coil}}{Z_{coil}} \cdot \frac{X_L}{I_{coil}}$$

$$\sin \phi_{coil} = \frac{X_L}{Z_{coil}} \quad ; \cos\phi_{coil} = \frac{R}{Z_{coil}}$$

$$V_C = V_{coil}' = V_r$$

$$\frac{1}{X_C} = \frac{X_L}{(Z_{coil})^2}$$

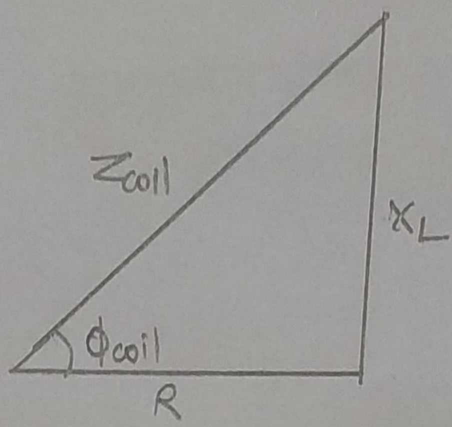
$$(Z_{coil})^2 = X_L \cdot X_C$$

$$\therefore (\sqrt{R^2+X_L^2})^2 = X_L \cdot X_C$$

$$\therefore R^2 + X_L^2 = X_L \cdot X_C$$

$$\therefore R^2 + X_L^2 = 2\pi f L \times \frac{1}{2\pi f C} = \frac{L}{C}$$

$$\therefore X_L^2 = \frac{L}{C} - R^2$$



IMPEDANCE TRIANGLE

$$\therefore \quad X_L = \sqrt{\frac{L}{C} - R^2}$$

$$\therefore \quad 2\pi f_r L = \sqrt{\frac{L}{C} - R^2}$$

$$\therefore \quad f_r = \frac{1}{2\pi L}\sqrt{\frac{L}{C} - R^2} = \frac{1}{2\pi}\sqrt{\frac{L}{CL^2} - \frac{R^2}{L^2}}$$

$$\therefore \quad f_r = \frac{1}{2\pi\sqrt{LC}}$$

- IMPEDANCE (Z)

$$I_T = \frac{V_T}{Z_T}, \quad I_{coil} = \frac{V_{coil}}{Z_{coil}}$$

$$\therefore \quad I_T = I_{coil}\cos\phi_{coil}$$

- CURRENT (I_T)

Because of largest impedance (Z_T), current flowing through the circuit (I_T) or parallel resonance circuit, current is minimum.

$$I_T = \frac{V_T}{Z_r}$$

PROCEDURE:

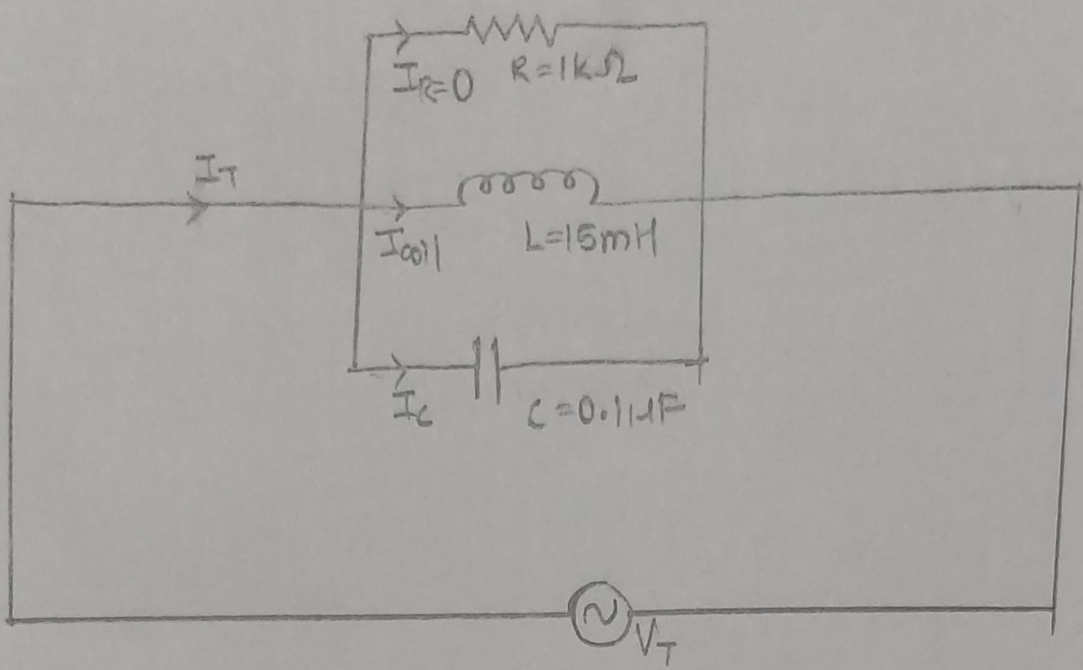
(i) Select sine wave from signal/function generator.

(ii) Set the range of frequency from 86 Hz to 1.1 kHz from frequency range knob.

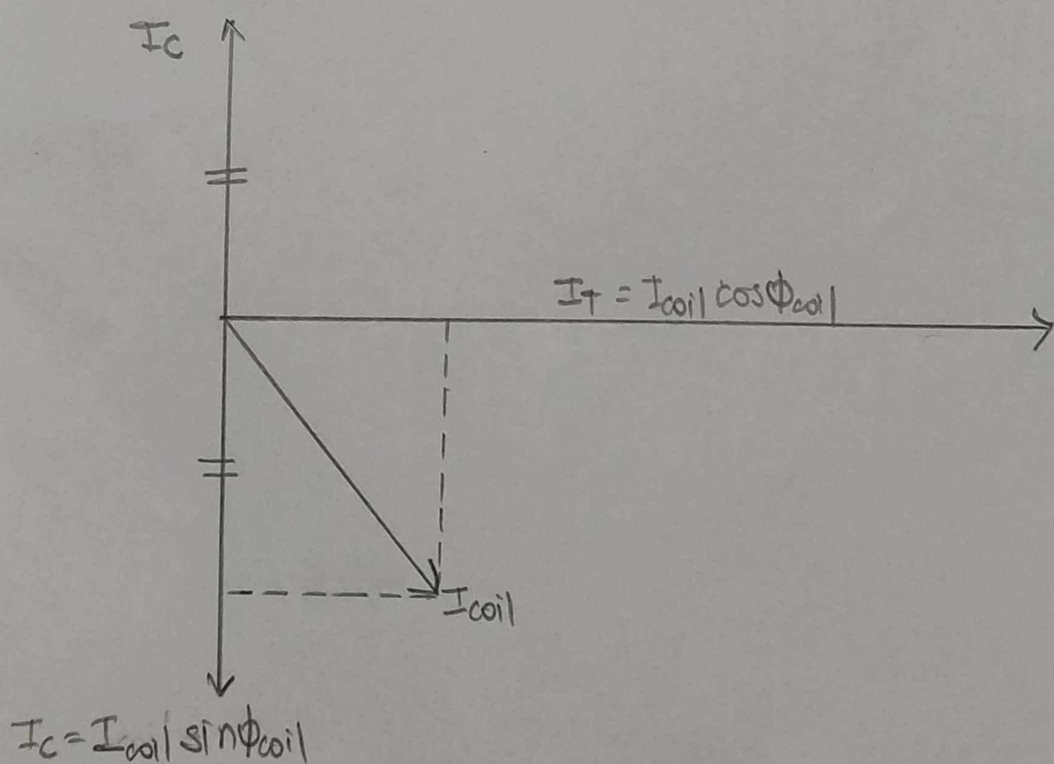
(iii) Connect the function generator output to the given assembled circuit as shown in figure.

(iv) Connect the multimeter in series with function generator and the resistance of the given circuit.

(v) Vary the frequency of the given input sinusoidal voltage by charging frequency variable knob of the given circuit (function generator)



PARALLEL RESONANT CIRCUIT



PHASOR DIAGRAM

(vi) Note the reading of current corresponding to change in frequency.
(vii) Change the range of frequency of input sinusoidal wave 1kHz to ~~H~~ 10kHz.
(viii) Vary the frequency and note the change in current.
(ix) Note the frequency for minimum value of current. This is the resonance frequency.
(x) Calculate the value of resonance frequency using formula

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

(xi) Compare the theoretical and practical values of resonant frequency.
(xii) Plot f_r Vs I.

OBSERVATION TABLE:

Sr. no.	Frequency (kHz)	Current (mA)
1	0.5	0.301
2	0.8	0.298
3	1	0.296
4	1.6	0.287
5	1.9	0.280
6	2.6	0.265
7	3	0.238
8	3.5	0.160
9	4.1	0.095
10	4.5	0.145
11	5	0.210
12	5.5	0.237
13	6	0.248
14	7	0.257

CALCULATIONS:

Calculated resonance frequency of given apparatus

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{15\times10^{-3}\times1\times10^{-7}}}$$

$$= 4109.36 Hz$$

$$= 4.109 kHz$$

RESULT:

In parallel circuit,

Maximum result (current) = 0.301 mA (freq = 0.5 kHz)

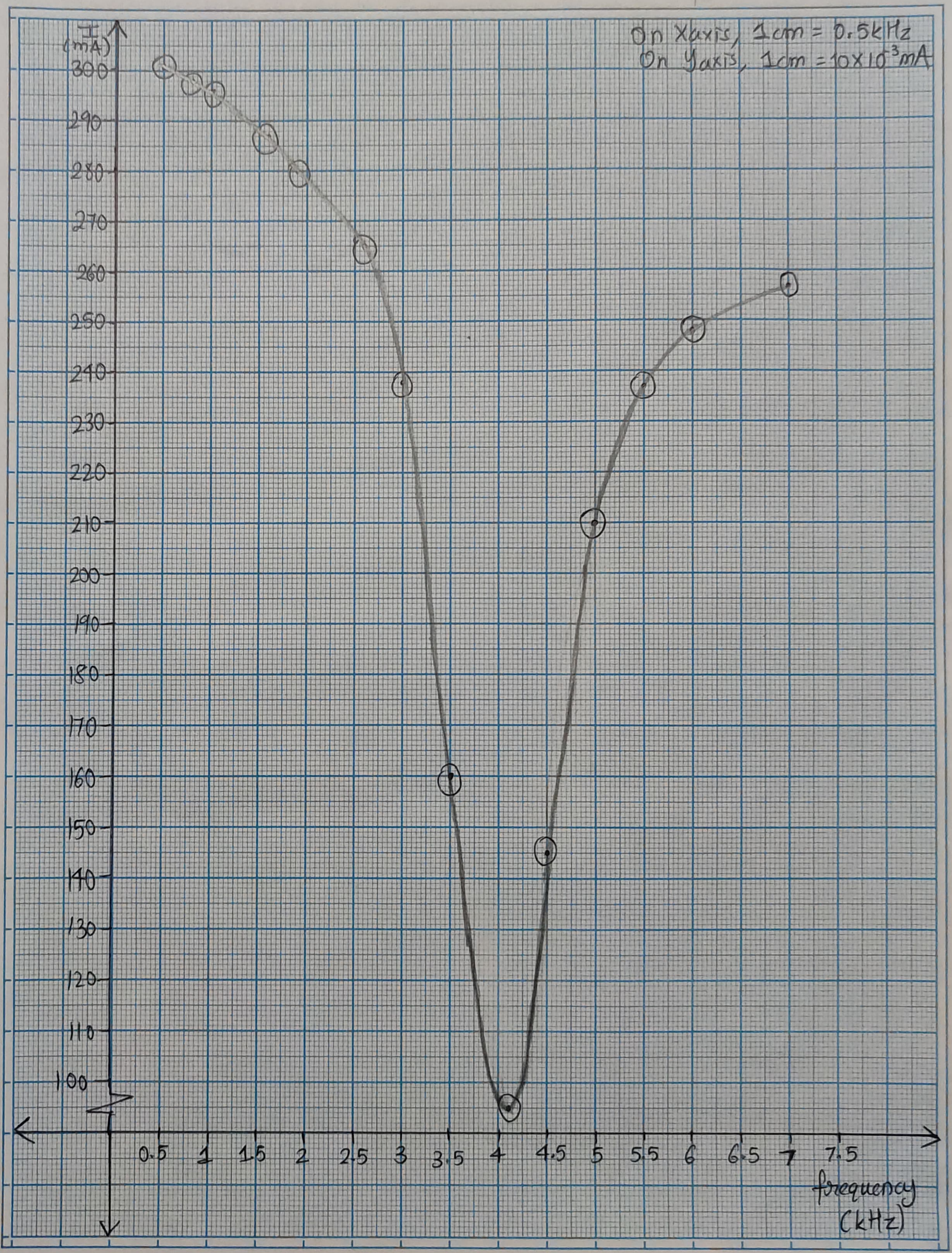
Minimum result (current) = 0.095 mA (freq = 4.1 kHz)

CONCLUSION:

The characteristics of parallel resonance are studied. As frequency is increased, current in the circuit is decreased. When the frequency is increased gradually, at a certain frequency minimum current is obtained. Then when we further increase the frequency, the current goes on increasing.

PRECAUTIONS:

(i) Patch cords should be connected tightly and properly.
(ii) Check the connections before switching ON the circuit.
(iii) Frequency must be increased gradually.
(iv) Voltage should be adjusted properly.



On Xaxis, 1cm = 0.5kHz
On Yaxis, 1cm = 10×10⁻³mA
I (mA)
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
frequency (kHz)

Experiment No. 6
Open Circuit And Short Circuit.

OPEN CIRCUIT AND SHORT CIRCUIT TEST

AIM:
To perform open circuit and short circuit test on a single phase transfomer.

APPARATUS:
Voltmeter, Wattmeter, ammeter, auto-transfomer, tapped transfomer.

- SPECIFICATION FOR O.C. TEST

Auto-transfomer : I/P 0-240V, 50Hz
O/P 0-270V, 50Hz
Max load to 10A

- Transformer : Rated power 1kVA
Primary 230V/250V
Secondary 0-55V

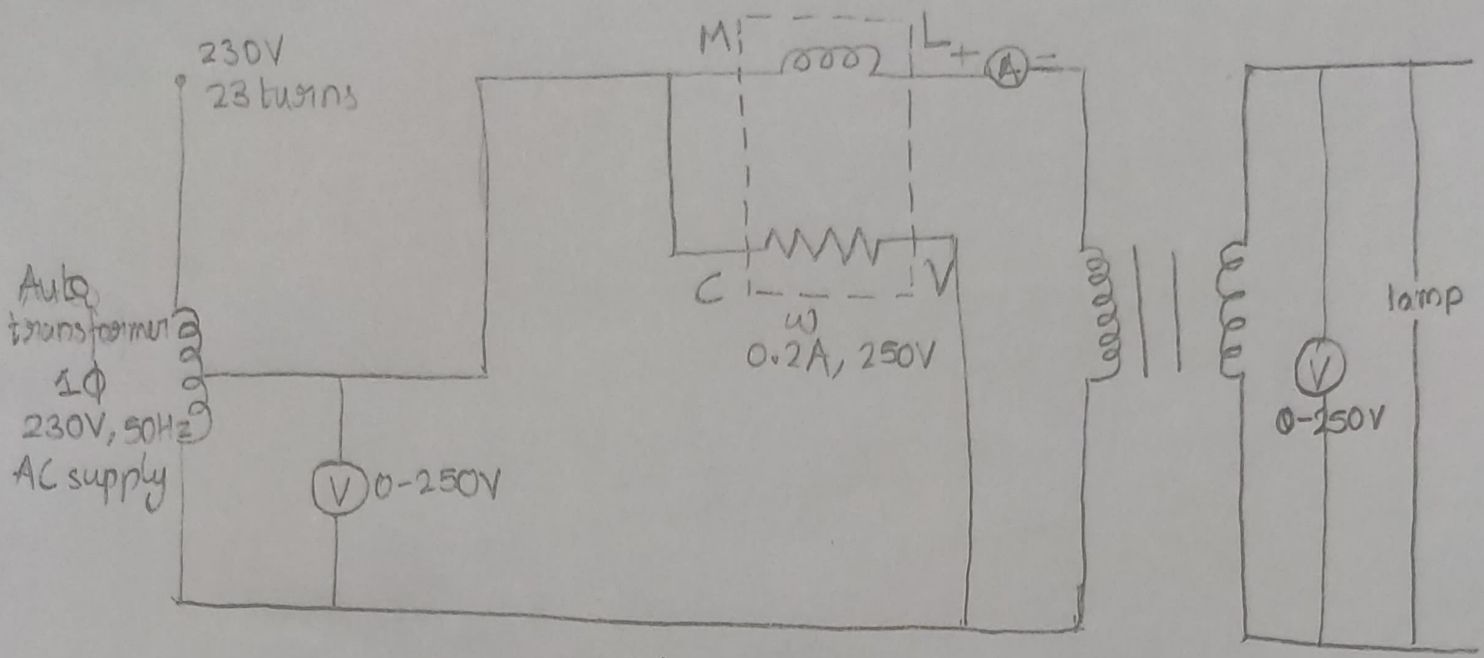
Voltmeter : 0-250V
Ammeter : 0-1A
Wattmeter : 0.2A, 250V, 0-50W

- SPECIFICATION FOR S.C. TEST

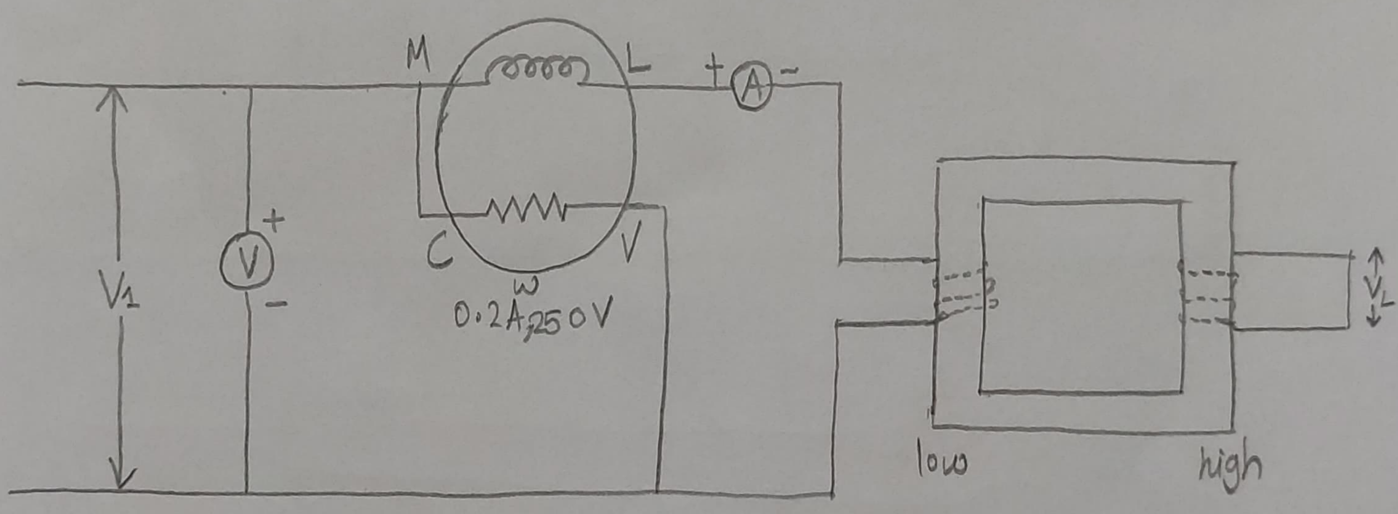
Auto-transformer : I/P 0-240V, 50Hz
O/P 0-270V, 50Hz
Max load is 10A

Transformer : Rated power 1kVA
Primary 230V
Secondary 0-30, 50, 100, 150, 270V

Voltmeter : 0-50V, 100V
Ammeter : 0-5, 10A
Wattmeter : 0-250W, 1A, 250V



OPEN CIRCUIT TEST



OPEN CIRCUIT

THEORY:

• TRANSFORMER TESTS

The performance of a transformer can be calculated on the basis of its equivalent circuit which contains four main parameter.

(i) The equivalent resistance R_{01}, as referred to primary (or secondary ~~R_{02}~~ R_{02})

(ii) The equivalent leakage reactance X_{01} as referred to primary (or secondary X_{02})

(iii) The core loss conductance C_0 (or reactance R_0).

(iv) The magnetising suspectance B_0 (or reactance X_0).

These constants can be easily determined by two tests:

(1) Open Circuit Test

(2) Short Circuit Test

These tests are economical and convenient, because they furnish the required information without actually loading transformer.

OPEN CIRCUIT OR NO LOAD TEST

The purpose of this test is to determine no loss ~~ore~~ coreless and no load to which is helpful in finding R_0, X_0 and R_s. One winding of the transformer, whichever is convenient but usually high voltage winding is left open and other is connected to its supply of normal voltage and frequency.

(i) A wattmeter W, voltmeter V and an ammeter A are connected in the low voltage winding i.e. primary.

(ii) ~~Whit~~ With normal voltage applied to the primary, normal flux will set up in the core, hence normal from losses will occur which one recorded by wattmeter.

(iii) As the primary no load current I_0 (as measured by ammeter)

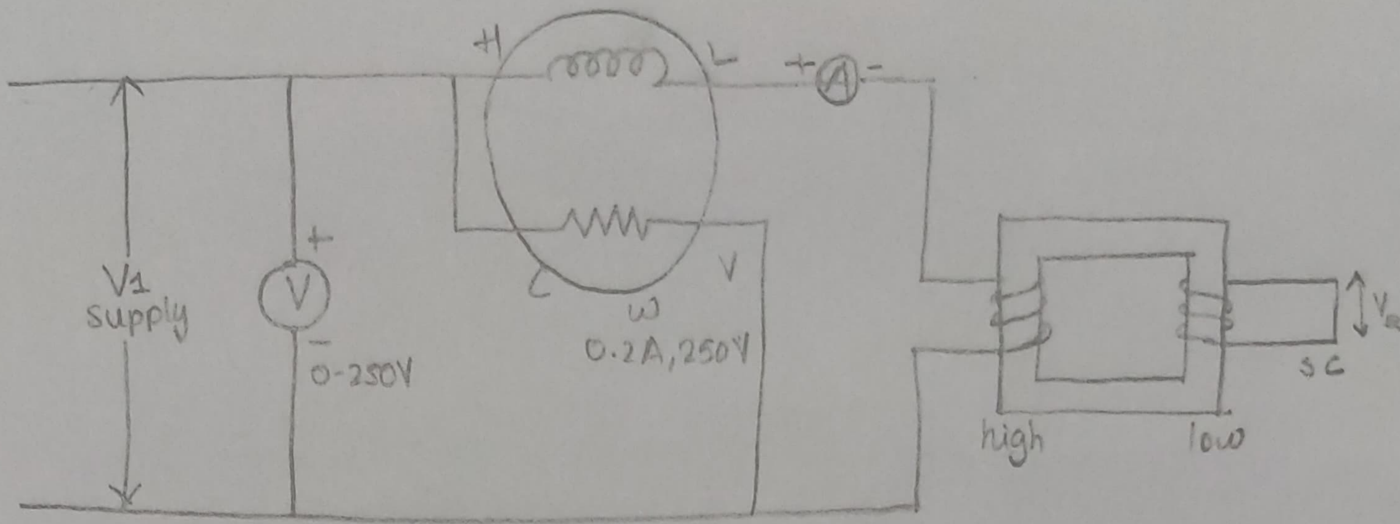


Fig ①

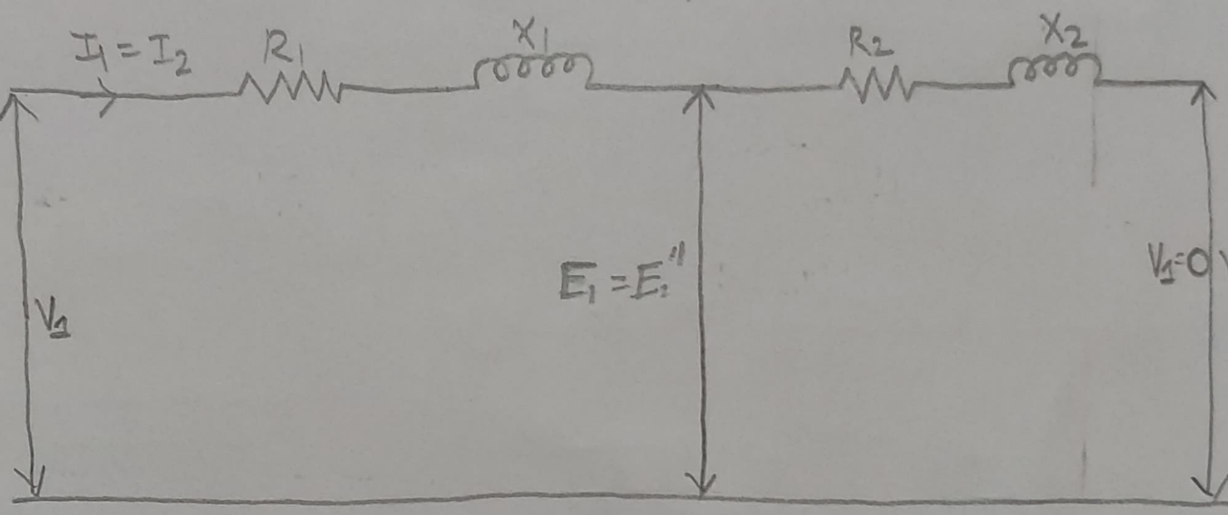


Fig ②

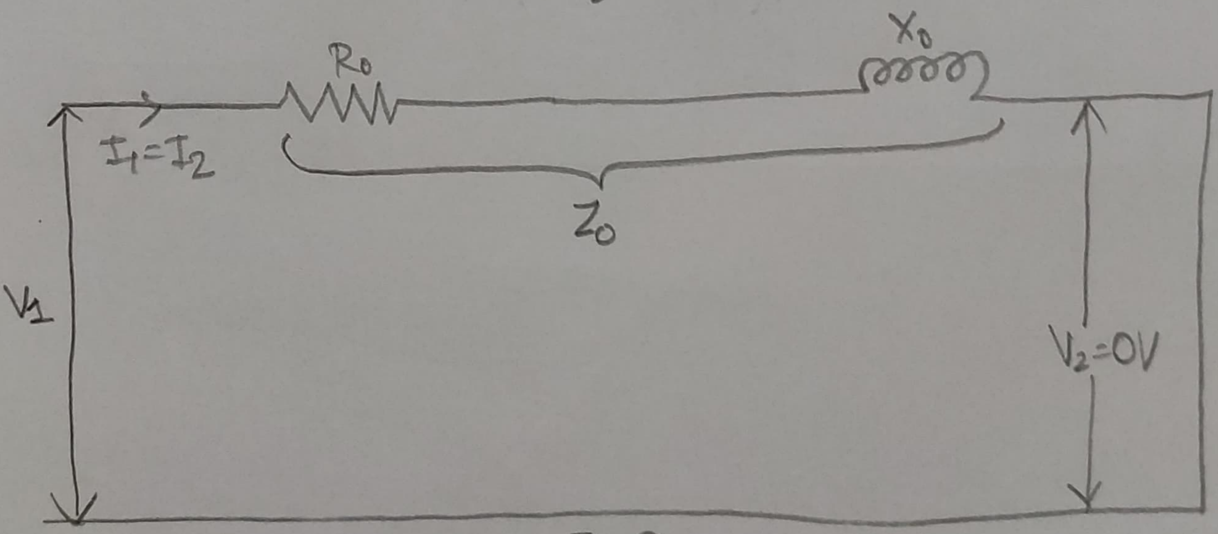


Fig ③

SHORT CIRCUIT

is small (usually ~~2~~ to 10% of rated load current), copper loss is negligibly small in primary and nil in secondary (it is being open).

(iv) Hence the wattmeter reading represents practically the core loss ~~is negligibly small in primary and nil in~~ under no load condition.

(v) It should be noted that since I_0 is itself very small, the pressure coils of the wattmeter the voltmeter is connected such that the current in there does not pass through the current coil of the ~~vo~~ wattmeter.

(vi) Sometimes a high resistance voltmeter ~~gives the~~ is connected across the secondary. The reading of the voltmeter gives the induced emf in the secondary winding. This helps to find transformation ratio K.

(vii) We know the no-load vector diagram, if W is the wattmeter reading, then

$$W = V_1 I_0 \cos\phi_0$$

$$\cos\phi_0 = \frac{W}{V_1 I_0}$$

$$I_m = I_0 \sin\phi_0$$

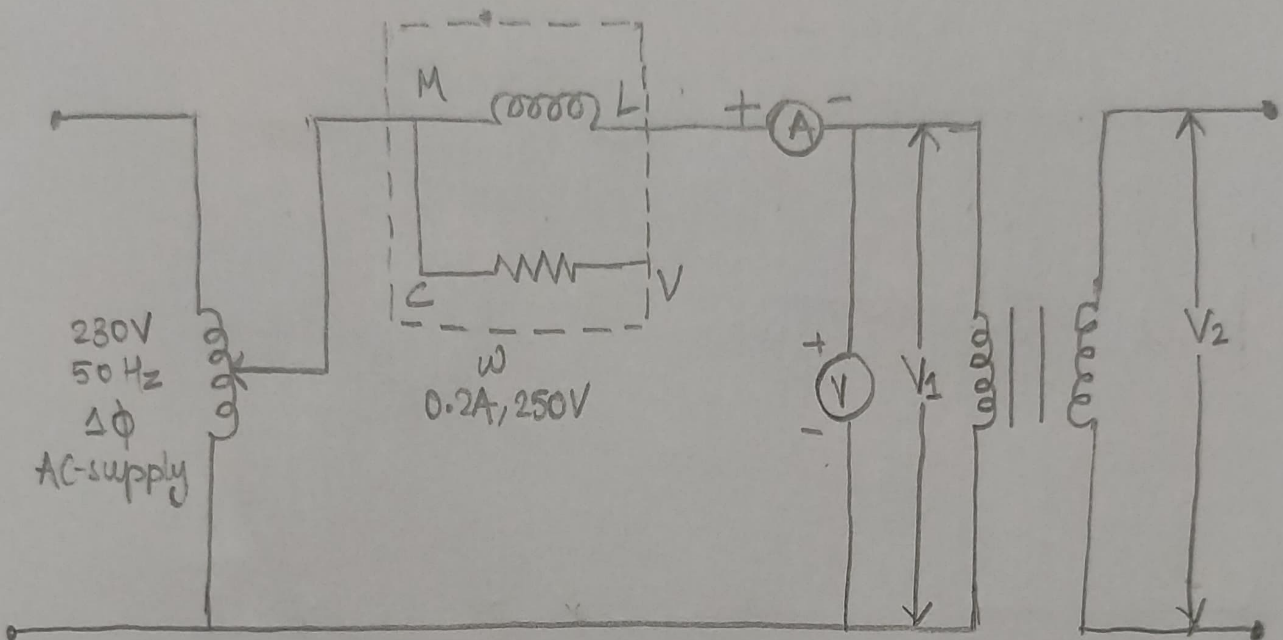
$$I_W = I_0 \cos\phi_0$$

∴ Current is practically on existing current when a transformer is on no load (i.e. $I_0 \cong I_m$) and as the voltage drop in primary leakage impedance is small, hence exciting admittance is Y_0 of transformers is given by $I_0 = V_1 Y_0$ or $Y_0 = \frac{I_0}{V_1}$

The exciting conductance $G_0 \Rightarrow W = V_1^2 G_0$

$$\therefore G_0 = W/V_1^2$$

The exciting suspectance $B_0 \Rightarrow B_0 = \sqrt{Y_0^2 - G_0^2}$



OPEN CIRCUIT TEST

① SHORT CIRCUIT OR IMPEDACE TEST

This is an economical method for determining the following

(i) Equivalent impedance (Z_{01} or Z_{02}) of the transformer as referred to primary winding in which the measuring instruments are placed.

(ii) Cu loss at full load (at any desired load). This loss is used in calculating the efficiency of transformer.

(iii) Keeping Z_{01} or Z_{02} the total voltage drop in the tranformer as referred to primary or secondary can be calculated and hence regulation of the transformer is determined.

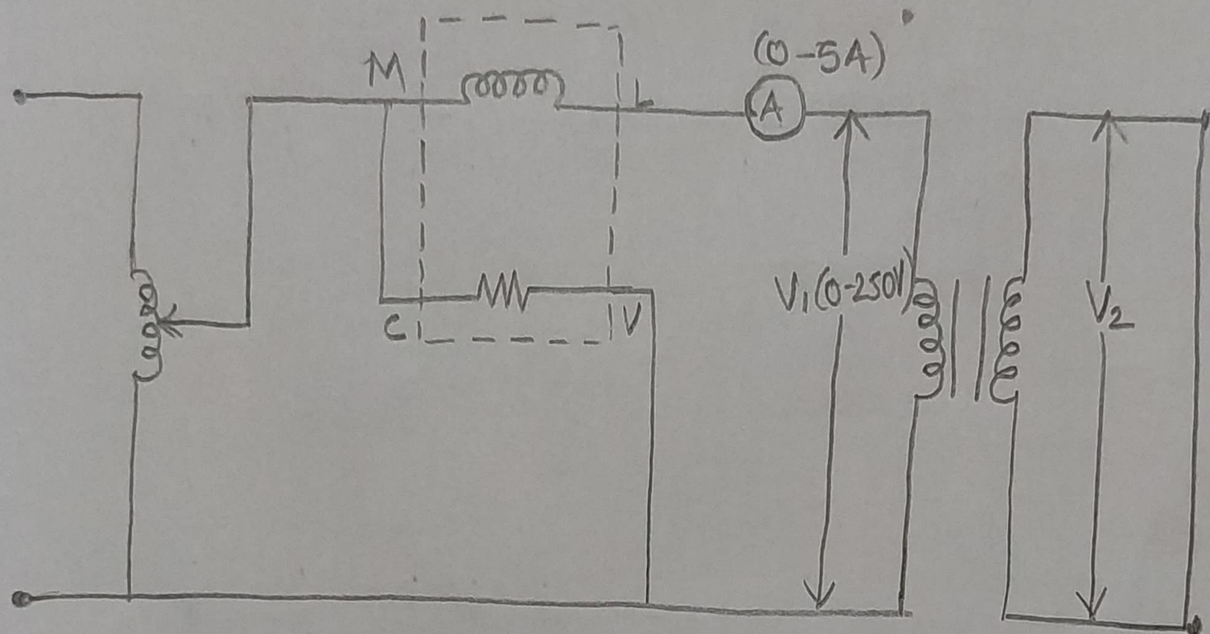
(iv) One winding usually the low voltage winding is slightly short circuited by a thick conductor (or through an ammeter) which may serve additional purpose of the indicating rated load current.

(v) A low voltage (usually 5 to 10% of normal primary voltage) at correct frequency is applied to the primary and is continuously and cautiously increased till full load currents are flowing (through) both in primary and secondary (as indicated by the respective ammeters).

(vi) In this test, the applied voltage is a small percentage of the normal voltage, the mutual flux produced is also a small percentage of its normal value.

Hence core losses are very small with the result that the wattmeter reading represents the full load Cu loss or I^2R loss for the whole transformer i.e. both primary Cu loss and secondary Cu loss.

The equivalent circuit of the transformer under short circuit conditions is shown in the figures ② and ③.



SHORT CIRCUIT TEST

If V_{sc} is voltage required to circulate rated load currents then $Z_{01} = \frac{V_{sc}}{I_1}$ and $W = \frac{I_1^2}{R_{01}}$

$$R_{01} = W/I_1^2$$
$$X_{01} = \sqrt{(Z_{01})^2 - (R_{01})^2}$$

PROCEDURE:

• FOR OPEN CIRCUIT

(i) Connect voltmeter in parallel with 230V, 1ϕ, 50 Hz AC supply.

(ii) Connect ammeter in series with AC supply and M terminal of the wattmeter.

(iii) Short M and C terminals of the wattmeter to P_1 of the primary of the transformer

(iv) Connect V terminal of wattmeter to P_2 terminal of the transformer and neutral auto transformer terminal.

(v) Connect second voltmeter in parallel across S_1 and S_2 of secondary transformer.

(vi) Set the variance to zero and switch on AC supply and set rated primary voltage of 230V to the auto transformer. Note it as V_0.

(vii) Measure the reading of ammeter. Note it as I_0 and measure wattmeter reading and note it as P_0.

• FOR SHORT CIRCUIT

(i) Set primary voltage such that rated current flows through primary terminal. Note it as Isc.

$$\therefore I_{rated} = \frac{P_{rated}}{V_{rated}} = \frac{1000}{230} = 4.347\,A$$

$$\therefore I_{rated} = I_{sc} = 4.347A$$

CALCULATIONS:

- FOR OPEN CIRCUIT

$$\cos\phi = \frac{W_1}{V_1 I_0} = \frac{48}{0.44(221.4)} = \frac{48}{97.42} = 0.493$$

$$\therefore \phi = 60.462^\circ$$

$$R_{OC} = \frac{V_1}{I_0 \cos\phi} = \frac{221.4}{0.44(0.493)} = 1020.7\,\Omega$$

$$X_{OC} = \frac{V_1}{I_0 \sin\phi} = \frac{221.4}{0.44(0.87)} = 578.4\,\Omega$$

- FOR SHORT CIRCUIT

$$Z_{SC} = \frac{V_{Th}}{I_{Th}} = \frac{V_{SC}}{I_{SC}} = \frac{14.61}{4.34} = 3.366\,\Omega$$

$$R_{SC} = \frac{W_{SC}}{I_{SC}^2} = \frac{57.5}{(4.34)^2} = 3.053\,\Omega$$

$$X_{SC} = \sqrt{(Z_{SC})^2 - (+(R_{SC}))^2}$$

$$= \sqrt{(3.66)^2 - (+3.053)^2}$$

$$= 1.415\,\Omega$$

(ii) Connect voltmeter in parallel with 230V, 50Hz AC supply. Note ~~if~~ it as V_{sc}. Connect ammeter in series with voltmeter and wattmeter. Note it as P_{sc}

(iii) Short M and C terminals of wattmeter is to P_1 i.e. primary of the transformer.

(iv) Connect the V terminal of wattmeter to Pa terminal of the transformer and neutral terminal of auto transformer.

(v) Short S_1 and S_2 terminals of secondary of the transformation.

OBSERVATION TABLE:

- FOR OPEN CIRCUIT TEST

Sr. no.	V_1 (V)	I_0 (A)	W_0 (W)	V_2 (V)
1	221.4	0.44	48	111.6

- FOR SHORT CIRCUIT TEST

Sr. no.	V_{sc} (V)	I_{sc} (A)	P_{sc} (W)	V_2 (V)
1	14.61	4.34	57.5	0

RESULTS:

- FOR OPEN CIRCUIT TEST

~~Mag~~ Magnetising resistance $(R_{oc}) = 1020.7\ \Omega$

Magnetising reactance $(X_{oc}) = 578.4\ \Omega$

- FOR SHORT CIRCUIT TEST

Equivalent resistance $(R_{sc}) = 3.053\ \Omega$

Equivalent reactance $(X_{sc}) = 1.415\ \Omega$

CONCLUSIONS:

- FOR OPEN CIRCUIT TEST

As the no load current is usually 3to 5% of the full load current, copper losses are negligible and the wattmeter indicates iron loss. The ammeter indicates no load current drawn by the transformer. Thus, open circuit test gives parameters like R_{oc} and X_{oc} and iron loss.

- FOR SHOR CIRCUIT TEST

Normally, the applied voltage is 5 to 10% of the rated voltage of this winding. Hence, fluxes produced in the core and small and iron losses are very small. Thus, wattmeter indicates full load copper loss. Hence, short circuit test gives parameters like R_{sc}, X_{sc} and copper loss.

PRECAUTIONS:

(i) Do not touch any live wires.

(ii) Connect all the devices properly and then check conditions before turning supply on.

(iii) Voltages must be in accordance with the specifications mentioned.

(iv) In off condition, variance should be in 0V.

(v) Directly don't switch off the variance. Reduce the voltage slowly and continuously up till zero.

EXPERIMENT No. 7
EFFICIENCY AND VOLTAGE REGULATION OF A SINGLE PHASE TRANSFORMER

EFFICIENCY AND VOLTAGE REGULATION OF A SINGLE PHASE TRANSFORMER

AIM:
To find the efficiency and voltage regulation of a single phase ~~Ф~~ transformer by direct loading method using lamp load.

APPARATUS:
Auto-transformer, voltmeter (V_1), wattmeter, transformer, ammeter (I_1 and I_2), voltmeter (V_2), lamp load (11 or 12 bulbs)

- SPECIFICATIONS:

Auto-transformer: I/P 240 V, 50HZ
O/P 0-270V, 50H
Max load 10A

Voltmeter: 0-250 [V_1] (DMM)

Wattmeter: 5A, 250 V, 0-1250W

Tranformer: Primary 0-230/250V
Secondary 0-55V/110V (55-0-55)
Rated power 1kVA

Ammeter: 0-5/10 A

Voltmeter: 0-250V [V_2]

Lamp load (Resistive load): 200W, 250V (11 to 12 bulbs)

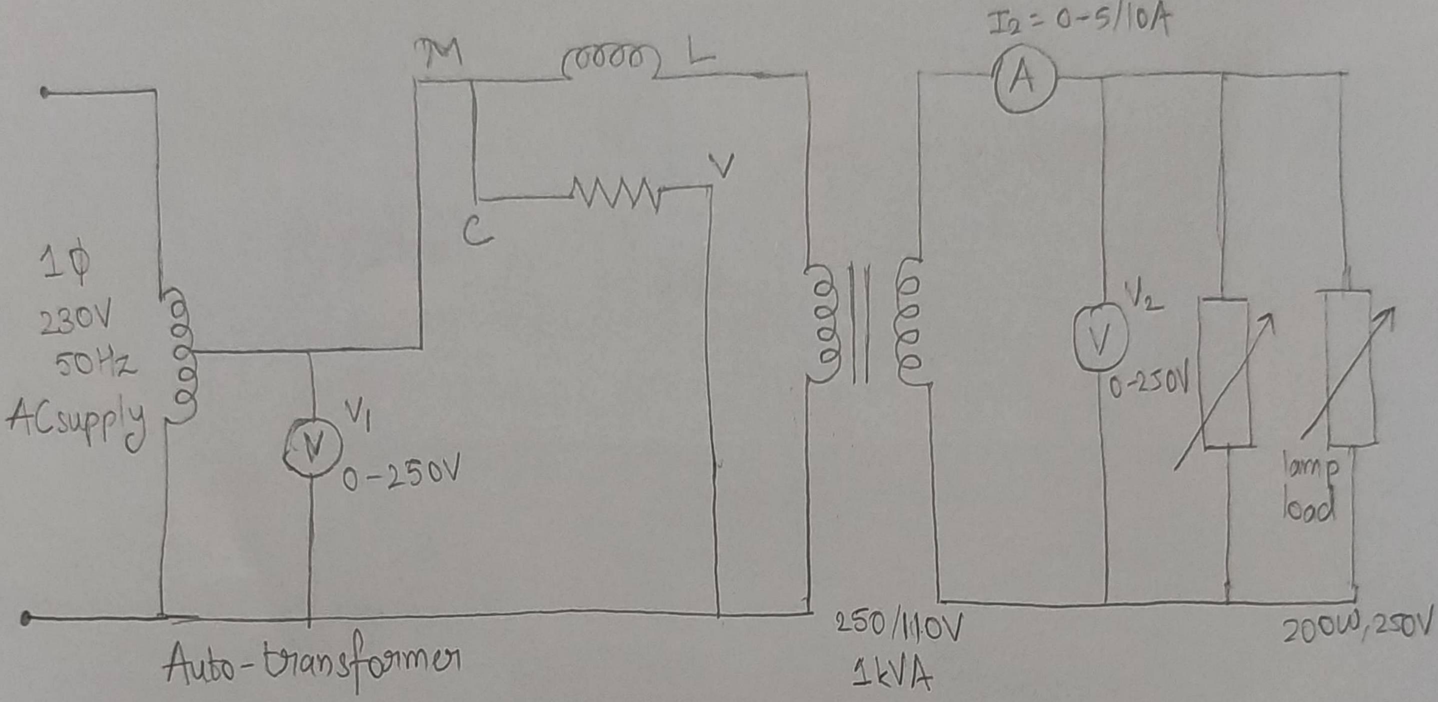
THEORY:

- EFFICIENCY OF A TRANSFORMER

Due to losses in a transformer, the output power of a transformer is less than the input power supplied. The efficiency of any device is defined as the ratio of the output power to the input power. So for a transformer, the efficiency can be expressed as

$$\eta = \frac{\text{o/p power}}{\text{i/p power}}$$

$$\eta = \frac{\text{o/p power}}{\text{o/p power total losses}}$$



CIRCUIT DIAGRAM

$$\eta = \frac{O/p \text{ power}}{O/p \text{ power} + W_i + W_w}$$

where, W_i = iron losses ; W_{cu} = Copper loss

In general, the efficiency at any load is given by

$$\% \eta = \frac{x \times \text{full load kVA} \times pf}{(x \times \text{full load kVA} \times pf) + W_i + x^2 [W_{cu}]_{FL}} \times 100$$

Where, W_i = iron loss in kW

$[W_{cu}]_{FL}$ = Copper loss at full load in kW

x = ratio of given load (actual to full load)

The explanation of the above expression of efficiency is given below:

For Transformer,

$$\text{Output power} = V_2 I_2 \cos\phi \text{ kW} = \frac{V_2 I_2}{1000} \cos\phi \text{ kW}$$

$$\text{But } \cos\phi = pf \text{ and } \frac{V_2 I_2}{1000} = \text{kVA}$$

~~But~~ So, O/p power = $(\text{kVA} \times pf)$ kW

The o/p power at any given load can be calculated as follows:

O/p power at any given load = (kVA at given load $\times pf$) kW

O/p power at any given load = ($x \times$ full load kVA $\times pf$) kW

Since kVA at given load = $x \times$ full load kVA

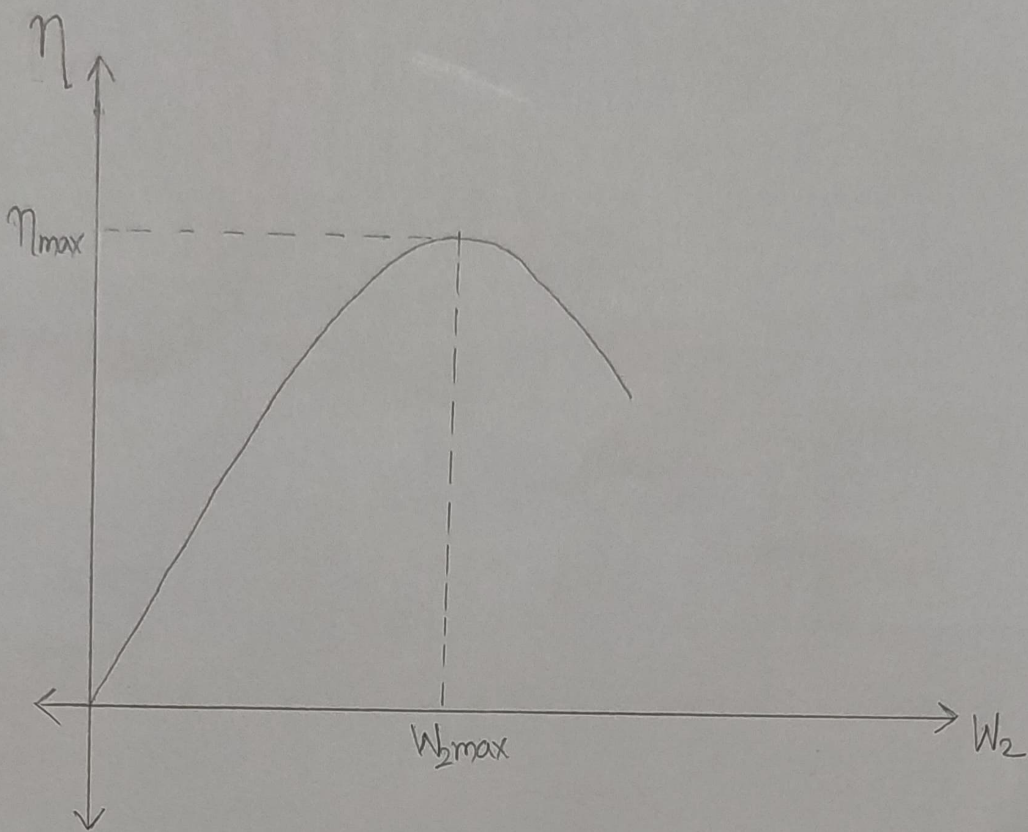
Where x is the ratio of given load (actual) to full load

~~EWcu~~ Since copper loss at any given load is given by

$[W_{cu}]$ at given load = $x^2 [W_{cu}]_{FL}$

So,

$$\% \eta = \frac{[x \times \text{full load} \times pf]}{[x \times \text{full load} \times pf] + W_i + x^2 [W_{cu}]_{FL}} \times 100$$



Fig①: Efficiency vs power load

- CONDITON FOR MAXIMUM EFFICIENCY

When a transformer works on a constant i/p voltage and frequency, efficiency varies with load. As load increases, the efficiency also increases. ~~As~~ At a certain load current, it achieves a maximum value. If transformer loaded further the efficiency starts decreasing. The graph of efficiency value versus load current I_2 is shown in fig①. The load current at which efficiency attains maximum value is denoted by $I_{2\,max}$ and maximum efficiency is denoted by η_{max}. We know that,

$$\eta = \frac{\text{o/p power}}{\text{i/p power}}$$

or

$$\eta = \frac{\text{i/p power} - \text{losses}}{\text{i/p}}$$

$\because$ (o/p power = i/p power − losses)

Let, $W_{cu} = I_1^2 R_{01}$ or $W_{cu} = I_2^2 R_{02}$

Iron (core) losses $= W_i$

i/p power $= V_1 I_1 \cos\phi$

$$\text{So, } \eta = \frac{V_1 I_1 \cos\phi - I_1^2 R_{01} - W_i}{V_1 I_1 \cos\phi} = 1 - \frac{I_1 R_{01}}{V_1 I_1 \cos\phi} - \frac{W_i}{V_1 I_1 \cos\phi}$$

The current I_1 varies according to the load. Therefore, in the above expression, the efficiency is a function of current I_1 assuming $\cos\phi$ as a constant. The applied voltage V_1 is also assumed as a constant.

For η_{max}, $\frac{d\eta}{dI_1} = 0$

$$\text{So, } \frac{d\eta}{dI_1} = 0 - \frac{R_{01}}{V_1 \cos\phi} + \frac{W_i}{V_1 I_1^2 \cos\phi} = 0$$

$$\therefore \quad \frac{W_i}{V_1 I_1^2 \cos\phi} = \frac{R_{01}}{V_1 \cos\phi}$$

$$W_i = I_1^2 R_{01}$$

or

$$W_i = I_2^2 R_{02} \quad [\because I_1^2 R_{01} = I_2^2 R_{02}]$$

Thus, condition for maximum efficiency achieved is
Iron loss = Copper loss

• VOLTAGE REGULATION

When a transformer is loaded, the secondary terminal voltage decreases due to a drop across secondary winding resistance and leakage reactance. This change in secondary terminal voltage from no load to full load conditions, expressed as a fraction of the no-load ~~to full load conditions~~ secondary voltage is called regulation of the transformer.

We can also express percentage regulation as:

$$\% \text{ regulation} = \frac{100 I_2 R_{02} \cos\phi}{E_2} \pm \frac{100 I_2 X_{02} \sin\phi}{E_2}$$

$$\therefore V_r \cos\phi \pm V_x \sin\phi$$

where, $V_r = \frac{100 I_2 R_{02}}{E_2}$ = percentage resistive drop

$V_x = \frac{100 I_2 X_{02}}{E_2}$ = percentage reactive drop

PROCEDURE:

(i) Connect the circuit
(ii) Switch on the primary i/p voltage at 250V
(iii) Switch on some of the load switches so that suitable current flows through secondary side
(iv) Take readings of i/p power from wattmeter, secondary voltage from voltmeter, secondary current from ammeter and primary current (I_1) connected in primary side.
(v) Repeat step 3 & 4 for diff. load current by switching of diff. nos. of lamps.
(vi) Calculate efficiency at different loads.
(vii) Plot graphs of η Vs W_2.

OBSERVATION TABLE:

Load	V_1	I_1	W_1	V_2	I_2	$W_2 = I_2 V_2$	$\eta = \frac{W_2}{W_1} \times 100$	% Regulation $\frac{E_2 - V_2}{E_2} \times 100$
0	230	0.39	25	110.4 ~~215~~	0 ~~110.4~~	0	0	
B_1	229.7	0.57	80	109.8	0.48	52.704	65.88	0.543
B_2	230.2	0.79	150	109.6	0.98	107.41	71.6	0.725
B_3	230.2	1	200	109.1	1.48	161.47	80.73	1.1777
B_4	228.4	1.2	262.5	108.2	1.93	208.826	79.5~~6~~5	1.993
B_5	229.3	1.42	312.5	107.7	2.43	261.711	83.75	2.446
B_6	228	1.64	362.5	107.1	2.91	311.66	85.97	2.989
B_7	227.8	1.87	425	106.5	3.4	362.1	85.2	3.533
B_8	227	2.09	475	105.9	3.87	409.833	86.18	4.076
B_9	226.3	2.31	525	105.9	4.36	461.72	87.94	4.076
B_{10}	226.9	2.54	575	105.3	4.84	509.62	88.63	4.619
B_{11}	227.9	2.77	637.5	105.6	5.32	561.8	88.12	4.348

CONCLUSION:

(i) The efficiency is maximum when iron loss is equal to copper loss.
(ii) Efficiency is maximum ~~ne~~ neither at full load nor at no load.
(iii) Efficiency is higher which shows accuracy because no rotating part is in the transformer.

PRECAUTIONS:

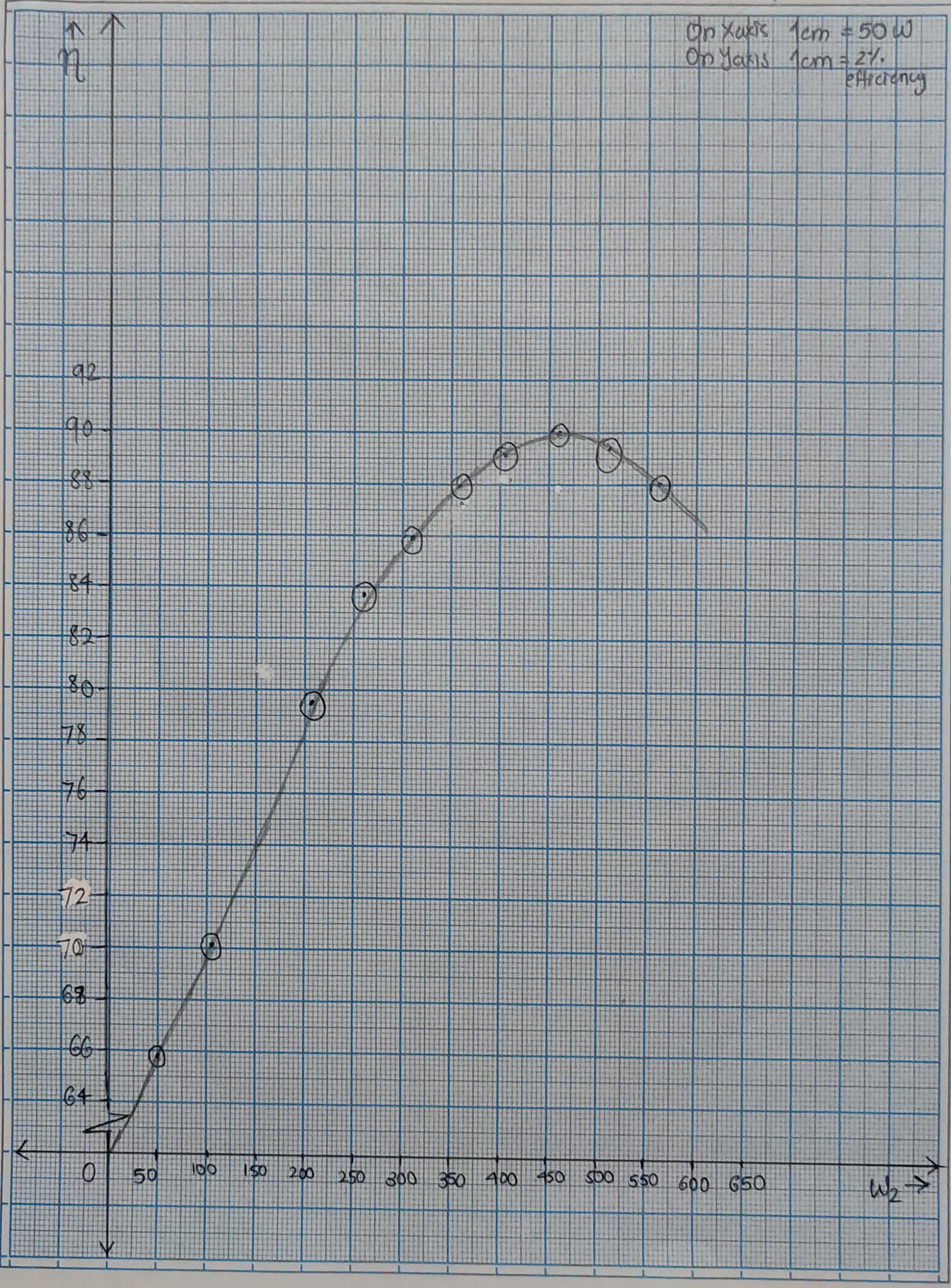
(i) Do not touch live wires
(ii) Connect all the devices properly and then check connections before turning supply ON.
(iii) The voltage must be increased slowly and gradually and similarly decreased gradually and continously uptil zero before switching OFF the circuit.
(iv) Voltages and currents must be in accordance with the

specifications mentioned.

(v) Ratings of the voltmeter and ammeter should be slightly greater than desired range

RESULT:

Maximum efficiency is obtained at 10A load and secondary current is 5.32 A which is equal to 88.12%.



On X axis 1cm = 50 W
On Y axis 1cm = 2% efficiency
η
92
90
88
86
84
82
80
78
76
74
72
70
68
66
64
0
50
100
150
200
250
300
350
400
450
500
550
600
650
W_2

EXPERIMENT No. 8

STAR AND DELTA CONNECTIONS

STAR AND DELTA CONNECTION

AIM:

To study the relationship between line and phase currents in a 3-phase star connected system and 3-phase delta connected system.

APPARATUS REQUIRED:

Auto transformer, bulbs (as load), digital multimeter (as ammeter and wattmeter), patch cords and power supply

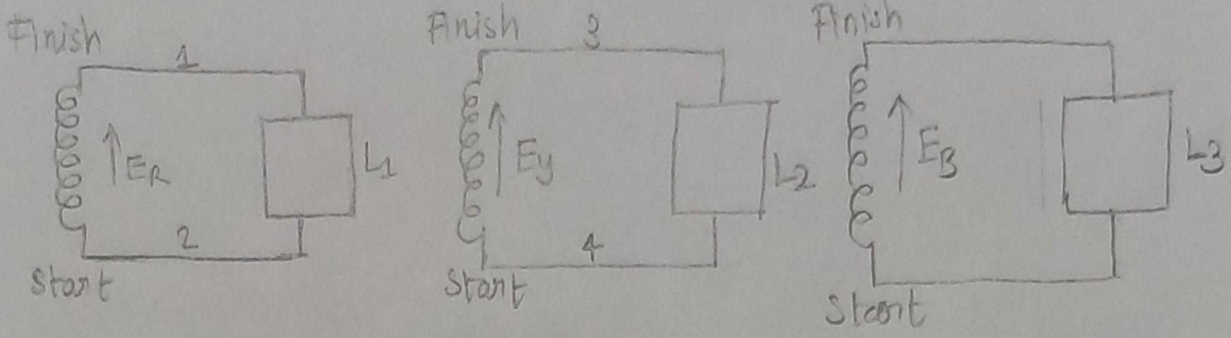
- SPECIFICATIONS
  - Auto transformer
    Connection for max o/p equal to voltage. I/p at A_1, A_2, A_3, 415V, 3ϕ, 50-60 Hz O/p at E_1, E_2, E_3 at 0.415V
    Connection for max o/p greater than i/p. I/p at B_1, B_2, B_3 415V, 3ϕ, 50-60 Hz. O/p at E_1, E_2, E_3 0.47V o/p current 20A/line
  - Bulbs (acting as load)
    $P = 100W$
    Voltage = 250V

THEORY:

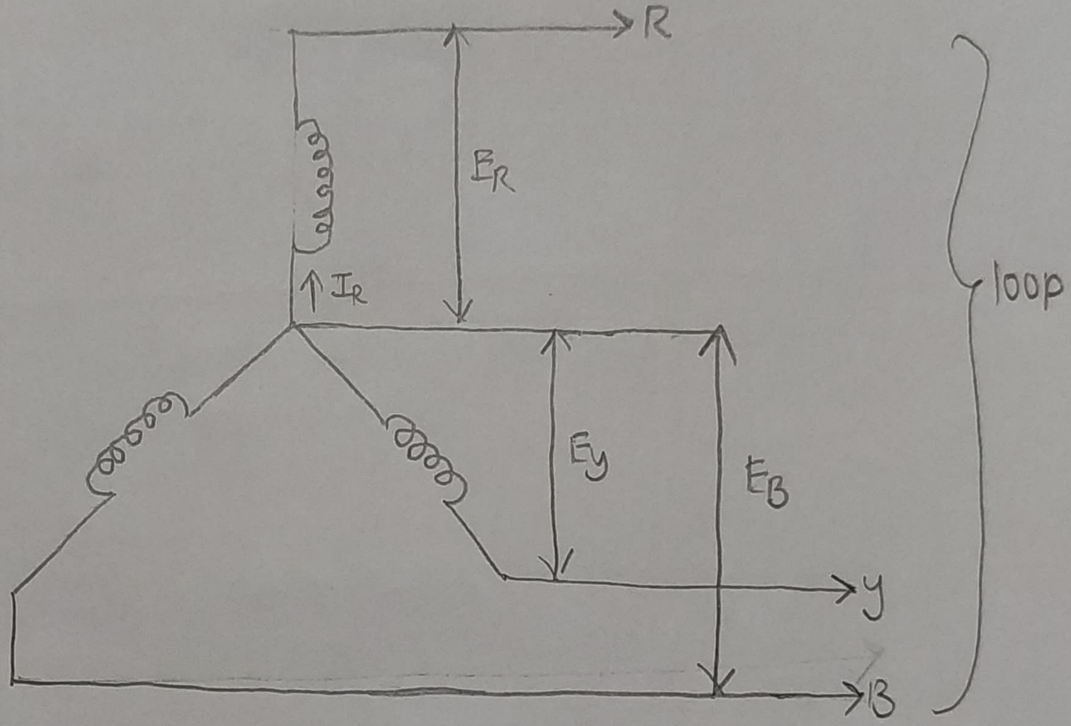
Iterconnection of three phases:

If the ammeter coils of the 3-phase alternator are not interconnected but one kept seperate as shown in fig①, then each phase would need two conductors, the total number of conductors in that case, being six, it means that each transmission cable could contain 6 conductors which ~~all~~ will make the whole system complicated and expensive. Hence, the three phases are generally interconnected which results in substantial saving of copper.

The general method of interconnections are



Loads fig①

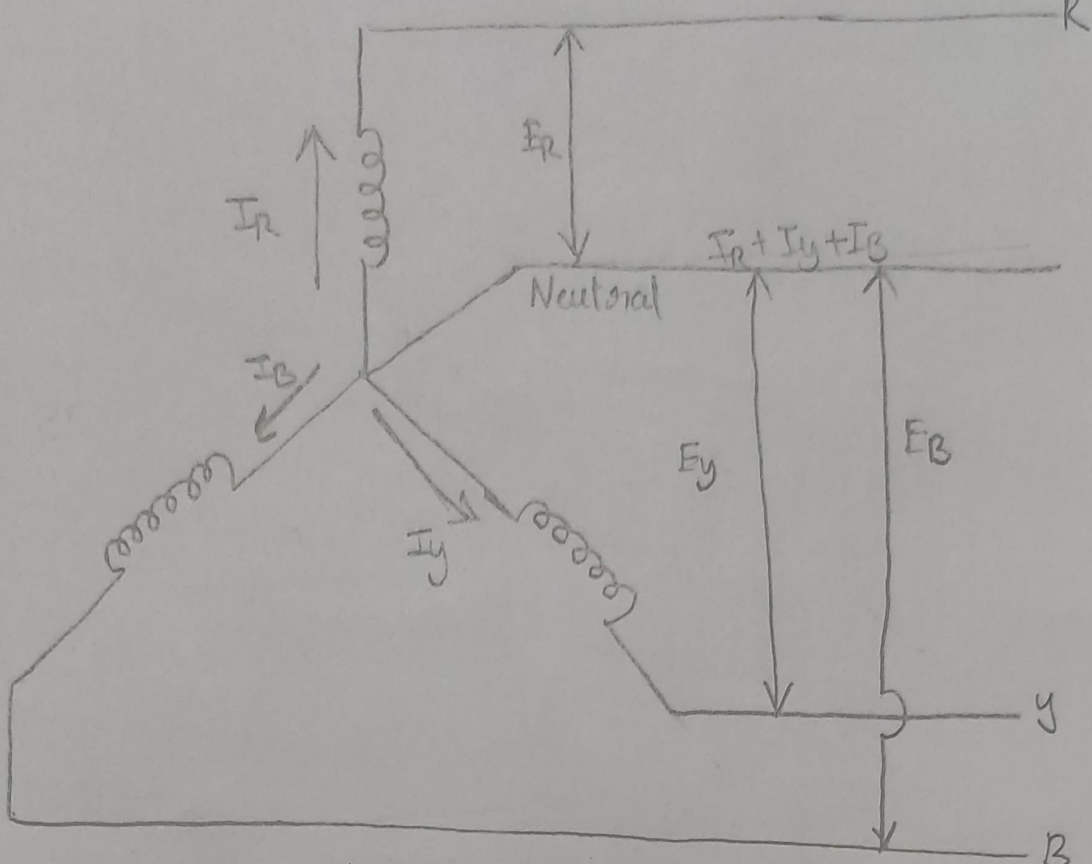


Four Wire Three Phase Connection

(i) Star or Wye (Y) connection
(ii) Mesh or Delta (Δ) connection

(i) Star or Wye (Y) connection
(a) In this similar ends say start ends of the three coil (finished end also) are joined togther at point N as shown in fig②.
(b) The point N is known as star point or neutral point.
(c) The three conductors meeting point N are replaced by single conductor called as neutral conductor (fig2(a)) Such an interconnected system is known as 4wire 3 phase system.
(d) If this 3 phase voltage system is applied across a balanced symmetrical load, the neutral wire will be carrying 3 currents which are exactly equal in magnitude but are 120° out of phase with each other. Hence, their value or vector sum is zero.

i.e. $I_R + I_y + I_B = 0$
(e) The neutral wire in that case my be omitted although its retention is useful in supplying lightning loads at low voltages
(f) The P.D. between any two lines gives the line to line voltages or simple line voltage.
(g) All the line voltage are sine waves of 50 Hz and phase shift between adjacent line voltage is 60°
(h) All the phase voltages are sine waves and phase difference between adjacent phase voltage is 120°.
(i) Voltages and currents in star connection
(1) Instantaneous values of P.D. between any two terminals is arthimetic difference of the two phase emf's concerned.
(2) RMS value of their P.D. is given by vector difference



Four Wire Three Phase System
(fig 2(b))

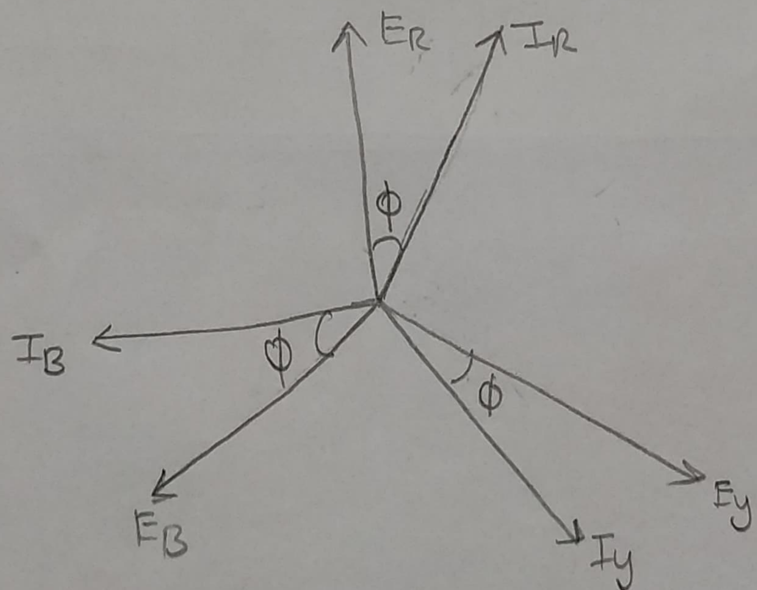


Fig (b)

(3) The vector diagram is shown in fig ⓑ. where a ~~bla~~ balanced system has been assumed.

Balanced system is one which voltange and currents in all 3ϕ's are equal in magnitude and also differ in phase by equal angles i.e. $120°$.

i.e. $E_R = E_y = E_B$

$V_{Ry} = E_R - E_y$, $V_{yB} = E_y - E_B$, $V_{BR} = E_B - E_R$

(j) Line voltages and phase voltanges:

P.D. between line R and y (line ① & ②) is

$V_{Ry} = E_R - E_y$ compounding

∴ Its value is given by diagonal of the parallelogram of fig.

∴ Angle between E_R and E_y reversed $= 60°$

$E_R = E_y = E_B = E_{ph}$ (phase)

$V_{Ry} = 2 \times E_{ph} \times \cos(60°/2)$

$= 2 \times E_{ph} \times \cos 30°$

$= \sqrt{3}\, E_{ph}$

$\boxed{V_{Ry} = \sqrt{3}\, E_{ph}}$

Similarly,

$V_{yB} = E_y - E_B = \sqrt{3}\, E_{ph}$; $V_{BR} = E_B - E_R = \sqrt{3}\, E_{ph}$

If $V_{Ry} = V_{yB} = V_{BR} = V_L$

then,

$\boxed{V_L = \sqrt{3}\, V_{ph}}$

∴ For star connection, $V_L = \sqrt{3}\, V_{ph}$

For phasor diagram,

(1) Line voltage are $120°$ apart

(2) Line voltage are $30°$ ahead of their respective phase voltages.

(3) Angles between line currents and corresponding line voltage is $(30 + \phi)$ with current lagging.

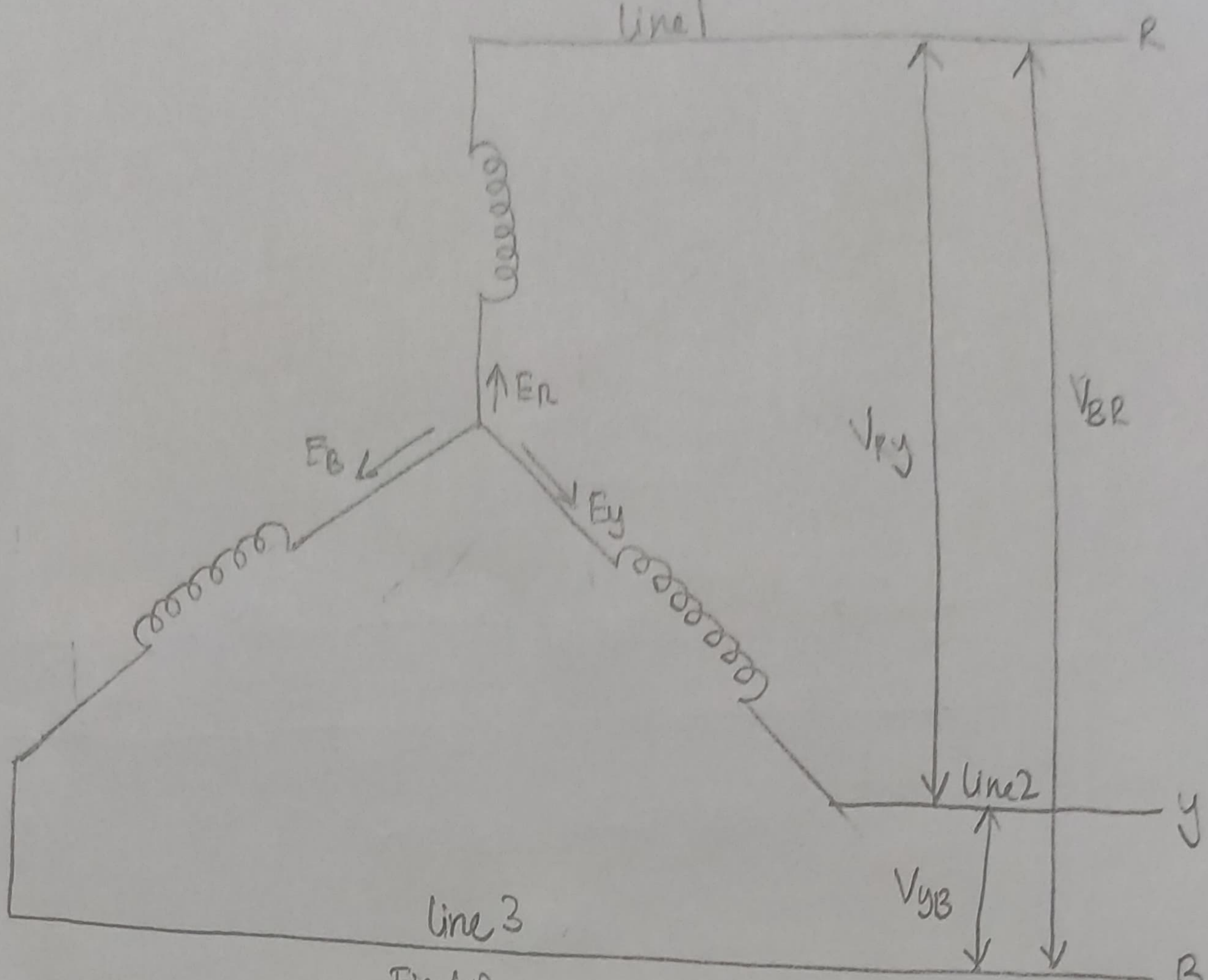
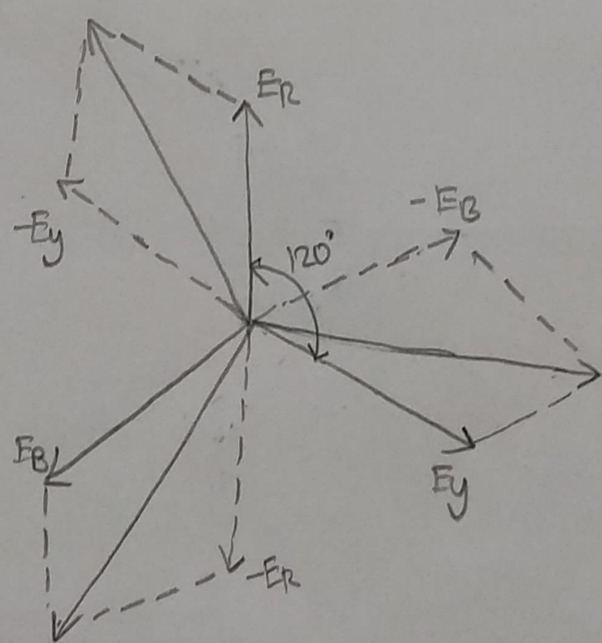


Fig (a)



Phasor Diagram for
Star Connection

(k) Line currents and phase currents:

From fig. ⓐ each line is in series with its individual phase winding

∴ Line current in each line is the same as the current in phase winding to which the line is connected.

∴ Current in line 1 (I_{CR}) $= I_R$

$I_R = I_Y = I_B = I_{ph}$ (Phase current)

∴ Line current $\boxed{I_L = I_{ph}}$

(l) Power

$P = \sqrt{3}\, V_L I_L \cos\phi$ where ϕ = angle b/w phase voltage and phase current

Total Reactive Power ⇒ $Q = \sqrt{3}\, V_L I_L \sin\phi$

$S = \sqrt{3}\, V_L I_L$

$S = \sqrt{P^2 + Q^2}$

(ii) Delta (Δ) or mesh connection

(a) Three windings are joined in series to form a closed ~~path~~ mesh.

(b) Voltage and Current in Delta Connection

Line voltage and Phase voltages

There is only one phase winding completely included b/w ~~and~~ any pair of terminals.

∴ Voltage b/w any pair of lines = phase voltage of phase windings connected b/w two lines (considered)

$V_{RY} = V_{YB} = V_{BR} = V_L$

i.e. $V_L - V_{ph}$

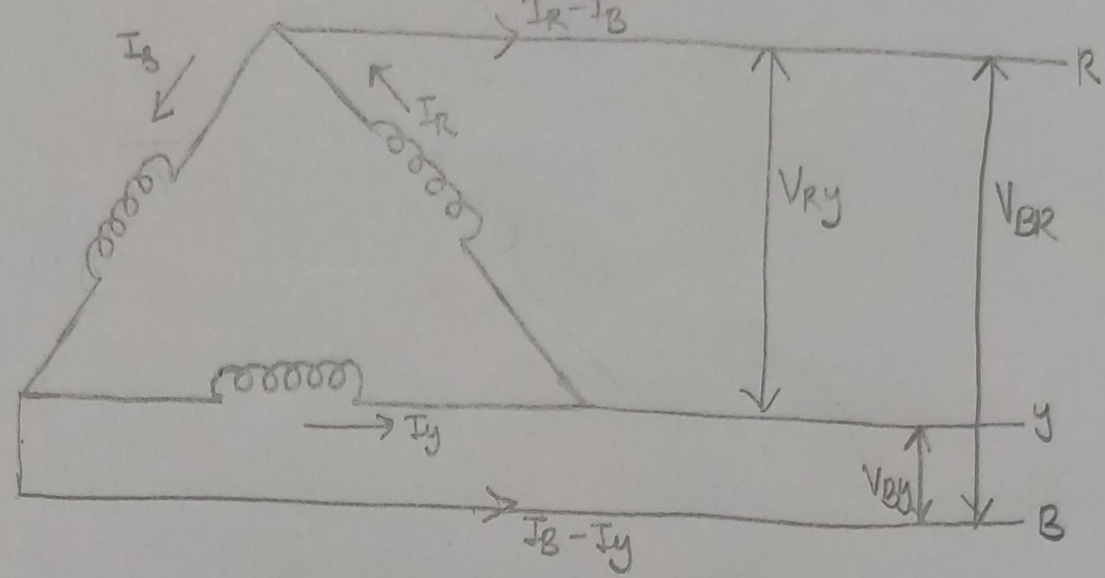
(c) Line current and Phase Current

Current in: Line R $= I_R - I_B$

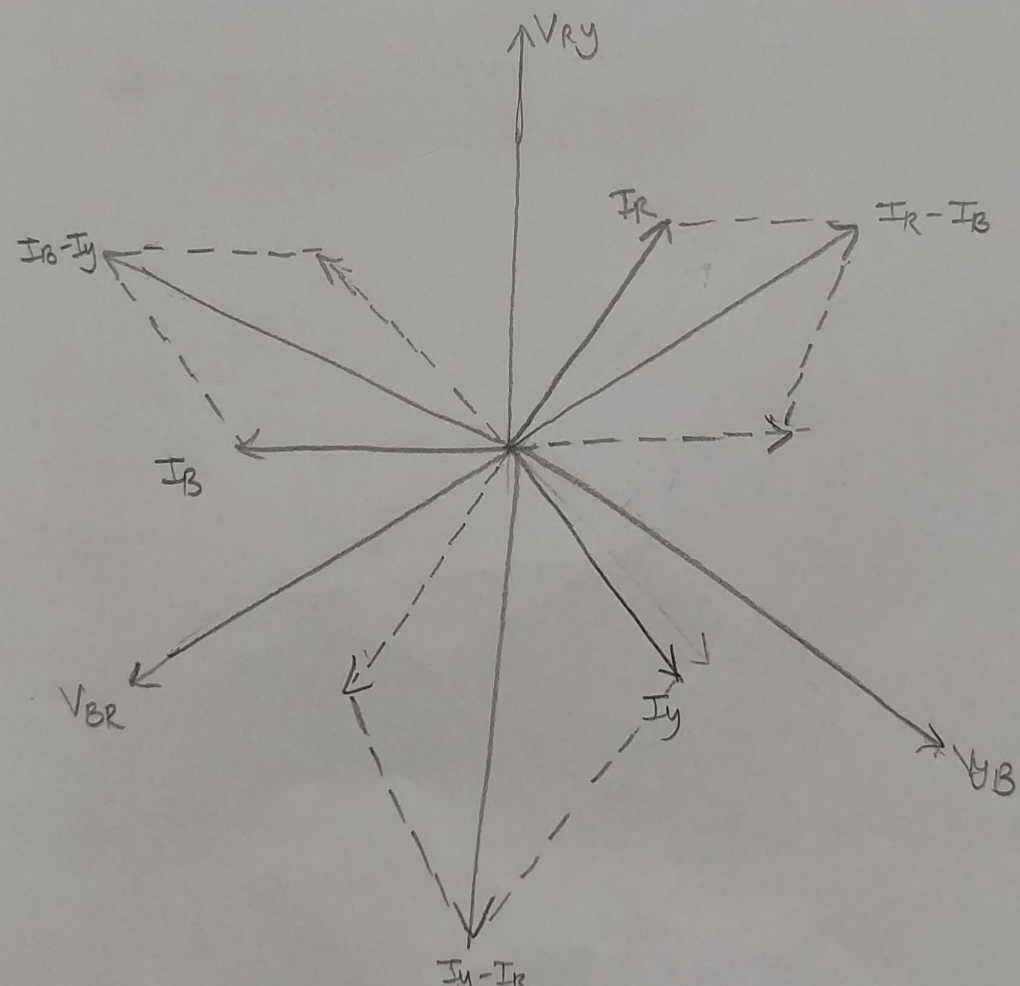
Line B $= I_Y - I_R$

Line Y $= I_B - I_Y$

Current in line ① (i.e. R) is formed by I_R and I_B reversed



3ϕ 3wire system



Phasor Diagram for Delta Connection

and its value is given by the ~~diagram~~ diagonal of the parallelogram

If $I_R = I_y = I_B = I_{ph}$ then,

Current in line ① (i.e. R) is

$$I_R - I_B = I_1 = 2 \times I_{ph} \times \cos(60/2)$$

$$= 2 \times I_{ph} \times \sqrt{3}/2$$

$$\therefore \boxed{I_1 = \sqrt{3}\, I_{ph}}$$

Similarly,

$$I_2 = I_B - I_y = \sqrt{3}\, I_{ph}$$

$$I_3 = I_2 = I_1 = \sqrt{3}\, I_{ph}$$

From vector diagrams its noted that,

(1) Line currents are 120° apart

(2) Line currents are 30° behind their respective phase currents.

(3) Angle b/w line currents and corresponding line voltages is $(30+\phi)$ with current lagging.

(d) Power

Power/Phase $= V_{ph} I_{ph} \cos\phi$

Total Power $= 3 V_{ph} I_{ph} \cos\phi$

But $V_{ph} = V_L$

$$I_{ph} = \frac{I_L}{\sqrt{3}}$$

$P = \sqrt{3}\, V_L I_L \cos\phi$, ϕ = Phase (Power factor angle)

& $Q = \sqrt{3}\, V_L I_L \sin\phi$

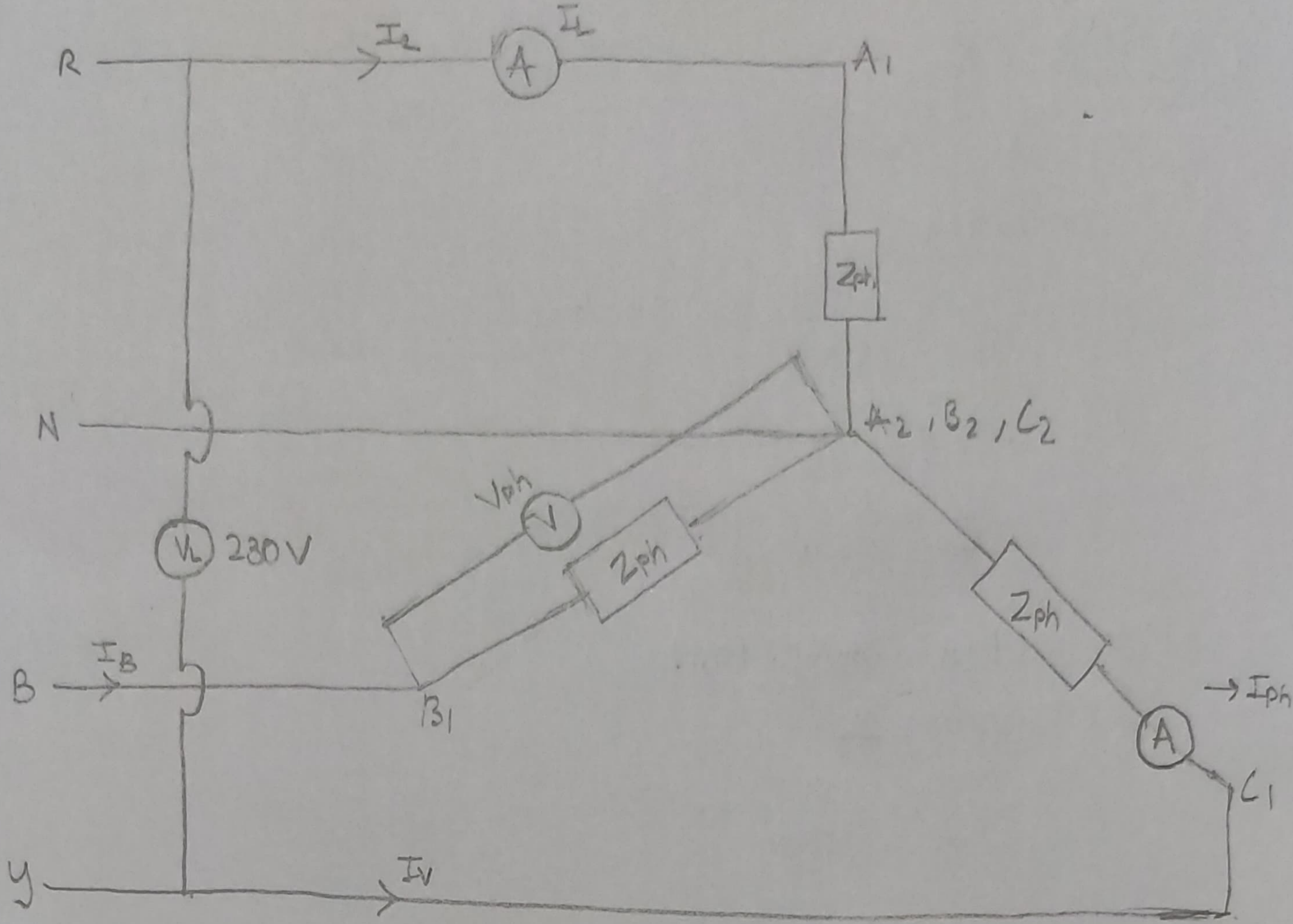
& $S = \sqrt{3}\, V_L I_L$

PROCEDURE:

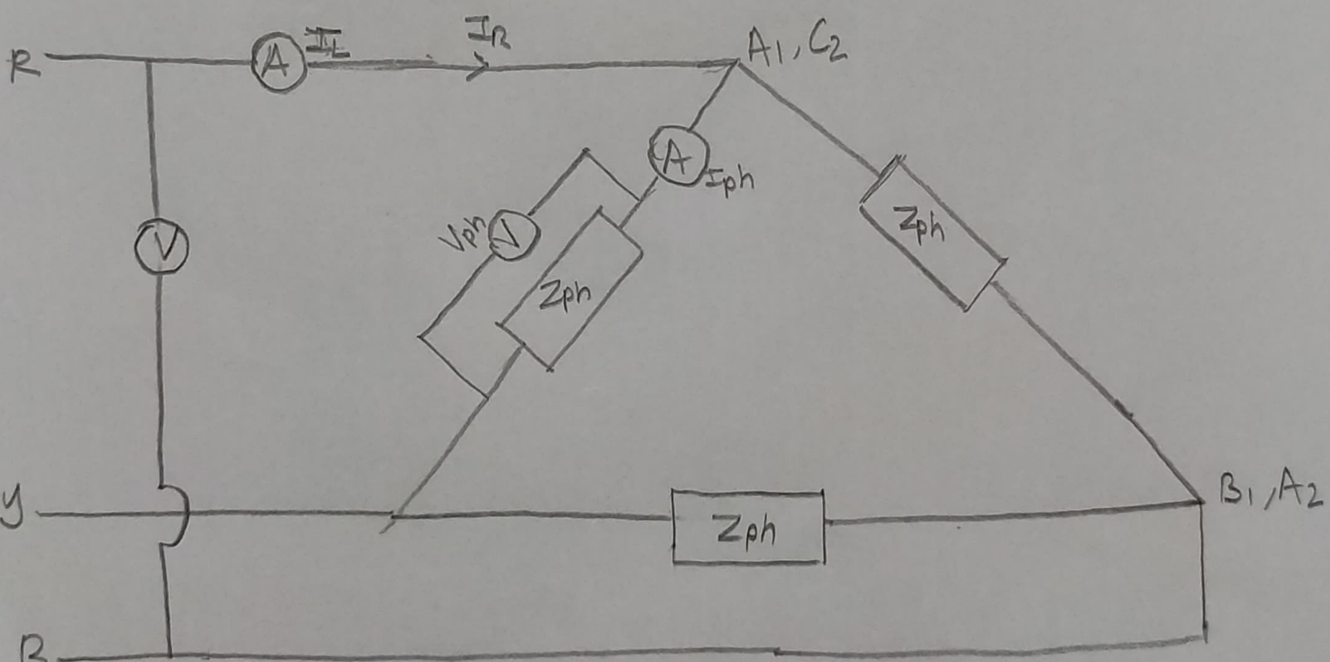
FOR STAR CONNECTION

(i) Setup the circuit as shown in the fig.

(ii) Insert an ammeter in R wire of supply and a terminal of lamp load to measure line current I_R/I_L.



CIRCUIT DIAGRAM FOR STAR CONNECTION



CIRCUIT DIAGRAM FOR DELTA CONNECTION

(iii) Connect a voltmeter b/w R and Y phase of 3ϕ AC supply to measure line voltage R_Y/V_P

(iv) For start connection similar terminals b_2, C_2 and a_2 are connected to form star point. Also connect it to neutral of 3ϕ AC supply.

(v) Each phase of supply R, Y, B is connected to a_1, b_1 and C_1 terminal of given 3 lamp load.

(vi) Insert an ammeter in series with anyone of the phase of lamp load then in a lamp load to measure phase current.

(vii) Connect a voltmeter in parallel to any one lamp load to 0 to 230V through measure phase voltage (V_{ph}), hence across C_1 & C_2.

(viii) Increase supply from 0-230V through auto-transformer.

(ix) Note the reading of V_L, V_{ph}, I_L and I_{ph} at no load.

(x) Switch on equal no. of lamp from 1 to 4 to each lamp load for balanced load and note reading of meters.

- FOR DELTA CONNECTION

(i) Set up the circuit as shown in fig.

(ii) Insert an ammeter in R line and a terminal of 1st lamp load to measure line current I_L/I_R.

(iii) Connect a voltmeter b/w R and Y of 3ϕ AC supply to measure line voltage V_{RY}/V_L.

(iv) For Delta connection of given three lamp loads, start terminal of one lamp load is connected to and terminal of other i.e. ac_2, a_2b, b_2c are connected.

(v) Insert an ammeter in series with any one of the phase lamp load (here 3 lamp load) to measure the phase current.

(vi) Connect a voltmeter across any one lamp load to measure phase voltage V_{ph} (here across C_1 and C_2).

CALCULATIONS:

- FOR STAR CONNECTION

(i) Reading 1

$$\frac{V_L}{V_{ph}} = \frac{220.9}{127.2} = 1.736 \approx \sqrt{3}$$

(ii) Reading 2

$$\frac{V_L}{V_{ph}} = \frac{219.3}{126.6} = 1.732 \approx \sqrt{3}$$

- FOR DELTA CONNECTION

(i) Reading 2

$$\frac{I_L}{I_{ph}} = \frac{199.7}{199.6} = 1.77$$

(ii) Reading 4

$$\frac{I_L}{I_{ph}} = \frac{195.6}{195.4} = 1.77$$

(vii) Each phase of supply R, Y, B, P_s connected to respective points of lamp load.

(viii) Increase supply ~~fo~~ from 0 to 230V through auto transformer.

(ix) ~~Increase supply~~ Note the readings of V_L, V_{ph}, I_L, I_{ph} at no load.

(x) Switch on equal no. of lamp load from 1 to 4 each lamp load for balanced load and note respective readings of meters.

OBSERVATION TABLE:

- FOR STAR CONNECTION

Lamp load	V_L	I_L	V_{ph}	I_{ph}	V_L/V_{ph}
0	220.9	0	127.2	0	1.736
1	219.3	0.53	126.6	0.5	1.732
2	218	1.08	12~~7~~6.3	1.08	1.730
3	216.8	1.61	125.5	1.60	1.737
4	216	2.15	125.1	2.40	1.726

- FOR DELTA CONNECTION

Lamp load	V_L	I_L	V_{ph}	I_{ph}	I_L/I_{ph}
0	200.6	0	201.3	0	–
1	199.7	1.19	199.6	0.67	1.77
2	198	2.37	198	1.34	1.76
3	195.6	3.54	195.6	2	1.77
4	194.5	4.71	194.2	2.66	1.77

RESULT:

FOR STAR - It has been verified, $I_L = I_{ph}$ and $I_L = \sqrt{3} V_{ph}$

FOR DELTA - It has been verified, $V_L = V_{ph}$ and $I_L = \sqrt{3} I_{ph}$

CONCLUSIONS:

The concept of 3 phase star and delta connection has been studied and the relation between power, line current, phase current and line and phase voltage has been studied.

PRECAUTIONS:

(i) Do not touch live wires.

(ii) Connect all devices properly and check connections before turning supply ON.

(iii) ~~Volge~~ Voltages must be in accordance with mentioned specifications.

(iv) Do not swith off the variac. Reduce voltage slowly.

EXPERIMENT No. 9
D.C MACHINES

AIM:
Study of D.C. Machines

APPARATUS:
D.C. Motor

THEORY:

• D.C. GENERATOR

(i) A machine that converts mechanical energy/power to electrical power of DC nature is called DC Generator.

(ii) Working Principle - Faraday's law of EMI:
If there is a relative motion b/w a inductor placed in a magnetic field and the field, a dynamically induced emf is produced in the conductor.

(iii) The direction of induced emf depends upon the direction of magnetic field and direction of motion is given by Fleming's right hand rule.

• D.C. MOTOR

A DC machine that converts electric power into mechanical power.

(i) Construction of DC Motor

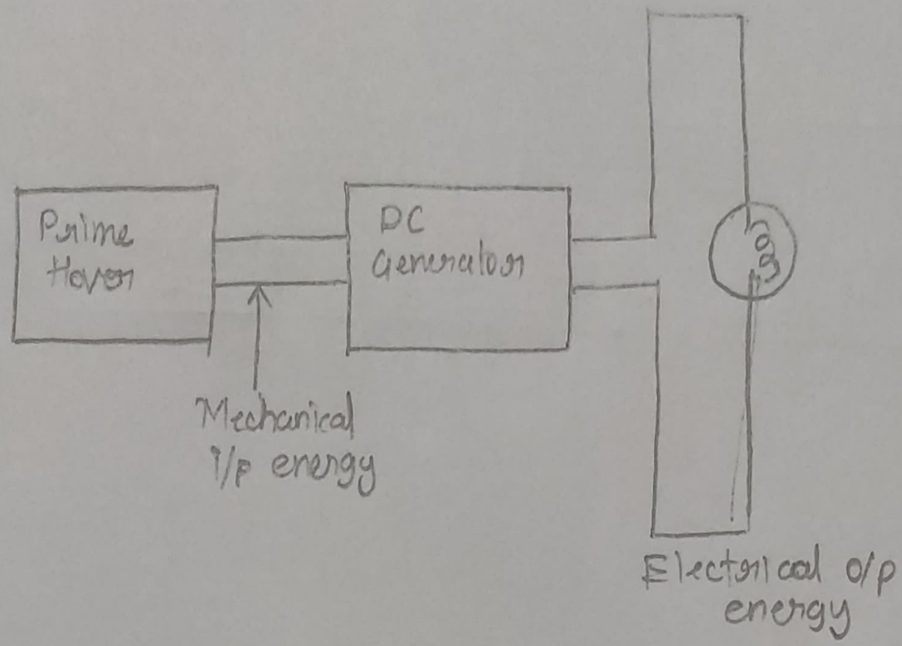
(a) The basic construction of DC motor is same as that of DC generator. It also consists of two windings - field windings and armature winding.

(b) The field winding is stationary and armature winding can rotate.

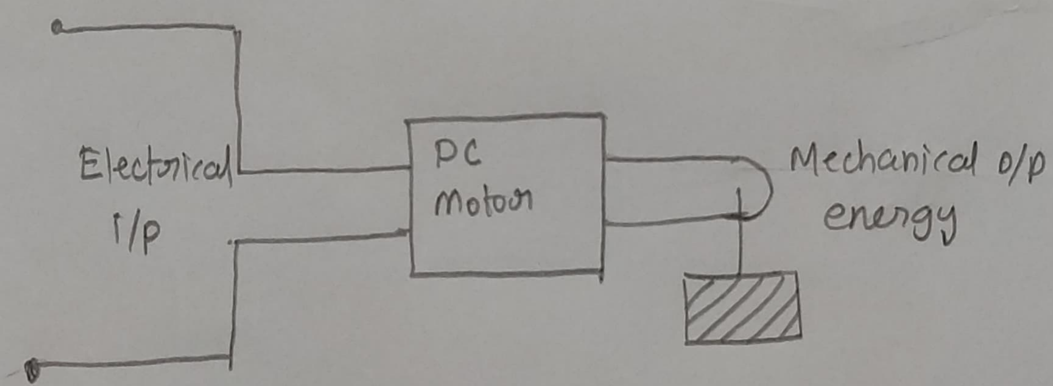
(1) YOKE : Yoke is also called as outer frame.

↳ It provides mechanical support for poles and acts as a protecting cover for whole pole.

↳ It is an iron body which carries the magnetic



ENERGY CONVERSION IN GENERATOR



ENERGY CONVERSION IN DC MOTOR

flux produced by the holes.

↳ Materials used for yoke are basically low reluctance materials.

(2) POLE CORES AND POLE SHOES

↳ The field magnet consists of pole cores and pole shoes.

↳ Pole shoes serve two purposes

↳↳ They spread out the flux in air gap and also ~~bring~~ being larger cross section reduce the reluctance of magnetic path.

↳↳ They support exciting coils.

↳ The construction of poles is done using lamination of particular shape to reduce power loss (due to eddy currents)

(3) POLE COILS

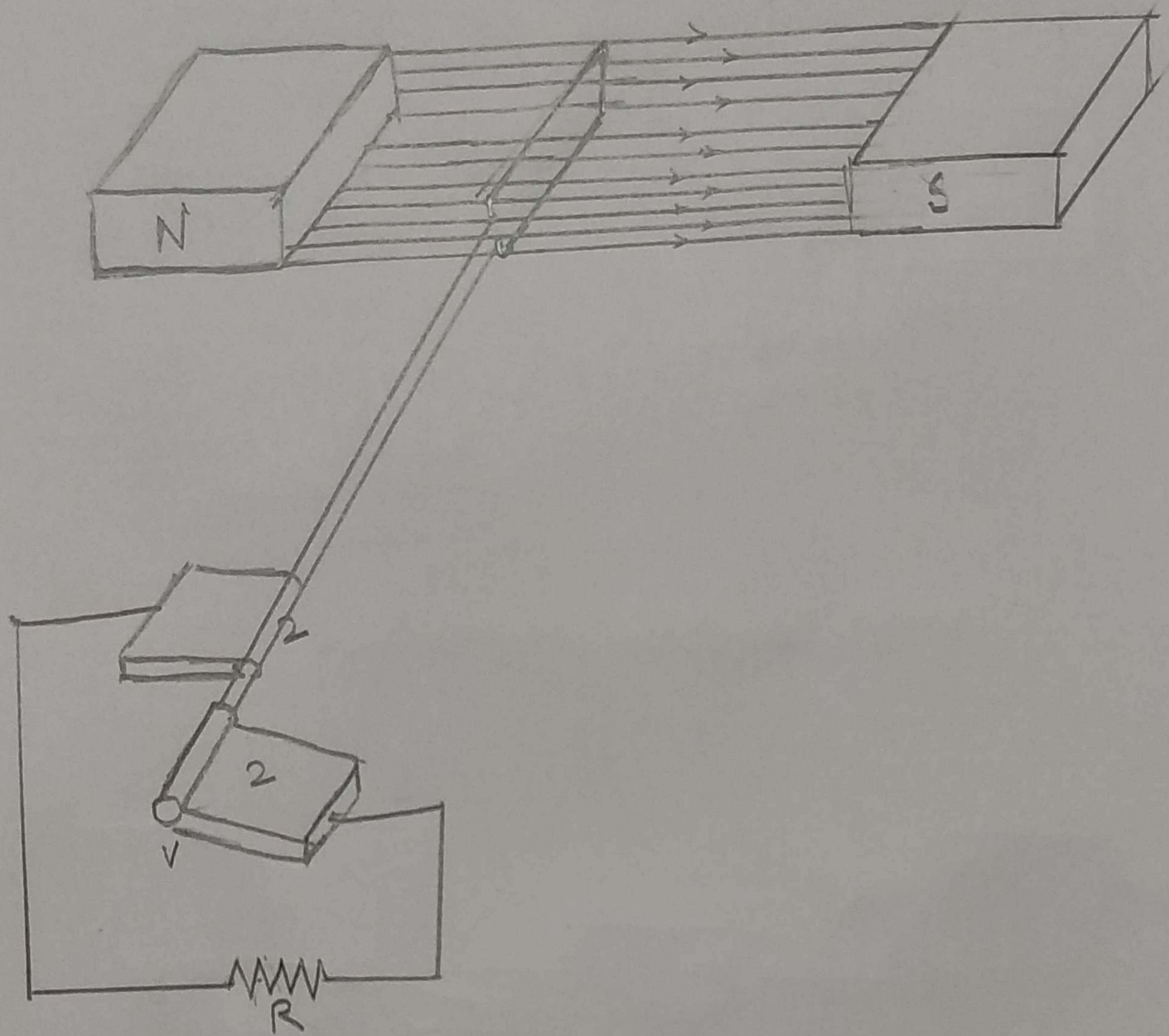
↳ Field coils or pole coils which consist of copper wire ship or former wound for correct dimension. Then former is removed and wound coil is put into place over the core

(4) ARMATURE CORE

↳ It houses the armature, conductors or coil and causes them to rotate and hence cut the magnetic flux of the ~~magnetic~~ field magnets.

↳ Its most important function is to provide a path of very low reluctance to the flux throught armature from N-pole to S-pole.

↳ It is cylindrical or drum shaped. It is build up of usually circular sheet steel discs or laminations approx 0.5mm thick.



N
S
2
2
v
R

It is keyed to shaft.
- Laminations are perforated for air ducts for cooling purposes.
- Purpose of using laminations is to reduce the loss due to eddy currents

(5) ARMATURE WINDINGS
- These are usually former wound. They are first wound in the form of flat rectangular coils and then pulled into their proper shape in a coil puller.
- Various conductors of the coils are insulted from each other.
- The conductor are placed in armature slots which are linked through insulating material.
- Armature winding is connected to external slot through commutator and brushes.

(6) COMMUTATOR
- A commutator is a cylindrical drum mounted on a shaft along armature core.
- No. of segments = No. of armature coils.
- Function: To facilitate collection of current from the armature condition.

(7) BRUSHES AND BEARINGS
- Function is to collect current from commutator
- Brushes should be inspected regularly and replaced occassionally.

(8) ARMATURE WINDINGS

Depending upon the manner of connecting the conduction the armature windings are classified into 2 types:

ARMATURE WINDING

Lap winding	Wave Winding
No. of parallel path(A) = No. of poles (P)	No. of parallel path (A)=2
Used for L.V. high current M/C	Used for H.V. low current M/C

↳ The main difference is that in DC motor, we connect the field winding as well as armature windings to DC supply.

↳ Current carrying conductor i.e. armature winding is placed in this magnetic field.

(9) FIELD WINDING

↳ In DC generator, the field winding is connected to external DC supply produced magnetic field in the air gap b/w field and armature.

↳ While in DC machine, it is connected to external DC supply and produces magnetic field in the gap b/w field and armature.

(10) ARMATURE WINDING

↳ It is connected to electrical load in DC generator and we get energy from armature.

↳ In DC machines it is connected to external DC supply. Armature rotates in magnetic field to produce mechanical power.

(11) Principle of working of DC Motor

(a) When operating as DC motors, it is supplied by electrical current and it develops torque which in turn produces mechanical rotation.

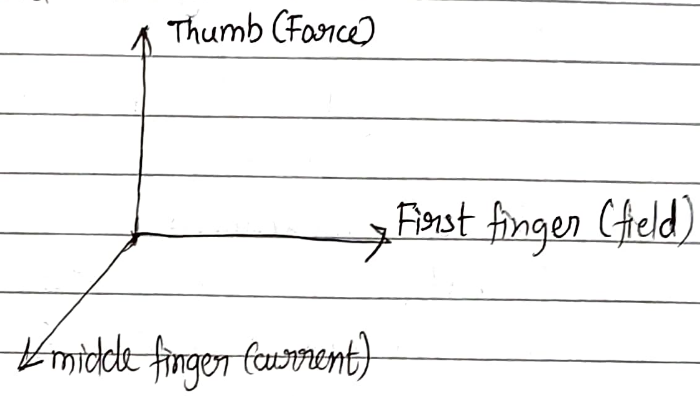
(b) When a current carrying conductor is placed in a magnetic field, it experiences a force.

(c) The magnetic field is developed by field current i.e. the current flowing in the field winding.

(d) The armature winding is connected to external DC source hence it plays the role of current carrying conductor placed in magnetic field.

(e) The direction of rotation depends on direction of magnetic field produced by the field winding as well as the direction of armature current.

(f) The direction of rotation is decided by Fleming's left hand rule.



(iii) EMF equation of DC Motor

The applied voltage across armature has to:

(a) Overcome back emf E_b.

(b) Supply armature electric drop $I_a R_a$.

$$V_a = E_b + I_a R_a$$

This is known as voltage equation of a motor. Now, multiplying both sides by I_a we get,

$$I_a V_a = E_a I_a + I_a^2 R_a$$

$V_a I_a \rightarrow$ Electrical i/p to the armature

$E_a I_a \rightarrow$ Electrical eq of mechanical power developed in armature.

Hence, out of armature i/p, some is worked in I^2R loss and rest is converted into mechanical powers within the armature.

(IV) DC Motor Applications

(a) Shunt Motor Applications

(1) As it mainly constant speed motor having it starting torque 30 to 40% more then it is rated torque also speed of shunt motor can be easily adjusted over a wide range.

(2) Such a motor can be used for:

↳ Various m/c tools ~~so~~ such as drilling m/c, milling m/c, etc.

↳ Printing machinery

↳ Paper m/c

↳ centrifugal and reciprocating ~~pow~~ purpose

↳ Blowers and fans, etc

(b) Series Motor Applications

(1) It develops very high starting torque and it has adjustable varying speed.

(2) Widely used for

↳ Electrical twins

↳ Diesel, electrica machines

↳ Cranes

↳ Hoists

↳ Trolley cars and trolley buses

↳ Rapid transit system

↳ Conveyors, etc

(c) Cumulative compound Motor Applications

(1) Variable speed

(2) Adjustable variable speed

(3) High starting torque

(4) Used for

↳ Shears and punches

↳ Elevators

↳ Conveyors

↳ Heavy planers

↳ Rolling mills, printing presses, air compressors

(d) Differential Compound Motor Applications

(1) The speed of these motors will increases with increase in load which leads to an unstable load.

(2) Therefore, we cannot use this motor for any special practical applications.