BUDDHA INSTITUTE OF TECHNOLOGY

DEPARTMENT OF APPLIED SCIENCE & HUMANITIES- I

BUDDHA SERIES

(UNIT WISE SOLVE QUESTION & ANSWER)

COURSE –B. TECH (ASH)

COLLEGE: BUDDHA INSTITUTE OF TECHNOLOGY

(AKTU CODE – 525)

DEPARTMENT OF APPLIED SCIENCE & HUMANITIES

SUBJECT: FUNDAMENTAL OF ELECTRICAL ENGG.

(BEE-101/201)

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Unit-1

Electrical Circuit Analysis

Q. 1. Define Electrical Network.

Sol. It is define as a physical inter-connection between energy sources and energy converter through the conducting wire between them.

Q. 2. Distinguish between active and passive elements. ***[2015-16, 2016-17]***

Sol. Active element Those element which can supply electrical energy to the electrical network are know as active electrical element.

e.g. : Battery, Generator, cell etc.

Passive Element : Those element which can dissipates or loss or consume electrical energy in electrical network are known as passive electrical element.

e.g. : Resistor, Inductor, Capacitor

Q. 3. Define linear and non-linear element. ***[2015-16]***

Sol. Linear Element : Those element which can follow OHM's law or gives straight line in V-I characteristics is known as linear element.

e.g. : Resistor, Inductor, Capacitor

Non-linear element : Those element which doesn't follow OHM's law or gives other than straight line curve in $V - I$ characteristics is known as non-linear element.

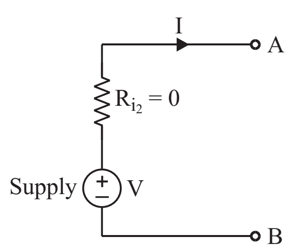
e.g. : Diode, Semiconductor, SCR etc.

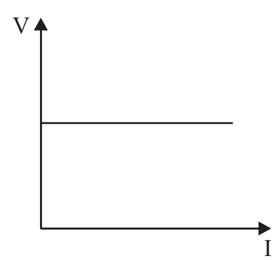
Q. 4. Define ideal voltage and current source. ***[2014-15, 2011-12, 2013-14]***

Sol. Ideal Voltage Source : It consist following two properties :

(a) It gives always constant value w.r.t. current.

(b) It internal resistance is always zero (0)

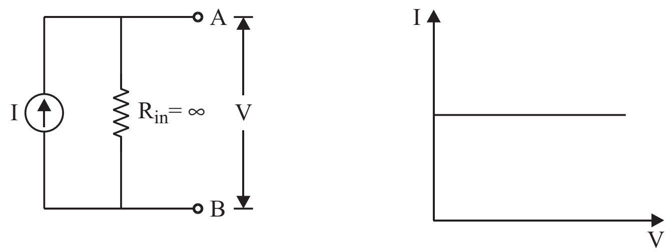




Ideal Current Source : It also consist following two properties :

(a) It gives always constant value w.r.t. voltage

(b) Its internal resistance is always infinite (∞)



Q. 5. Define unilateral and bi-lateral with examples.

[2014-15, 2015-16, 2016-17, 2013-14]

Sol. Unilateral Element : Those element whoes behaviour orV-I characteristics are depend on current direction are know as uni-lateral element.

e.g. : Diode, Semiconductor, SCRs etc.

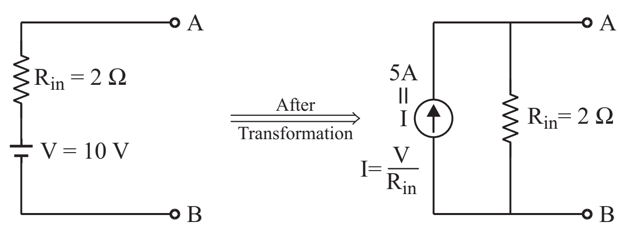
Bi-lateral Element : Those element whoes behaviour or V-I characteristics doesn't depend on current direction are known as Bi-lateral element.

e.g. : Resistor, Inductor, Capacitor.

Q. 6. What do you understnad for source-transformation? *[2011-12, 2014-15]*

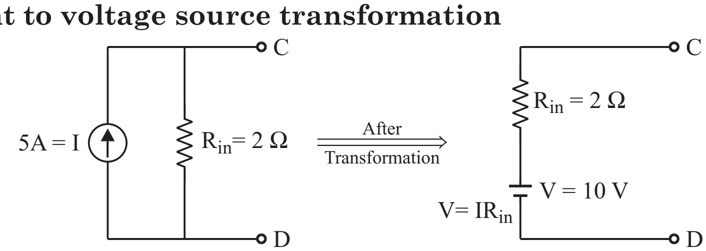
Sol. It is the process of conversion voltage source to current source or vice-versa.

(i) Voltage to current source transformation



Note. Rin will be same after transformation.

(ii) Current to voltage source transformation



Q. 7. On what factors do the resistance of conductor depends? *[2012-13]*

Sol. We know that

Resitance, $$R = \frac{\rho l}{a}$$

where, $\rho \rightarrow$ Resistivity of conductor material

$l \rightarrow$ length of conductor material

$a \rightarrow$ cross-section area of conductor material

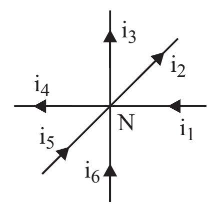
It means resistance of conductor depend on ρ, l and a.

Q. 8. State and explain Kirchhoff's law. What are limitation and application of Kirchhoff's law in circuit theory explain. *[2016-17]*

Sol. (i) Kirchhoff's Current Law (KCL)

"Law of convervation of charge"

According to this law the algebric sum of all the currents meeting at a junction, point/node is always zero.



$$\Sigma I = 0$$

at junction N

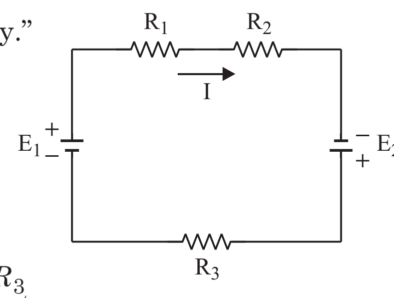
$$\Sigma I_{in} = \Sigma I_{out}$$

$$i_1 + i_5 + i_6 = i_2 + i_3 + i_4$$

(ii) Kirchhoff's Voltage Law (KVL)

"Law of conservation of energy."

According to this law in any closed path (loop or mesh) the algebraic sum of al the branch voltage drops and emf's is always zero.



$$\Sigma V = \Sigma E = 0$$

or
$$\Sigma V = \Sigma E = \Sigma IR$$

$$\underbrace{E_1 + E_2}_{\Sigma E} = \underbrace{IR_1 + IR_2 + IR_3}_{\Sigma IR}$$

Limitation 1. Not. applicable to high frequency ac. circuits.

2. Applicable to only lumped network not for distributed network.

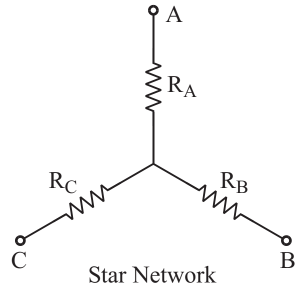
Application 1. KCL in used in nodal analysis to find out voltage and current in a particular branch/all branch.

2. KVL is used in mesh analysis to find out current/voltage in a particular branch or all branch.

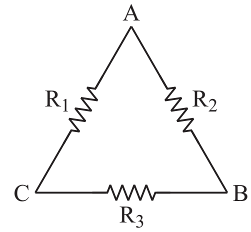
Q. 9. Define star and delta network.

Sol. Star : When three resistor R_A ,R_B and R_C are comected as in from whoes one terminal connected to a common or neutral point and other terminals are open for various purpose is known as star network K.

Delta : When three resistor R_1, R_2 and R_3 are connected as in form to make a close mesh between them is known as delta network.



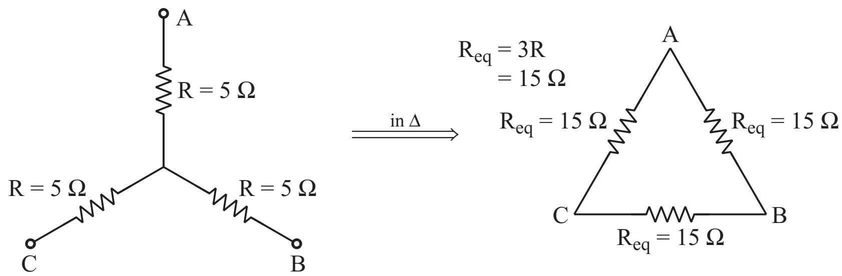
Star Network



Delta Network

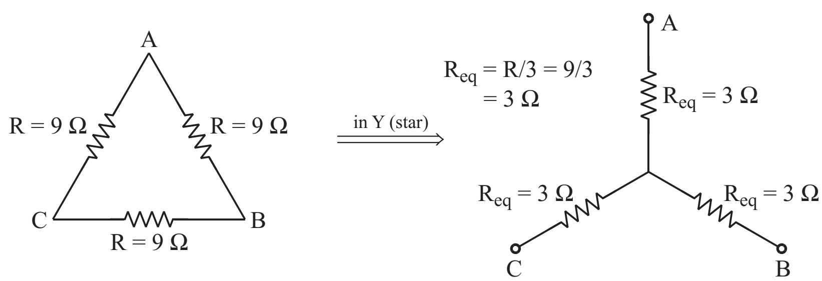
Q. 10. Three equal resistance of 5 Ω are connected in star. Find the equivalent delta? ***[2014-15]***

Sol.



Q. 11. Three equal resistance of 9 Ω are connected in delta. Find the equivalent in star? ***[2015-16]***

Sol.



Q. 12. Define following terms :

(a) Wave form **(b) Instantaneous value**

(c) Cycle **(d) Half-cycle**

(e) Time-period and frequency

Sol. (a) Wave form The shape of the curve of the voltage or current when plotted against time as base is called the waveform. The waveform of an alternating voltage varying sinusoidally.

(b) Instantaneous Value The value of alternating quantity (emf, voltage or current) at any particular instant is called the instantaneous value and is designated by small italic letter (i.e., for emf, ν for voltage and i for current).

(c) Cycle One complete set of positive and negative values it is said to have complete one cycle.

(d) Half-cycle One complete set of either positive or negative values, it completes one alternation or half-cycle.

(e) Time-period The time taken in second by an alternating quantity to complete one cycle is know as time-period or periodic time and is denoted by T.

Frequency The number of cycles completed per second by an alternating quentity is known as frequency of measured in Hertz (Hz).

Q. 13. Define following terms : ***[2015-16, 2014-15, 2011-12]***

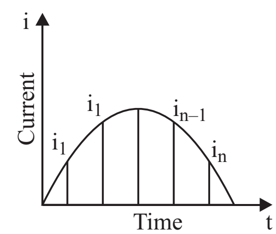
(a) Amplitude or peak value

(b) Average value

(c) Effective or RMS value

Sol. (a) Amplitude or peak value : The maximum value, positive or negative, which an alternating quantity attains during one cycle is called the amplitude or peak value.

(b) Average Value : The average (or mean) value of an alternating current is equal to the value of direct current which transfer across any circuit the same charge as it transferred by that alternating current during a given time.



$$I_{avg.} = \frac{i_1 + i_2 + i_3 + \ldots + i_n}{n}$$

$$= \frac{\text{Area of one alternation (or half cycle)}}{\text{Length of base} - \text{over half cycle}}$$

by using integral calculus the average (or mean) value of, I

$$I_{avg.} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} i(t)\, dt = \frac{1}{T} \int_0^T f(t)\, dt$$

i.e., for symmetrical waveform,

$$I_{avg.} = \frac{2}{T} \int_0^{T/2} i(t)\, dt$$

Note : The average or mean value over a complete cycle to symmetrical alternating quantity is **zero** hence for such quantity consider **half cycle** or **one alternation.**

(c) RMS value or effective value of alternating quantity : The rms of effective value of an alternating current or voltage is given by that steady current or voltage which when flow or applied to a given resistance applied to the same resistance for the same time.

$$I_{eff} = \sqrt{\frac{i_1^2 + i_2^2 + \ldots + i_n^2}{n}}$$

The effective or virtual value of alternating current or voltage is equal to the square root of the mean of the square of succsssive ordinates and that is why it is known as root mean square (rms) voltage.

Using the integral calculates the rms or effective value

$$I_{\text{eff}} = I_{\text{rms}} = \sqrt{\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} i^2(t)\,dt} = \sqrt{\frac{1}{T}\int_0^T i^2(t)\,dt}$$

Q. 14. Define form factor and Peak factor. ***[2014-15]***

Sol. Form factor, (K_f) If is defined as the ratio of effective (or rms) value to average value of periodic wave.

$$\text{Form factor}\,(K_f) = \frac{\text{RMS value}}{\text{Avg. value}}$$

Peak factor, (K_p) It is defined as the ratio fo maximum or peak value to the rms value of the periodic wave.

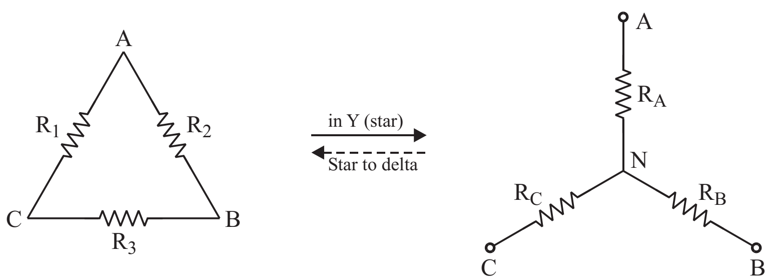
$$\text{Peak factor},\,(K_p) = \frac{\text{Maximum or Peak Value}}{\text{RMS Value}}$$

Q. 15. Deduce the relation for

(a) Delta to star transformation

(b) Star to delta transformation ***[2014-15, 2013-14, 2012-13]***

Sol. (a) Delta to star transformation : The replacement of delta or mesh by equivalent star system is known as delta-Star transformation.



The two system will be equivalent of identical if the resistances measured ($R_{\text{eq.}}$) between any two terminal of lines is equal in both of the system.

Hence $R_{\text{eq.}}$ between terminals B and C,

In Δ (Delta)

$$R_{\text{eq.}} = R_{BC} = R_3 \,||\, (R_1 + R_2) = \frac{R_3(R_1 + R_2)}{R_1 + R_2 + R_3}$$

In Y (Star)

$$R_{\text{eq.}}\ R_{BC} = R_B + R_C$$

Since two system are identical, if

$$R_{BC}\ (\text{in Y}) = R_{BC}\ (\text{in }\Delta)$$

$$R_B + R_C = \frac{R_3 (R_1 + R_2)}{R_1 + R_2 + R_3} \quad \text{...(1)}$$

Similarly $R_{eq.}$ between terminals C and A.

$$R_{CA} \text{ (in } Y) = R_{CA} \text{ (in } \Delta)$$

$$R_C + R_A = \frac{R_1(R_2 + R_3)}{R_1 + R_2 + R_3} \quad \text{...(2)}$$

Similarly $R_{eq.}$ between terminals A and B

$$R_{AB} \text{ (in } Y) = R_{AB} \text{ (in } \Delta)$$

$$R_A + R_B = \frac{R_2(R_1 + R_3)}{R_1 + R_2 + R_3} \quad \text{...(3)}$$

Adding eqn. (1), (2) and (3)

$$2(R_A + R_B + R_C) = \frac{2(R_1R_2 + R_2R_3 + R_3R_1)}{(R_1 + R_2 + R_3)}$$

$$R_A + R_B + R_C = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_1 + R_2 + R_3} \quad \text{...(4)}$$

Subtracting eqn. (1), (2) and (3) from (4)

$$R_A = \frac{R_1R_2}{(R_1 + R_2 + R_3)} \quad \text{...(5)}$$

$$R_B = \frac{R_2R_3}{(R_1 + R_2 + R_3)} \quad \text{...(6)}$$

$$R_C = \frac{R_3R_1}{(R_1 + R_2 + R_3)} \quad \text{...(7)}$$

(b) Star to Delta Transformation

Multiplying eqn. (5) and (6), (6) and (7), and (7) and (5) and then adding them, we get

$$R_AR_B + R_BR_C + R_CR_A = \frac{R_1R_2^2R_3 + R_1R_2R_3^2 + R_1^2R_2R_3}{(R_1 + R_2 + R_3)^2}$$

$$= \frac{R_1R_2R_3(R_1 + R_2 + R_3)}{(R_1 + R_2 + R_3)^2}$$

$$R_AR_B + R_BR_C + R_CR_A = \frac{R_1R_2R_3}{(R_1 + R_2 + R_3)} \quad \text{...(8)}$$

Dividing eqn. (8) by (5), (6) and (7)

$$R_3 = \frac{(R_AR_B + R_BR_C + R_CR_A)}{R_A}$$

$$R_2 = \frac{(R_AR_B + R_BR_C + R_CR_A)}{R_B}$$

$$R_3 = \frac{(R_AR_B + R_BR_C + R_CR_A)}{R_C}$$

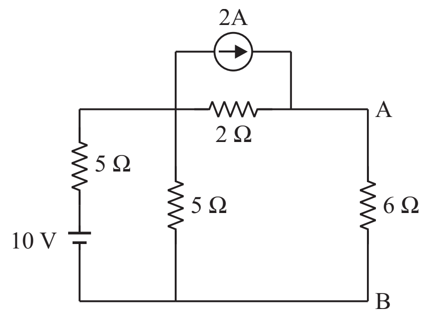
Note (i) If three resistance of R connected in A, then Req. in γ

$$R_{eq} = \frac{R}{3}$$

(ii) If three resistance of R connected in Y, the $R_{eq.}$ in Δ

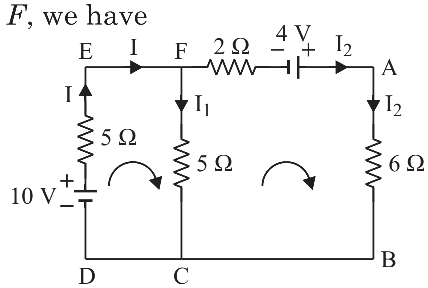
$$R_{eq.} = 3R$$

Q. 16. Use source transformation method to compute the current through 6 Ω resistor of fig. ***[2014-15]***



Sol. By using source transformation

Applying KVL at point F, we have



$$I = I_1 + I_2 \qquad \ldots(1)$$

Apply KVL in mesh *CDEFC*

$$10 - 5I - 5I_1 = 0$$

$$\Rightarrow \qquad 10 = 5I + 5I_1$$

$$I + I_1 = 2$$

$$\Rightarrow \qquad (I_1 + I_2) + I_1 = 2$$

$$2I_1 + I_2 = 2 \qquad \ldots(2)$$

Apply KVL in mesh *FABCF*

$$5I_1 - 2I_2 + 4 - 6I_2 = 0$$

$$-5I_1 + 8I_2 = 4 \qquad \ldots(3)$$

Solving eqn. (2) and (3), we have

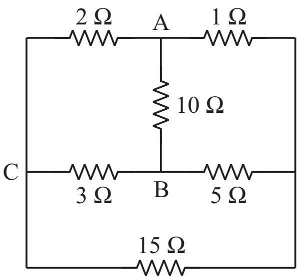
$$I_1 = \frac{4}{7} \text{ amp.}$$

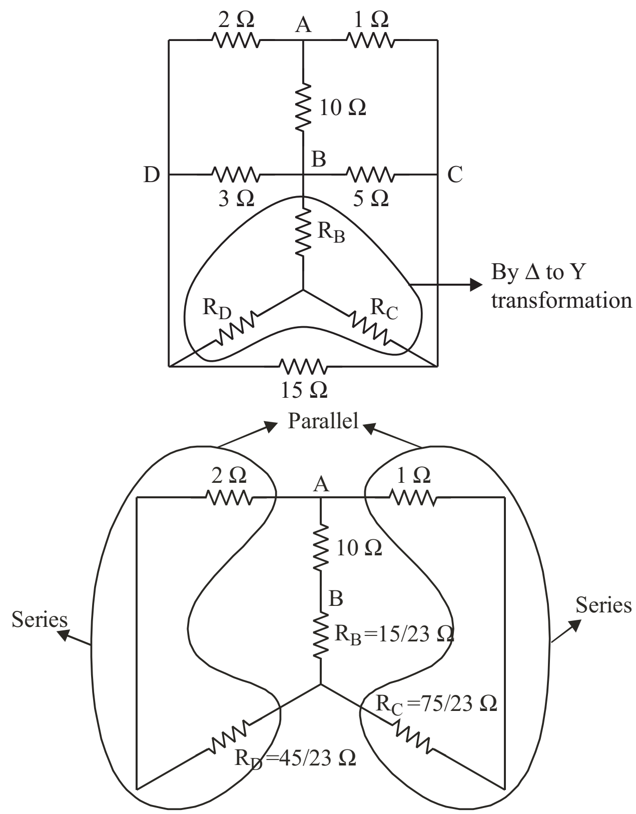
$$I_2 = \frac{6}{7} \text{ Amp.}$$

Current in 6 Ω

$$I_{6\,\Omega} = I_3 = \frac{6}{7} \text{ Amp.} (\downarrow)$$

Q. 17. Determine the effective resistance ($R_{eq.}$) between terminal $A - B$ in the network of fig. ***[2014-15]***





Sol. Now,

$$R_B = \frac{(3 \times 5)}{(3 + 5 + 15)} = \frac{15}{23}\ \Omega$$

$$R_C = \frac{(5 \times 15)}{(3 + 5 + 15)} = \frac{75}{23}\ \Omega$$

$$R_D = \frac{(3 \times 15)}{(3 + 5 + 15)} = \frac{45}{23}\ \Omega$$

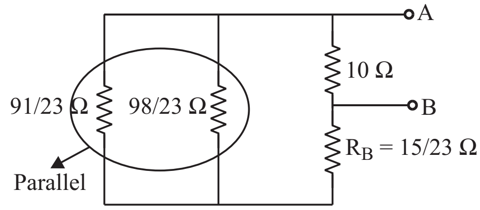
$$\Rightarrow \quad 2 + R_D = 2 + \frac{45}{23} = \frac{91}{23}\ \Omega$$

$$1 + R_C = 1 + \frac{75}{23} = \frac{98}{23}\ \Omega$$

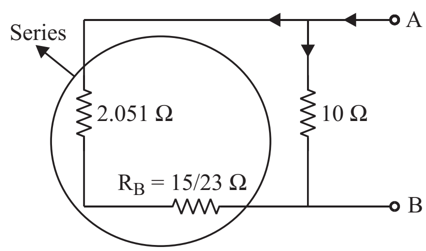
$$\Rightarrow \quad \left(\frac{91}{23} \,||\, \frac{98}{23}\right) = (3.9565 \,||\, 4.261)$$

$$= \frac{3.9565 \times 4.261}{(3.9565 + 4.261)}$$

$$= \frac{16.859}{8.218} = 2.051\ \Omega$$



$$\Rightarrow \qquad 2.051 + R_B = 2.703\ \Omega$$

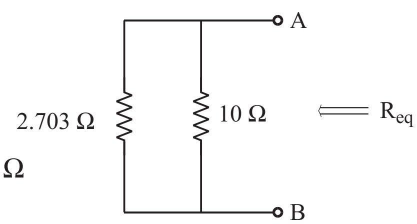


$$R_{eq.} = (10 \,||\, 2.703)$$

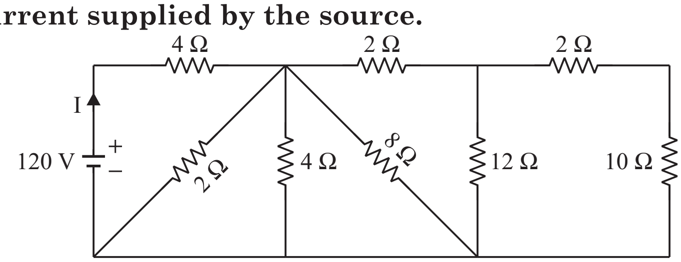
$$= \frac{10 \times 2.703}{10 + 2.703}$$

$$R_{AB} = \frac{27.03}{12.703} = 2.127\ \Omega$$

$$R_{eq.} = R_{AB} = 2.127\ \Omega$$



Q. 18. Find the equivalent resistance for the following circuit and hence calculate the current supplied by the source. ***[2011-12]***



Sol. $R_{eq.}$ from 120 V side

$$R_{eq.} = [4 + \{2 \,||\, \{4 \,||\, \{8 \,||\, \{2 + \{12 \,||\, (10 + 2)\}\}\}\}\}]$$

$$= [4 + \{2 \,||\, \{4 \,||\, \{2 \,||\, \{12 \,||\, \}\}\}\}]$$

$$= [4 + \{2 \,||\, \{4 \,|||\, \{8 \,||\, \{2 + \{\sqrt{2} \,||\, \sqrt{2}\}\}\}\}]$$

$$= [4 + \{2 \,||\, \{4 \,||\, \{8 \,||\, 8\}\}\}]$$

$$= [4 + \{2 \,||\, \{4 \,||\, 4\}\}]$$

$$= [4 + \{2 \,||\, 2\}]$$

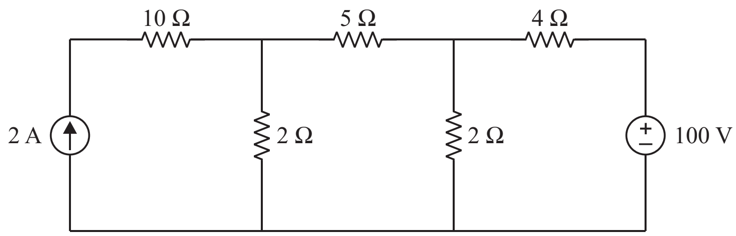
$$= [4 + 1]$$

$$= 5\ \Omega$$

Current supplied by source, $I = \dfrac{V}{R_{eq.}} = \dfrac{120}{5}$

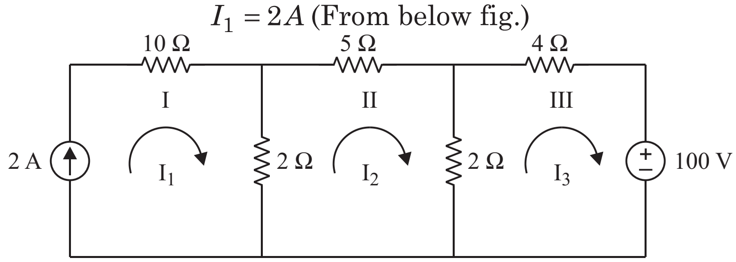
$= 24$ Amp.

Q. 19. Applying mesh analysis, obtain the current through 5 Ω resistance in following circuit. ***[2011-12]***



Sol. Let current in each mesh I_1, I_2 and I_3 in respective meshes.

$$I_1 = 2A \text{ (From below fig.)} \quad \ldots(1)$$



Now, KVL in mesh (II)

$$2I_1 - 2I_2 - 5I_2 - 2I_2 + 2I_3 = 0$$

$$2I_1 - 9I_2 + 2I_3 = 0$$

$$-9I_2 + 2I_3 = -4 \quad \ldots(2)$$

KVL in mesh (III),

$$2I_2 - 2I_3 - 4I_3 - 100 = 0$$

$$2I_2 - 6I_3 = 100 \quad \ldots(3)$$

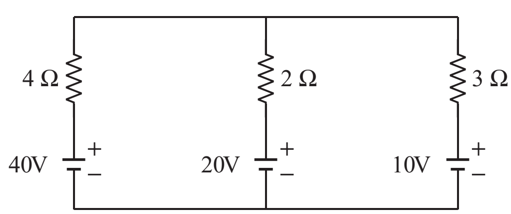
Solving eqn. (2) and (3), we have

$$I_2 = \frac{88}{25} = -3.52 \text{ Amp.}$$

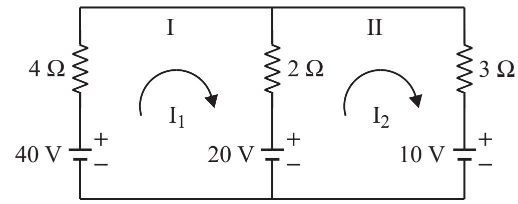
Current in 5 Ω resistance

$$I_{5\,\Omega} = I_2 = -3.52 \text{ Amp.} (\rightarrow)$$

Q. 20. Find the current in 2 Ω resistance in the following fig. using loop analysis method. ***[2015-16]***



Sol. Let I_1 and I_2 in respective mesh in clock-wise direction.



KVL in mesh (I)

$$40 - 4I_1 - 2I_1 + 2I_2 - 20 = 0$$

$$3I_1 - I_2 = 10 \qquad \ldots(1)$$

KVL in mesh (II)

$$20 - 2I_2 - 3I_2 + 2I_1 - 10 = 0$$

$$-2I_1 + 5I_2 = 10 \qquad \ldots(2)$$

Solving eqn. (1) and (2), we have

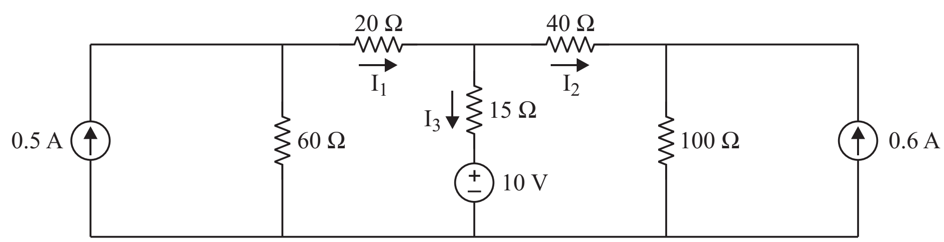
$$I_1 = \frac{60}{13} \text{ Amp. and } I_2 = \frac{50}{13} \text{ Amp.}$$

Now, current in 2 Ω resistance

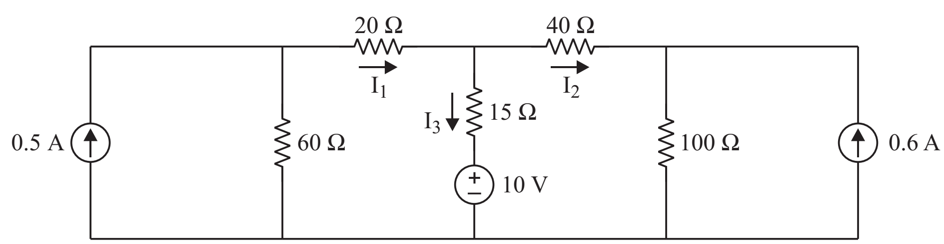
$$I_{2\,\Omega} = I_1 - I_2 = \frac{60}{13} - \frac{50}{13}$$

$$= \frac{10}{13} \text{ Amp.}$$

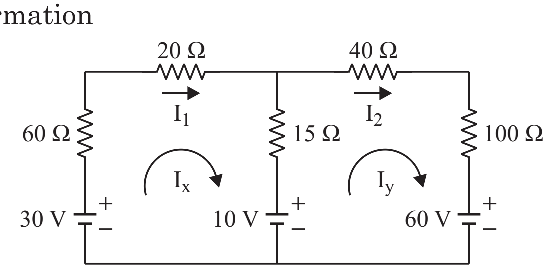
Q. 21. Using mesh analysis, find the currents I_1, I_2 and I_3 in the following circuis of fig. ***[2016-17]***



Sol.



Circuit transform by using source transformation



KVL in mesh (I)

$$30 - 60I_x - 20I_x - 15I_x + 15I_y - 10 = 0$$

$$95I_x - 15I_y = 20 \qquad \ldots(1)$$

KVL in mesh (II)

$$10 + 15I_x - 15I_y - 40I_y - 100I_y - 60 = 0$$

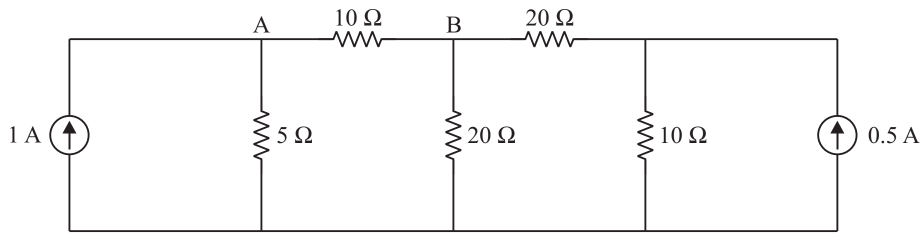
$$-15I_x + 155I_y = -50 \qquad \ldots(2)$$

Solving eqn. (1) and (2), we get

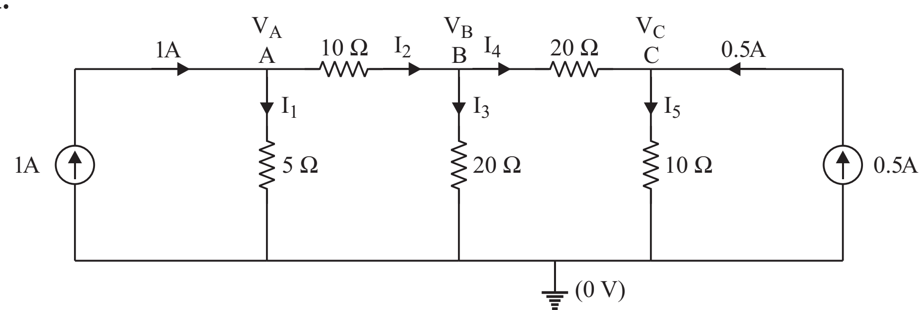
$$I_x = 0.162 \text{ Amp.}$$
$$I_y = -0.306 \text{ Amp.}$$

Now,
$$I_{2\,\Omega} = I_1 = I_x = 0.162 \text{ Amp.} (\rightarrow)$$
$$I_{4\,\Omega} = I_2 = I_y = -0.306 \text{ Amp.} (\rightarrow)$$
$$I_{15\,\Omega} = I_3 = I_x - I_y = 0.468 \text{ Amp.} (\downarrow)$$

Q. 22. Find current in each branch by using nedal analysis. Also calculate total power loss. ***[2013-14]***



Sol.



Applying KCl at node A

$$1 = I_1 + I_2$$
$$1 = \frac{V_A - 0}{5} + \frac{V_A - V_B}{10}$$
$$3V_A - V_B = 10 \quad \ldots(1)$$

Applying KCl at node B

$$I_2 = I_3 + I_4$$
$$\frac{V_A - V_B}{10} = \frac{V_B - 0}{20} + \frac{V_B - V_C}{20}$$
$$2V_A - 4V_B + V_C = 0 \quad \ldots(2)$$

Applying KCl at C

$$I_4 + 0.5 = I_5$$
$$\frac{V_B - V_C}{20} + 0.5 = \frac{V_C - 0}{10}$$
$$V_B - 3V_C = -10 \quad \ldots(3)$$

On solving eqn. (1), (2) and (3), we have

$$V_A = \frac{40}{9}, V_B = \frac{10}{3} V, V_C = \frac{40}{9} V$$

Current in all resistor $\quad I_{5\,\Omega} = I_1 = \frac{V_A - 0}{5} = \frac{8}{9}$ A

$$I_{10\,\Omega} = I_2 = \frac{(V_A - V_B)}{10} = \frac{1}{9} \text{ A}, I_{20\,\Omega} = \frac{(V_B - 0)}{20} = \frac{1}{6} \text{ Amp.}$$

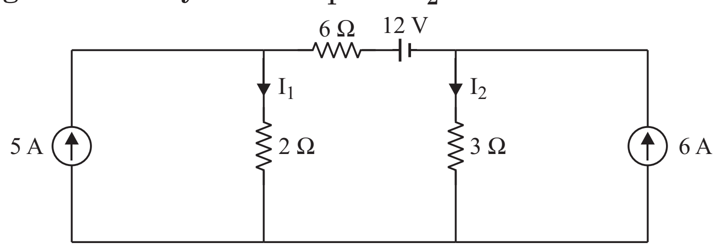
$$I_{20\,\Omega} = I_4 = \frac{(V_B - V_C)}{20} = \frac{-1}{18} \text{ Amp}, I_{10\,\Omega} = I_5 = \frac{(V_C - 0)}{10} = \frac{4}{9} \text{ Amp.}$$

$$\text{Total power loss} = I_1^2 5 + I_2^2 10 + I_3^2 20 + I_4^2 20 + I_5^2 10$$

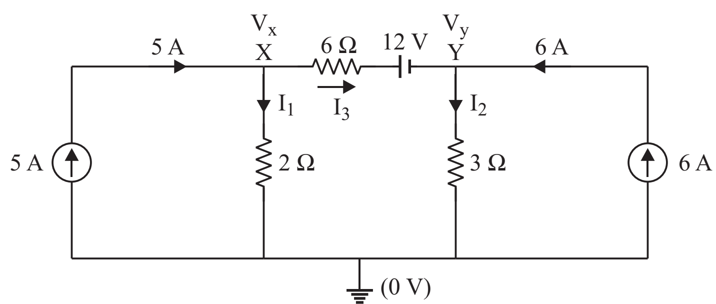
$$P = \frac{20}{3}$$

$$P = 6.66 \text{ Watts}$$

Q. 23. Using nodal analysis find I_1 and I_2. *[2013-14]*



Sol.



Applying KCl at node X

$$5 = I_1 + I_3$$

$$5 = \frac{V_x - 0}{2} + \frac{V_x - 12 - V_y}{6}$$

$$30 = 4V_x - V_y - 12$$

$$4V_x - V_y = 42 \qquad \ldots(1)$$

Applying KCl at node Y

$$I_3 + 6 = I_2 \Rightarrow 6 = I_2 - I_3$$

$$6 = \frac{V_y - 0}{3} - \frac{(V_x - 12 - V_y)}{6}$$

$$36 = 3V_y - V_x + 12$$

$$-V_x + 3V_y = 24 \quad \ldots(2)$$

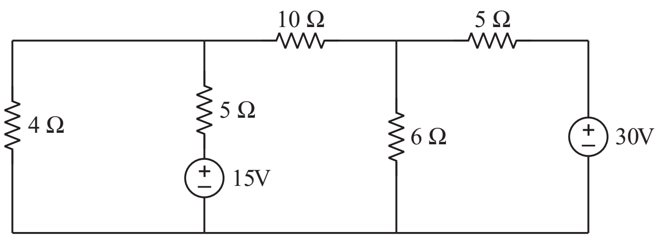
On solving eqn. (1) and (2), we have

$$V_x = 13.636 \text{ Volt}, V_y = 12.545 \text{ Volt}$$

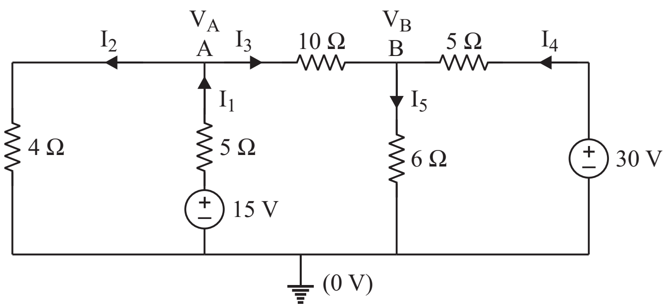
Now,
$$I_1 = \frac{V_x}{2} = 6.818 \text{ Amp.}$$

$$I_2 = \frac{V_y}{3} = 4.181 \text{ Amp}$$

Q. 24. Using nodal analysis, find current through 10 Ω resistance. *[2011-12]*



Sol.



Applying KCl at node *A*

$$I_1 = I_2 + I_3$$

$$\frac{15 - V_A}{5} = \frac{V_A - 0}{4} + \frac{V_A - V_B}{10}$$

$$11V_A - 2V_B = 60 \quad \ldots(1)$$

Applying KCl at node *B*

$$I_3 + I_4 = I_5$$

$$\frac{V_A - V_B}{10} + \frac{30 - V_B}{5} = \frac{V_B - 0}{6}$$

$$3V_A - 14V_B = -180 \quad \ldots(2)$$

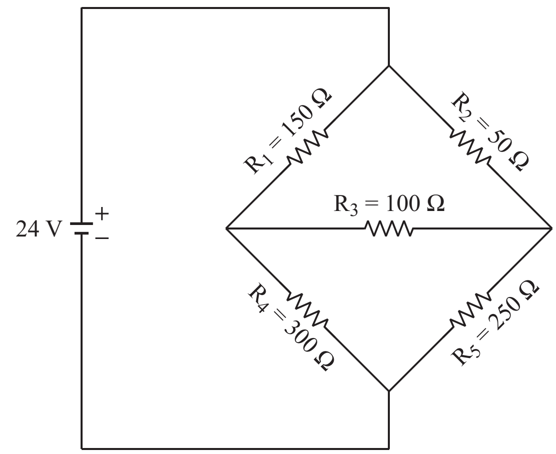
On solving eqn. (1) and (2), we have

$$V_A = \frac{300}{37} \text{ V and } V_B = \frac{540}{37} \text{ V}$$

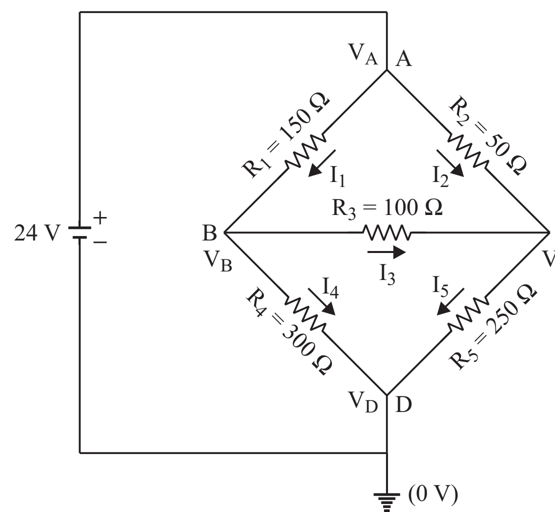
Current through 10 Ω resistance,

$$I_{10\,\Omega} = I_3 = \frac{V_A - V_B}{10} = \frac{-24}{37}\text{ Amp.} (\rightarrow)$$

Q. 25. Calculate the current in R_3 by using modal analysis in fig. ***[2015-16]***



Sol.



Let potential at all nodes are V_A, V_B, V_C and V_D for respective node.

Form fig.

$$V_A = 24\text{ V}$$

$$V_D = 0\text{ V} \qquad \text{[Because of ground at nods } D\text{]}$$

Applying KCl at node B

$$I_1 = I_3 + I_4$$

$$\frac{V_A - V_B}{150} = \frac{V_B - V_C}{100} + \frac{V_B - V_D}{300} \qquad \ldots(1)$$

Applying KCl at node C

$$I_2 + I_3 = I_5$$

$$\frac{V_A - V_C}{50} + \frac{V_B - V_C}{100} = \frac{V_C - V_D}{250} \quad \ldots(2)$$

On solving (1) and (2), we have

$$V_D = 17.65 \text{ V}, V_C = 19.31 \text{ V}$$

Now, current in R_3

$$I_{100\,\Omega} = I_{R_3} = I_3 = \frac{V_B - V_C}{100}$$

$$= -0.0166 \text{ Amp. } (\rightarrow)$$

Q. 26. An alternating voltage is given $v = 100 \sin 100$. Find

(i) Amplitude (ii) Tims-period and frequency, (iii) Angular velocity (iv) Form factor (v) Peak factor. ***[2011-12, 2010-11]***

Sol. Given, alternating voltage, $v = 100 \sin 100t$ standard instantaneous alternating voltage, $v = V_{max} \sin \omega t$

By Comparing both

(i) Amplitude of given wave,

$$V_{max} = 100 \text{ V}$$

(ii) Angular velocity, $\omega = 100$ rad/sec.

(iii) $$\omega = 2\pi f \Rightarrow f = \frac{\omega}{2\pi}$$

Frequency, $$f = \frac{100}{2\pi} = 15.9 \text{ Hz}$$

and Time-period, $$T = \frac{1}{f}$$

$$= \frac{1}{15.9} = 0.063 \text{ second}$$

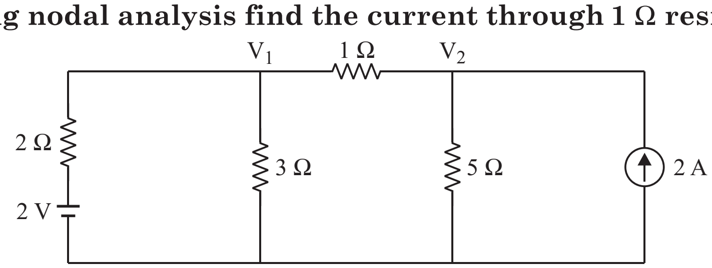
$$= 63 \text{ m sec.}$$

(iv) Form factor, $$K_f = \frac{V_{rms}}{V_{avg}} = \frac{(V_{max}/\sqrt{2})}{(0.637\,V_{max})}$$

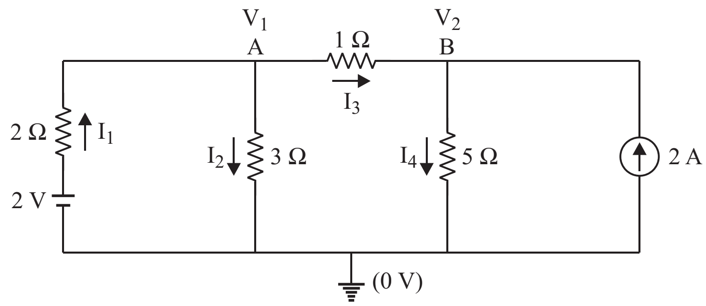
$$= 1.11$$

(v) Peak factor $$K_p = \frac{V_{max}}{V_{rms}} = \frac{V_{max}}{(V_{max}/\sqrt{2})} = \sqrt{2} = 1.41$$

Q. 28. Using nodal analysis find the current through 1 Ω resistance. ***[2016-17]***



Sol.



Apply KCl at node A

$$I_1 = I_2 + I_3$$

$$\frac{2 - V_1}{2} = \frac{V_1 - 0}{3} + \frac{V_1 - V_2}{1}$$

$$6 - 3V_1 = 2V_1 + 6V_1 - V_2$$

$$11V_1 - V_2 = 6 \qquad \ldots(1)$$

Apply KCl at node B

$$I_3 + 2 = I_4 \Rightarrow 2 = I_4 - I_3$$

$$2 = \frac{V_2 - 0}{5} - \frac{(V_1 - V_2)}{1}$$

$$-5V_1 + 6V_2 = 10 \qquad \ldots(2)$$

On solving eqn. (1) and (2)

$$V_1 = 0.754 \text{ volt}, V_2 = 2.294 \text{ volt}$$

Now current through 1 Ω resistance

$$I_{1\,\Omega} = I_3 = \frac{V_1 - V_2}{1} = V_1 - V_2$$

$$I_{1\,\Omega} = -1.54 \text{ Amp.}(\rightarrow)$$

Q. 29. Draw a phasr diagram showing the following voltages :

$$\boldsymbol{v_1 = 100 \sin 500t, v_2 = 200 \sin (500t + \pi/3)}$$

$$\boldsymbol{v_3 = -50 \cos 500t, v_3 = 150 \sin (500t - \pi/4)}$$

Find rms value of resultant voltage. ***[2016-17]***

Sol. First of all check quantities are in same form or not v_3 is different from another all v_1, v_2 and v_4

Now,

$$\left.\begin{aligned} v_3 &= -50 \cos 500t \\ &= -50 \sin(\pi/2 - 500t) \\ &= 50 \sin(500t - \pi/2) \end{aligned}\right\} \text{Cosine change in sine format}$$

Algebraic sum of component

$v_x = 100 \cos 0° + 200 \cos 60° + 50 \cos(-90°) + 150 \cos(-45°) = 306$ Volt

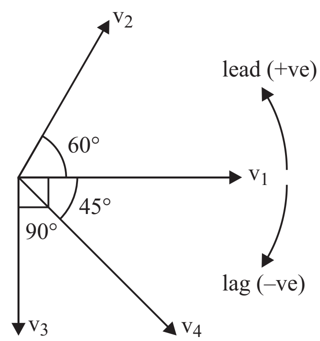
$$v_y = 100 \sin 0° + 200 \sin 60° + 50 \sin(-90°) + 150 \sin(-45°) = 172 \text{ Volt}$$

Maximum value of resultant, $v_{r\ \max} = \sqrt{V_x^2 + V_y^2}$

$= 306.5$ Volt

Rms value of resultant, $V_{r\ rms} = \dfrac{V_{r\ \max}}{\Omega} = 216.72$ Volt

Phasor diagram



Q. 30. An alternating voltage is given by $v = 141.4 \sin 314t$. Find

(i) frequency (ii) rms value (iii) average value (iv) instantaneous value of voltage when t is 3 ms (v) the time taken for the voltage to reach 100 volt for the first time after passing through zero value.

Sol. Given that

Alternative voltage $v = 141.4 \sin 314t$

(i) Frequency, $f = \dfrac{\omega}{2\pi} = \dfrac{314}{2\pi} = 50$ Hz

(ii) Rms value, $V_{\text{rms}} = \dfrac{V_{\max}}{\sqrt{2}} = \dfrac{141.4}{\sqrt{2}}$

$= 100$ volt

(iii) Avg. value, $V_{avg.} = 0.637 V_{\max} = 0.637 \times 141.,4$

$= 90$ volt

(iv) $v = ?$, when $t = 3 \max = 3 \times 10^{-3}$ sec.

Note : When we **put the value of 't'** in instantaneous eqn. or **calculate the of 't'** from eqn. by using calculator then calculator **in 'radian' mode**.

$$x = 141.4 \sin(314 \times 3 \times 10^{-3}) \text{ in radian mode}$$

$= 114.4$ volt

(v) $t = ?$ when $v = 100$ volt (Ist time after passing zero value)

$$v = 141.4 \sin(314\ t + 0°) \Rightarrow 100 = 141.4 \sin(314\ t)$$

$$t = \frac{1}{314} \sin^{-1}\left(\frac{100}{141.4}\right) \text{in radian mode calculator}$$

$$= 2.5 \text{ m sec.}$$

Q. 31. If two alternating quantities represented by $i_1 = 7 \sin \omega t$ and $i_2 = 10 \sin (\omega t + \pi/3)$ are fed into a common conductor, then find equation for resultant current and its rms value. ***[2013-14]***

Sol.

$$i_1 = 7 \sin \omega t$$

$$i_2 = 10 \sin (\omega t + \pi/3)$$

X-component, $i_x = 7 \cos 0° + 10 \cos 60° = 12$ Amp

Y-component, $i_y = 7 \sin 0° + 10 \sin 60° = 8.66$ Amp.

(Algebric calculation in degree mode)

Resultant, $i_{r\,max} = \sqrt{i_x^2 + i_y^2}$

$$= \sqrt{12^2 + 8.66^2}$$

$$= 14.8 \text{ Amp.}$$

Phase displacement of resultant, $i_r = \tan^{-1}\left(\frac{i_y}{i_x}\right)$

$$= 0.199\pi \text{ L (in radian)}$$

Resultant current expression

$$i_r = i_{r\,max} \sin (\omega t + dr)$$

$$i_r = 14.8 \sin (\omega t + 0.199\pi)$$

Rms value of resultant,

$$I_{r\,rms} = \frac{I_{r\,max}}{\sqrt{2}} = \frac{14.8}{\sqrt{2}}$$

$$= 10.46 \text{ Amp.}$$

Q. 32. Find the resultant voltage of following $v_1 = 25 \sin \omega t$, $v_2 = 10 \sin (\omega t + \pi/6)$, $v_3 = 30 \cos \omega t$, $v_4 = 20 \sin (\omega t - \pi/4)$ ***[2014-15]***

Sol. Given that

$$v_1 = 25 \sin \omega t, v_2 = 10 \sin (\omega t + \pi/6)$$

$$v_3 = 30 \cos \omega t, v_4 = 20 \sin (\omega t - \pi/4)$$

First of chek all quantities are in same form or not. v_3 is different from another all v_1, v_2 and v_4

Now, $v_3 = 30 \sin (\pi/2 + \omega t)$

$= 30 \sin (\omega t + \pi/2)$

(Now cosine chang in sine format)

Algetric sum of component (calculator in degree mode)

$v_x = 25 \cos 0° + 10 \cos 30° + 30 \cos 90° + 20 \cos(-45°) = 47.80$

$v_y = 25 \sin 0° + 10 \sin 30° + 30 \sin 90° + 20 \sin(-45°) = 20.85$

Resultant magnitude, $v_{r\,max} = \sqrt{v_x^2 + v_y^2}$

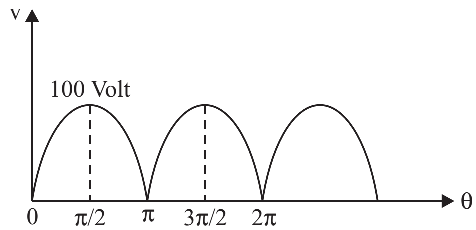
$$= \sqrt{(47.80)^2 + (20.85)^2}$$
$$= 52.15 \text{ Volt}$$

Phase displacement of resultant, $\phi_r = \tan^{-1} \dfrac{v_y}{v_x} = 23.56°$

Now, resultant voltage expression

$$v_r = v_{r\max} \sin(\omega t \pm \phi_r)$$
$$= 52.15 \sin(\omega t + 23.56°)$$

Q. 33. Find the rms value, average value and form factor of the voltage waveform in fig.



Sol. Now, the time period

$$T = \pi$$

Average value

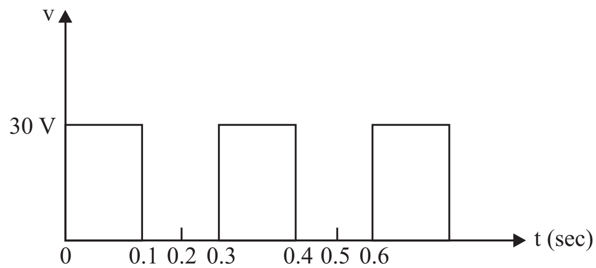
$$V_{avg} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} v\, d\theta = \frac{1}{\pi - 0} \int_0^{\pi} V_{\max} \sin\theta\, d\theta$$
$$= \frac{1}{\pi} \cdot V_{\max} \int_0^{\pi} \sin\theta\, d\theta = \frac{100}{\pi} [-\cos\theta]_0^{\pi}$$
$$= \frac{100}{\pi} [-(\cos\pi - \cos 0)] = \frac{2}{\pi} \times 100$$
$$= 63.66 \text{ volt}$$

Rms value

$$V_{rms} = \sqrt{\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} v^2\, d\theta} = \sqrt{\frac{1}{\pi - 0} \int_0^{\pi} (V_{\max}^2 \sin^2\theta)\, d\theta}$$
$$= \sqrt{\frac{V_{\max}^2}{\pi} \int_0^{\pi} \sin^2\theta\, d\theta} = \sqrt{\frac{V_{\max}^2}{\pi} \int_0^{\pi} \left(\frac{1 - \cos 2\theta}{2}\right) d\theta}$$
$$= 70.71 \text{ volt}$$

Form factor, $K_r = \dfrac{\text{Rms value}}{\text{Avg. value}} = \dfrac{70.71}{63.66} = 1.11$

Q. 34. Find rms value, average value and form factor of the wave shown in fig.



Sol. The given voltage waveform may be expressed

$$i = V_{max} \text{ for } 0 < t < 0.1$$
$$= 30 \text{ V for } 0 < t < 0.1$$

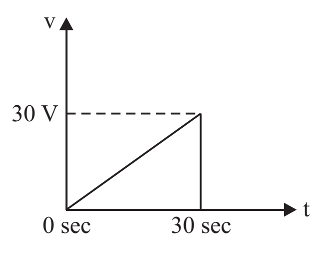
Average value

$$V_{avg.} = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} v \, d\theta = \frac{1}{0.3 - 0}\int_0^{0.1} 30 \, dt$$
$$= \frac{10}{0.3} \times 30 \, [t]_0^{0.1}$$
$$= \frac{10}{0.3} \times 30 \times 0.1$$
$$= 10 \text{ volt.}$$

Rms value
$$V_{rms} = \sqrt{\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} v^2 \, dt} = \sqrt{\frac{1}{0.3 - 0}\int_0^{0.1} (30)^2 \, dt}$$
$$= \sqrt{\left(\frac{900}{0.3}\right)(t)_0^{0.1}} = \sqrt{300}$$
$$= 17.32 \text{ volt}$$

Form factor,
$$K_f = \frac{V_{r\,rms}}{V_{avg.}} = \frac{17.32}{10} = 1.732$$

Q. 35. Find form factor and peak factor for given waveform. ***[2014-15]***



Sol. Instantaneous value of wave,

$$v = \frac{30}{3} \cdot t = 10t$$

Avg. value
$$V_{avg} = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} v \, dt = \frac{1}{(3 - 0)}\int_0^3 10t \, dt$$

$$= \frac{1}{3}\,10\left[\frac{t^2}{2}\right]_0^3 = \frac{10}{3}\left(\frac{9}{2}\right)$$

$$= 15 \text{ volt}$$

Rms value $$V_{\text{rms}} = \sqrt{\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} v^2\, dt} = \sqrt{\frac{1}{(3-0)}\int_0^3 (10t)^2\, dt}$$

$$= \sqrt{\frac{1}{3} \times 100\left(\frac{t^3}{3}\right)_0^3} = \sqrt{\frac{100}{9} \times 9 \times 3}$$

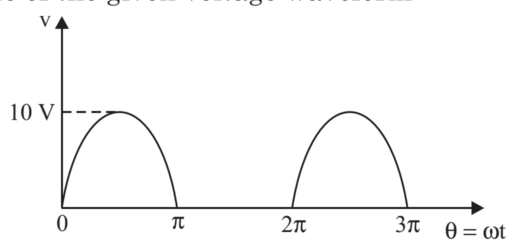
$$= 10\sqrt{3} \text{ volt.}$$

K_f, $$\text{(from factor)} = \frac{V_{\text{rms}}}{V_{\text{avg}}} = \frac{10\sqrt{3}}{15} = 1.1547$$

K_p, $$\text{(peak factor)} = \frac{V_{\max}}{V_{\text{rms}}} = \frac{30}{10\sqrt{3}} = \sqrt{3}$$

Q. 36. Find average and rms values of the following waveform. ***[2015-16]***

Sol. Maximum value of the given voltage waveform



$$V_{\max} = 10 \text{ V}$$

Average value

$$V_{\text{avg}} = \frac{V_{\max}}{\pi} = \frac{10}{\pi} = 3.183 \text{ volt}$$

$$\text{Rms value } V_{\text{rms}} = \frac{V_{\max}}{2} = \frac{10}{2} = 5 \text{ volt}$$

❑

Unit-2

Steady State Analysis of 1-ϕ AC Circuit, Network Theorems

Q. 1. Prove that in pure resistive circuit average power is $V_{rms} \cdot I_{rms}$ and define a.c. circuit.

Sol. A.C. Circuit The closed path followed by an alternating current is called an **a.c. circuit.**

Pure Resistive Circuits

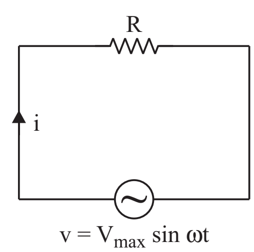
Consider an ac circuit containing a **non-inductive resistance of R ohm** connected across simusoidal voltage represented by $v = V_{max} \sin \omega t$ as shown in fig.

$$iR = v \Rightarrow iR = V_{max} \sin \omega t$$

$$i = \frac{V_{max}}{R} \sin \omega t$$

$$i = I_{max} \sin \omega t,$$

where $$I_{max} = \frac{V_{max}}{R}$$



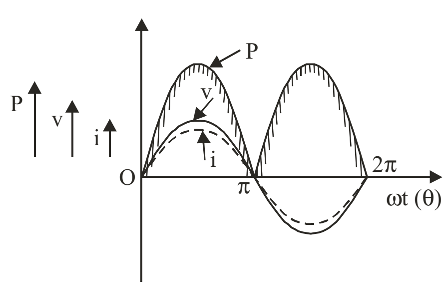
Circuit diagram

from the expression of instantaneous voltage, v and current, i we can see that there **no phase difference** between v and i.

Phasor Diagram

(Phase angle, $\phi = 0°$)

Wave form



Power Power consumed at any instant is the product of voltage and current at that instant that is

instantaneous power, $p = vi$

$$= (V_{max}\ \sin \omega t)(I_{max}\ \sin \omega t)$$
$$= V_{max} I_{max}\ \sin^2 \omega t$$
$$= V_{max} I_{max}\ \frac{(1 - \cos 2\ \omega t)}{2}$$
$$= \frac{V_{max} I_{max}}{2} - \frac{V_{max} I_{max}}{2} \cos 2\omega t$$

Avg. power P = Avg. of $\left(\frac{V_{max}}{\sqrt{2}} 2 \cdot \frac{I_{max}}{\sqrt{2}}\right)$ – Avg. of $\left(\frac{V_{max} I_{max}}{2} \cos 2\omega t\right)$

Since Avg. of $\left(\frac{V_{max} I_{max}}{2} \cos 2\omega t\right)$ over a complete cycle is zero.

$$P = \frac{V_{max}}{\sqrt{2}} \cdot \frac{I_{max}}{\sqrt{2}} = V_{rms} I_{rms} = VI$$

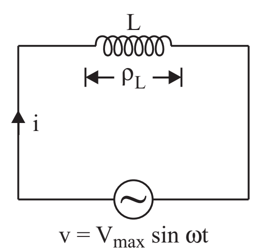
$$P = VI \text{ watts.}$$

Q. 2. Prove that in pure inductive circuit average power is zero.

Sol.

Pure Inductive Circuits

When an alternating voltage is applied to **pure inductive coil** (Coil with or without an iron core having negligible resistance), an emf, known as **self induced emf**, is induced in the coil which opposes the applied voltages. Since coil **has no resistance**, at every instant applied voltage has to overcome time self-induced emf only.



Let the applied voltage, $v = V_{max}\ \sin \omega t$

and self-inductance of coil = L henry

Applied voltage = Self induce back emf

$$v = \rho_L$$

$$V_{max}\ \sin \omega t = L\frac{di}{dt} \Rightarrow \frac{di}{dt} = \frac{V_{max}}{L} \sin \omega t$$

$$di = \frac{V_{max}}{L} \sin \omega t\ dt$$

Integrating both sides, we get $-\int di = \frac{V_{max}}{L} \int \sin \omega t\ dt$

$$i = \frac{V_{max}}{\omega L}(-\cos \omega t)$$

$$i = \frac{V_{max}}{\omega L} \sin\left(\omega t - \frac{\pi}{2}\right)$$

Current will be max, when $\sin\left(\omega t - \frac{\pi}{2}\right) = 1$

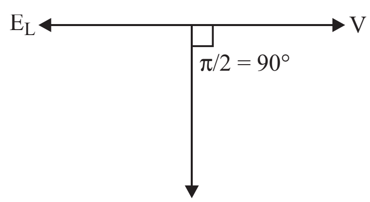
$$I_{max} = \frac{V_{max}}{\omega L}$$

$$i = I_{max} \sin\left(\omega t - \frac{\pi}{2}\right)$$

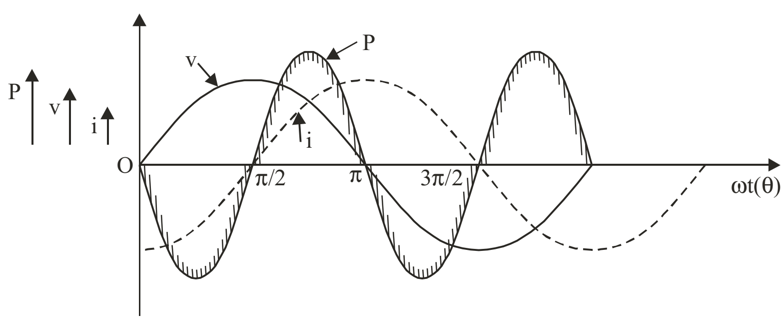
From the expression of instantaneous applied voltage, v and current, i flowing through pure inductive coil, it is observed that

Current, I **lags behind** the applied voltage, V by $\frac{\pi}{2}$ (90°).

Phasor Diagram



Waveform



Inductive Reactance ωL, in the expression $I_{max} = \frac{V}{L}$ is known as inductive reactance and is denoted by X_L, i.e., $X_L = \omega_L$ is measured in Ω (ohms).

Power Stantaneous power, $p = vi$

$$= (V_{max} \sin \omega t)(I_{max} \sin (\omega t - \pi/2))$$

$$= (V_{max} \sin \omega t)(I_{max} \cos \omega t)$$

$$= -V_{max} I_{max} \cdot \frac{1}{2} \cdot 2 \sin \omega t \cos \omega t$$

$$p = -\frac{V_{max} I_{max}}{2} \sin 2\omega t$$

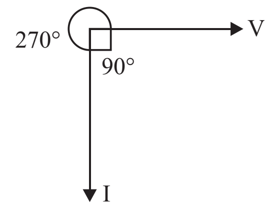
$$\text{Avg. power, } P = \text{Avg. of}\left(-\frac{V_{max} I_{max}}{2} \sin 2\omega t\right)$$

Over a complete cycle the average power **will be zero for pure inductive circuit.**

Q. 3. The voltage and current through a circuit element are $v = 100$ sin (314 + 429) volts, $i = 10$ sin (314 + 315°) Amper.

(i) Identify the circuit element (ii) Find the value (iii) Obtain the expression for power.

Sol. $v = 100 \sin(314 + 45°), i = 10 \sin(314 + 315°)$



$$\omega = 314$$

(i) Phase difference between v and i = 315 – 45° = 275°

By using phasor diagram

We can see inductor current i lags by 90° by inductor voltage v. So the element shows that purely inductive element behaviour.

(ii) $$X_L = \frac{V_{max}}{I_{max}} = \frac{100}{10} = 10$$

$$\omega L = 10 \Rightarrow L = \frac{10}{\omega} = \frac{10}{314} = 0.0318 \text{ H}$$

$$L = 31.8 \text{ mH}$$

(iii) Expression for power, $$p = -\frac{V_{max} I_{max}}{2} \sin 2\omega t$$

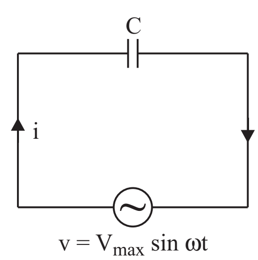
$$= \frac{-100 \times 10}{2} \sin(2 \times 314t)$$

$$p = -500 \sin 628t$$

Q. 4. Prove that in a pure capacitor circuit average power is zero. ***[2014-15]***

Sol. **Pure Capacitive Circuit**

Consider an alternating voltage applied to a capacitor of capator C farad as shown in fig. Let the applied alternating voltage is



$$v = V_{max} \sin \omega t$$

The expression for instanteous charge is given as

$$q = Cv = CV_{max} \sin \omega t$$

Circuit Current, $$i = \frac{dq}{dt} = \frac{d}{dt}(CV_{max} \sin \omega t) = \omega CV_{max} \cos \omega t$$

$$i = \omega c V_{max} \sin\left(\omega t + \frac{\pi}{2}\right)$$

Current is maximum when $\sin\left(\omega t + \frac{\pi}{2}\right) = 1$

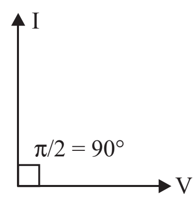
Where, $$I_{max} = \omega CV_{max} = \frac{V_{max}}{1/\omega C}$$

$$i = I_{max} \sin\left(\omega t + \frac{\pi}{2}\right)$$

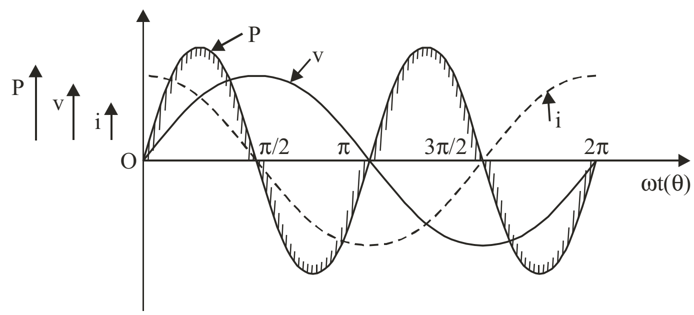
From the expression of instantaneous voltage, v and instantaneous cunce flowing through pure capacitive circuit, it is observed that

Current, I **leads** the applied voltage, V **by** $\frac{\pi}{2}$ **(90°).**

Phasor Diagram



Waveform



Capacitive Reactance $\frac{1}{\omega C}$ in the expression $I_{max} = \frac{V_{max}}{1/\omega C}$ is known as capacitive reactance and is denoted by X_C that is $X_C = \frac{1}{\omega C}$ its unit is Ω (ohm).

Power : Instantaneous power, $p = vi$

$$= (V_{max} \sin \omega t)(I_{max} \sin(\omega t + \pi/2))$$
$$= V_{max} I_{max} \sin \omega t \cos \omega t$$
$$= \frac{V_{max} I_{max}}{2} \cdot 2 \sin \omega t \cos \omega t$$
$$= \frac{V_{max} I_{max}}{2} \sin 2\omega t$$

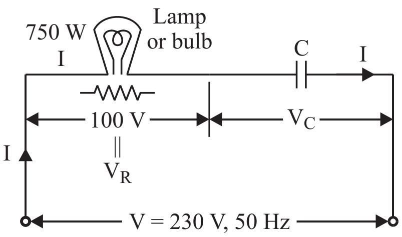
Average power, $P = \text{Avg. of} \left(\frac{V_{max} I_{max}}{2} \sin 2\omega t \right)$

Over a complete cycle **avg. power** is equal to **zero** for **purely capacitive circuit.**

Q. 5. A metal filament lamp, rated at 750 watt, 100 V is to be connected in series with a capacitor across 230 V, 50 Hz supply. Calculate the value of capacitance required. Draw phasor diagram. *[2013-14]*

Sol. Let a pure capacitance of C farads be connected in series with the lamp, as shown in fig.

Note. In this type of numericals lamp element always taking as a **resistive element**.



Now, circuit becomes $R - C$ combination

Supply voltage, $$V = \sqrt{V_R^2 + V_C^2}$$

$$V_C = \sqrt{V^2 - V_R^2} = \sqrt{230^2 - 100^2}$$

$$V_C = 207 \text{ volt}$$

Current in lamp

$$I = \frac{P}{V} = \frac{750}{100} = 7.5 \text{ Amp.}$$

Current, I sould be same in series combination we know that,

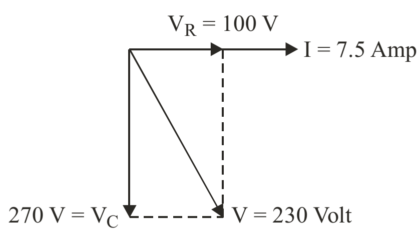
$$V_C = I\,X_C \Rightarrow X_C = \frac{V_C}{I}$$

$$= 27.6\ \Omega$$

$$X_C = \frac{1}{\omega C} \Rightarrow C = \frac{1}{(2\pi f \times C)}$$

$$= \mathbf{115.33}\ \mu\text{F}$$

Phasor diagram



Q. 6. The voltage applied to a circuit is $v = 100 \sin(\omega t + 30°)$ and current flowing in the circuit is $i = 20 \sin(\omega t + 60°)$. Determine the impedance, resistance, reactance, power and power factor of the circuit. ***[2011-12]***

Sol. Given that
$$\left.\begin{aligned} v &= 100\,(\omega t + 30°) \\ i &= 20 \sin(\omega t + 60°) \end{aligned}\right\} \text{ Instantaneous form}$$

Circuit impedance, $$Z = \frac{V_{max}}{I_{max}} \text{ or } \frac{V_{rms}}{I_{rms}} = \frac{100}{20} = 5\ \Omega$$

Phase difference, $\phi = 60° - 30° = 30°$ (Current leads)

Circuit resistance, $$R = Z \cos\phi$$
$$= 5 \cos 30° = 4.33\ \Omega$$

Circuit reactance, $$X = Z \sin\phi$$
$$= 5 \sin 30° = 2.5\Omega \text{ (capative)}$$

Power factor of the circuit $= \cos\phi$
$$= \cos 30°$$

$= 0.866$ (leading)

Power of the circuit, $P = V_{max} \times I_{rms} \cos\phi$

$$= \frac{V_{max}}{\sqrt{2}} \times \frac{I_{max}}{\sqrt{2}} \cos 30°$$

$$= \frac{V_{max} I_{max}}{2} \cos 30°$$

$= \mathbf{866\ Watt.}$

Q. 7. If load draws a current of 10 amperes at 0.8 pf lagging. When connected to 100 V supply. Calculate the values of real, reactive and apparent powers. Also find out the resistance of the load. ***[2011-12]***

Sol. Given that

$I = 10$ Amp, $\cos\phi = 0.8$ (loggin)

$V = 100$ volt, $\sin\phi = 0.6$

Real or Active Power, $P = VI \cos\phi$

$= 100 \times 10 \times 0.8$

$= \mathbf{800\ watt}$

Reactive power, $Q = VI \sin\phi$

$= 100 \times 10 \times 0.6$

$= \mathbf{600\ VAR}$

Apparent power, $S = VI$

$= 100 \times 10$

$= \mathbf{1000\ VA}$

Circuit Resistance, $R = Z \cos\phi$

Circuit Reactance, $X = Z \sin\phi$

Now, $$\boldsymbol{Z} = \frac{\boldsymbol{V}_{rms}}{\boldsymbol{I}_{rms}} = \frac{\boldsymbol{V}_{\mathbf{max}}}{\boldsymbol{I}_{\mathbf{max}}} = \frac{\mathbf{100}}{\mathbf{1}} = \mathbf{10\ \Omega}$$

$R = Z \cos\phi$

$R = 10 \times 0.8$

$R = 8\ \Omega$

$X_L = Z \sin\theta = 10 \times 0.6$

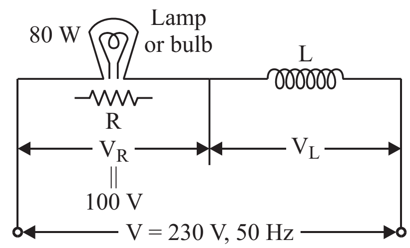
$X_L = 6\ \Omega$

Q. 8. A 100 V, 80 W lamp is to be operated on 230 V, 50 Hz ac supply. calculate the inductance to be connected in series with the lamp for the above operation. Lamp can be taken as pure resistance. ***[2012-13]***

Sol. Let a pure inductance of L henry be connected in series with the lamp, as shown in fig.

Now, the circuit becomes $R - L$ series combination.

We know that



Supply voltage, $V = \sqrt{V_R^2 + V_L^2}$

$$V_L = \sqrt{V^2 - V_R^2}$$

$$V_L = \sqrt{230^2 - 100^2}$$

$$V_L = 207 \text{ Volt}$$

Current in lamp, $I = \frac{P}{V}$

$$I = \frac{P}{V} = \frac{80}{100} = 0.80 \text{ Amp}$$

Current, I should be equal in series combination we know that

$$V_L = IX_L \Rightarrow X_L = \frac{V_L}{I} = \frac{207}{0.80}$$

$$X_L = 258.75\ \Omega$$

Now, $X_L = \omega L \Rightarrow L = \frac{X_L}{\omega} = \frac{X_L}{(2\pi f)}$

$$L = 0.824 \text{ Henergy}$$

Q. 9. A coil having a resistance of 30 Ω and inductance of 0.05 H is connected in series with a capacitor of 100 μF. The whole circuit has been connected to a single phase 230 V, 50 Hz supply. Calculate impedance, current power factor, power and apparent power of the circuit.

Sol. Given that

$$R = 30\ \Omega,\ L = 0.05 \text{ H},\ C = 100\ \mu\text{F} = 100 \times 10^{-6} \text{ F}$$

$$V = 230 \text{ V},\ f = 50 \text{ Hz}$$

$$X_L = \omega L = 2\pi f L,\ X_C = \frac{1}{\omega_C} = \frac{1}{2\pi fc}$$

$$X_L = 15.7\ \Omega = 31.8\ \Omega$$

Circuit impedance, $Z = \sqrt{R^2 + (X_L - X_L)^2} = \sqrt{(30)^2 + (15.7 - 31.8)^2}$

$$= 34.047\ \Omega$$

Current, $I = \frac{V}{Z} = \frac{230}{34.047}$

$$= 6.755 \text{ Amp.}$$

Power factor, $\cos\theta = \frac{R}{Z} = \frac{30}{34.047}$

$$= 0.881 \text{ (leading)} \qquad [\because X_C > X_L]$$

Power or Active power, $P = VI\cos\theta$

$$= 230 \times 6.755 \times 0.881$$

$$= 1368.765 \text{ Watt.}$$

Apparent power, $S = VI$

$= 230 \times 6.755$

$= 1553.65$ VA

Q. 10. A series $R - L - C$ circuit consisting of a resistance of 20 Ω, inductance 0.2 H and capacitance 150 μF is connected across a 230 V, 50 Hz source. alculate :

(i) Impedance, (ii) Current, (iii) Power factor,

(iv) The frequency of supply to be adjusted to make power factor is unity.

[2012-13]

Sol. Given that

$$R = 20\ \Omega, L = 0.2\ \text{H}, C = 150\ \mu\text{F}$$

$$V = 230\ \text{V}, f = 50\ \text{Hz}$$

$$X_L = \omega L = 2\pi f L, X_C = \frac{1}{\omega_C} = \frac{1}{(2\pi fc)}$$

$$X_L = 62.8\ \Omega\ X_C = 21.23\ \Omega$$

(i) Impedance, $Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{20^2 + (62.8 - 21)}$

$$Z = \sqrt{(20)^2 + (41.57)^2}$$

$$Z = 46.13\ \Omega$$

(ii) Current, $I = \frac{V}{Z} = \frac{230}{46.13}$

$= 4.986$ Amp

(iii) Power factor, $\cos\theta = \frac{R}{Z}$

$= \frac{20}{46.13}$

$= 0.4335$ (logging) $[\because X_L > X_C]$

(iv) When $\cos\phi = 1, \phi = 0°$

It will happen in series $R - L - C$ ckt. when ckt in resonance condition

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

$$f_r = 29.05\ \text{Hz}$$

Q. 12. A series circuit consisting of 25 Ω resistor, 64 mH inductor and 80 μF capacitor is connected to a 110 V, 50 Hz supply. Calculate the current voltage across individual element, power and over all power factor of the circuit.

[2013-14]

Sol. Given that

$R = 25\ \Omega$, $L = 64$ mH $= 64 \times 10^{-3}$ H, $C = 80\ \mu$F $= 80 \times 10^{-6}$ F

$V = 110$ V, $f = 50$ Hz

$$X_L = \omega L = (2\pi f)L,\ X_C = \frac{1}{\omega C} = \frac{1}{(2\pi f C)} = 39.809\ \Omega$$

$$X_L = 20.096\ \Omega$$

Circuit impedance, $Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(25)^2 + (20.096 - 39.809)^2}$

$$= 31.837\ \Omega$$

Current, $I = \frac{V}{Z} = \frac{110}{31.837} = 3.4550$ Amp.

Voltage across resistance, $R \Rightarrow V_R = IR = 3.455 \times 25$

$$= 86.377 \text{ Volt}$$

Voltage across inductance, $L \Rightarrow V_L = IX_L$

$$= 3.455 \times 20.096$$

$$= 69.43 \text{ Volt}$$

Voltage across capacitance, $C \Rightarrow V_C = IX_C$

$$= 3.455 \times 39.809$$

$$= 137.54 \text{ Volt}$$

Power or active power, $P = VI\cos\phi = 110 \times 3.455 \times \left(\frac{25}{31.837}\right)$ (25 → R, 31.837 → Z)

$$= 298.434 \text{ Watt.}$$

Over all power factor of the circuit, $\cos\phi = \frac{R}{Z} = \frac{25}{31.837} = 0.7852$

Q. 13. A choke coil having a resistance of 10 Ω and inductance of 0.05 H is connected in series with a condanser of 100 μF. The whole circuit has been connected to 220 V, 50 Hz suply. Calculate : (i) Impedance, (ii) Current, (iii) Power factor, (iv) Power input, (v) Voltage across resistance. ***[2015-16]***

Sol. Given that

$$R = 10\ \Omega,\ L = 0.05\ \text{H},\ C = 100\ \mu\text{F} = 100 \times 10^{-6}\text{F}$$

$$V = 220\ \text{V},\ f = 50\ \text{Hz}$$

$$X_L = \omega L = 2\pi f L,\ X_C = \frac{1}{\omega C} = \frac{1}{(2\pi f C)} = 31.8\ \Omega$$

$$X_L = 15.7\ \Omega$$

(i) Impedance, $Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(10)^2 + (15.7 - 31.8)}$

$$= 18.953\ \Omega$$

(ii) Current, $I = \frac{V}{Z} = \frac{220}{18.953}$

$$= 11.607 \text{ Amp.}$$

(iii) Power factor, $\cos\phi = \frac{R}{Z} = \frac{10}{18.953}$

$= 0.527$ (leading) $[\because X_C > X_L]$

(iv) Power input or active power, $P = VI \cos\phi$

$= 220 \times 11.607 \times 0.527$

$= 1347.30$ Watt.

(v) Voltage across resistance, $V_R = IR$

$= 11.607 \times 10$

$= 116.07$ Volt

Q. 13. Voltage across *R*, *L*, *C* comected in series are 5, 8, 10 volts respectively. Calculate the value of supply voltage at 50 Hz. Also find the frequency at which this circuit would resonate. ***[2011-12]***

Sol. Given that

Voltage across R, $V_R = 5$ V

Voltage across L, $V_L = 8$ V

Voltage across C, $V_C = 10$ V

Supply voltage, $V = \sqrt{V_R^2 + (V_L - V_C)^2} = \sqrt{5^2 + (8-10)^2}$

$= 5.39$ volt

We know that $V_L = IX_L \Rightarrow I = \dfrac{V_L}{X_L}$ ...(1)

$V_C = IX_C \Rightarrow I = \dfrac{V_C}{X_C}$ ...(2)

From eqn. (1) and (2) $\dfrac{V_L}{X_L} = \dfrac{V_C}{X_C} \Rightarrow \dfrac{V_L}{V_C} = \dfrac{X_L}{X_C}$

$$\frac{8}{10} = \frac{(2\pi fL)}{1/(2\pi fC)}$$

$$0.8 = (2\pi f)^2 \cdot LC$$

$$LC = \frac{0.8}{(2\pi f)^2}$$

$$= \frac{(0.8)}{(2\pi \times 50)^2}$$

$$= 8.10569 \times 10^{-6}$$

Now resonant frequency, $f_r = \dfrac{1}{2\pi\sqrt{LC}}$

$$f_r = \frac{1}{2\pi\sqrt{8.10569 \times 10^{-6}}}$$

$$f_r = 55.90 \text{ Hz}$$

Q. 14. Why power factor measurement is important? What are causes and problems of low power factor? How power factor can be improved?

[2012-13, 2013-14, 2014-15, 2015-16, 2016-17]

Power Factor Improvement

Sol. Power Factor By using activer or Ture or Real power

$$P = VI\cos\phi \Rightarrow \cos\phi = \frac{P}{VI}$$

$$\Rightarrow \qquad I = \frac{P}{V\cos\phi}$$

If P and V are constant, the load current I is inversely promotional to power factor, $\cos\phi$, i.e., lower the power factor, higher the current and vice-versa.

The higher current due to poor power factor affects the system and results in the following disadvantages

(i) Rating of gerneraers and transformers are promotional to their output current hence inversely promotional to power factor, therefore large generates and transformers are required to deliver same load but at a low power factor.

(ii) For the same power to be transmitted but at low power factor, the transmission line or the distributor or cable will have to carry more current. Thus more conductor material is required for transmission lines, distributors and cables to deliver the same load but a low power factor.

(iii) Copper lasses are promotional to the square of current hence inversely promotional to the square of the power factor i.e. more copper losses incur at low power factor, which results in poor efficiency.

(iv) Low lagging power factor results in large voltage drop in generators, transformers, transmission line and distributors which results in poor regulation. Hence extra regulating equipment is required to keep the voltage drop with in permissible limits.

Causes of Low Power Factor

- Most of elecirical equipments are induction type.
- A transformer draws magnetizing current from the supply.
- At normal load, this current does not affect the p.f much but at light loads the primary current power factor is low.

Advantages of Power Factor Improvement

- Load output of a given plant is better wilized.
- Line lasses are reduced to minimum, therefore efficiency of the plant is improved.
- Voltage or voltage regulation is considerably reduced.

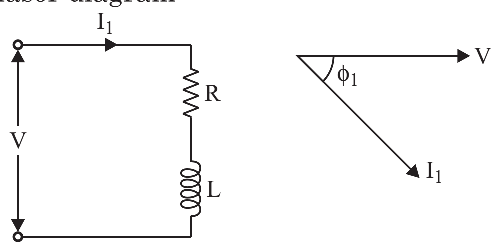
Power Factor Can Be Improved by

- Using induction motor with phase advancers.

- By using synchronous condensers litre shunt capacitors connected across the supply.
- Connecting the static capacitors in parallel with the equipment operating at lagging power factor such as induction motors.

Static Capacitor Method : For Inductive load.

At this condition, Phasor diagram

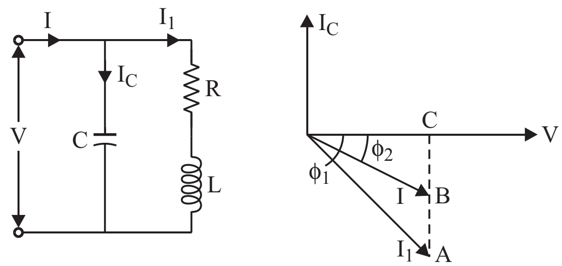


where, $V \rightarrow$ Supply voltage

$I_1 \rightarrow$ Load current

$\phi_1 \rightarrow$ Phase angle between V and I_1

Let a C volue capacitor be placed in parallel with the load



Now new phasor diagram will be

where $I \rightarrow$ supply current

$$\vec{I} = \vec{I_C} + \vec{I_1}$$

Phase angle of I is ϕ_2

$$\phi_2 < \phi_1$$

$$\cos\phi_2 > \cos\phi_1$$

So power factor is improved from $\cos\phi_1$ to $\cos\phi_2$.

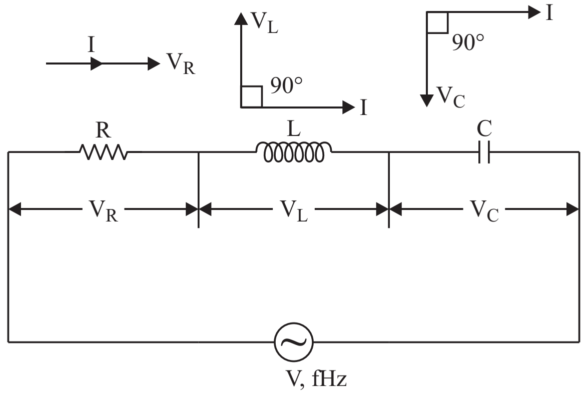
Q. 15. Derive an expression for resonant frequency. Write properties of series resonance circuit. ***[2015-16, 2016-17]***

Sol. Series ($R - L - C$) or Voltage Resonance

Consider an ac circuit containing a resistance R, an inductance and a capacitance C connected in series, as shown in fig.

For series $R - L - C$ circuit Impedance

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



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

If for some frequency of applied voltage, $X_L = X_L$ in magnitude

$$X_L = \omega L = 2\pi f L$$

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

The frequency of supply at which two reactances (X_L and X_C) are equal is called resonant frequency. It is denoted by

$$X_L = X_C$$

$$2\pi frL = \frac{1}{2\pi frC} \Rightarrow fr^2 = \frac{1}{(\pi^2) \cdot LC}$$

$$fr = \frac{1}{2p\sqrt{LC}} \text{ Hz}$$

At resonance

- Net reactance, X is zero i.e., $X = X_L - X_C = 0$
- Impedance of the circuit, $Z = R$
- j (imaginary) term is zero.
- Impedance is minimum
- current is maximum, $I_{max} = \frac{V}{Z} = \frac{V}{R}$ ***[2012-13]***
- Ckt becomes purely resistively.
- Phase angle, ϕ between supply V and I is zero, $\phi = 0$
- Power factor is unity. $\cos\phi = 1$

$$V_L = V_C$$

- Supply voltage, $v = V_R = IR$
- Power, $P = VI \cdot \cos\theta = VI$ watts $\{\because \cos\phi = 1\}$

Since in series resonance the voltage across inductance (V_L) and capacitance (V_C) is **maximum**, it is called the **voltage resonance**.

The series resonance is also called an **acceptor circuit** because such a circuit **accepts currents at one particular frequency but rejects current of other frequency.**

Q. 17. Derive the relation for Q-factor of the series $R - L - C$ circuit.

[2014-15, 2-11-12]

Sol. Quality Factor of a Series Resonant Circuit

The quality (Q factor) factor of an $R - L - C$ series circuit defined as voltage magnification that the circuit produces at resonance.

$$\text{Voltage magnification} = \frac{\text{Voltage across } L \text{ or } C}{\text{Supply voltage}}$$

$$= \frac{V_L}{V} \text{ or } \frac{V_C}{V}$$

at resonance

$$Z = R, I \rightarrow I_{\max}$$

$$Q\text{-factor} = \frac{I_{\max}\, X_L}{I_{\max}\, R} \text{ or } \frac{I_{\max} X_C}{I_{\max} R}$$

$$= \frac{X_L}{R} \text{ or } \frac{X_C}{R}$$

$$= \frac{2\pi frL}{R} \text{ or } \frac{1}{2\pi fr \cdot C \cdot R}$$

$$= 2\pi \times \frac{1}{2\pi\sqrt{LC}} \cdot \frac{L}{R} \text{ or } \frac{1}{2\,pi \cdot \frac{1}{2\pi\sqrt{LC}} \cdot CR}$$

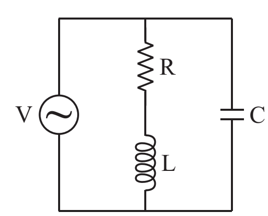
$$Q\text{-factor} = \frac{1}{R}\sqrt{\frac{L}{C}}$$

Q. 18. Deseribe the concept of parallel resonance with circuit diagram. Derive the relations for resonant frequency, current and impedance.

[2015-16, 2014-15]

Sol. **Parallel or Current Resonance**

A parallel a.c. circuit containing reactive elements (L and C) is said to be in resonance when the circuit **power factor is unity** i.e., reactive component of line current is zero. The frequency at which it occurs is called the **resonant frequency** fr.



For the parallel circuit admittance

$$Y = Y_{R-L} + Y_C$$

$$Y = \frac{1}{Z_{R-L}} + \frac{1}{Z_C}$$

$$Y = \frac{1}{R + j\omega L} + \frac{1}{1/j\omega C}$$

$$Y = \frac{R - j\omega L}{R^2 + \omega^2 L^2} + j\omega C$$

$$Y = \frac{R}{R^2 + \omega^2 L^2} + j\left[\omega C - \frac{\omega L}{R^2 + \omega^2 L^2}\right]$$

at resonance j term is equal to zero.

$$\omega_r C - \frac{\omega_r L}{R^2 + \omega_r^2 L^2} = 0 \Rightarrow C = \frac{L}{R^2 + \omega_r^2 L^2}$$

$$R^2 C + \omega_r^2 L^2 C = L$$

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

$$\omega_r = \sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$$

$$fr = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$$

if $R = 0$

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

If parallel circuit is in following form

Then

$$fr = \frac{1}{2\pi\sqrt{LC}}\sqrt{\frac{CR^2 - L}{CR_1^2 - L}}$$

Impedance at resonance Line current, $Ir = I_L \cos\phi$

$$\frac{V}{Z} = \frac{V}{Z_L} \cdot \frac{R}{Z_L}$$

$$\frac{1}{Z} = \frac{R}{Z_L^2} \Rightarrow \frac{1}{Z} = \frac{R}{L/C}$$

$\Rightarrow$ $\boxed{Z = \frac{L}{CR}}$ Impedance at resonance for given ckt. and its value is maximum in parallel resonance.

In parallel resonance impedance Z is high and current I is

$$I_{\min} = I = \frac{V}{Z} = \frac{VCR}{L}$$

[2012-13]

Q. 19. Derive the relation for *Q*-factor of the parallel $R - L - C$ circuit.

[2012-13]

Sol. **Quality Factor of a Parallel Resonant CKT** *[2015-16]*

Quality (Q-factor) of a parallel circuit is defined as the ratio of the circulating current to the line current or as the **current magnification**.

$$Q\text{-factor} = \frac{\text{Circulating current between } L \text{ and } C}{\text{Line current}}$$

$$= \frac{I_C}{I}$$

$$= \frac{2\pi frCV}{\frac{V}{Z}}$$

$$= \frac{2\pi frCV}{VCR/L}$$

$$= \frac{2\pi fr \cdot L}{R}$$

$$= \frac{2\pi}{R} \cdot \frac{1}{2\pi\sqrt{LC}} \cdot L$$

$$Q\text{-factor} = \frac{1}{R}\sqrt{\frac{L}{C}}$$

It is same as for series resonance circuit.

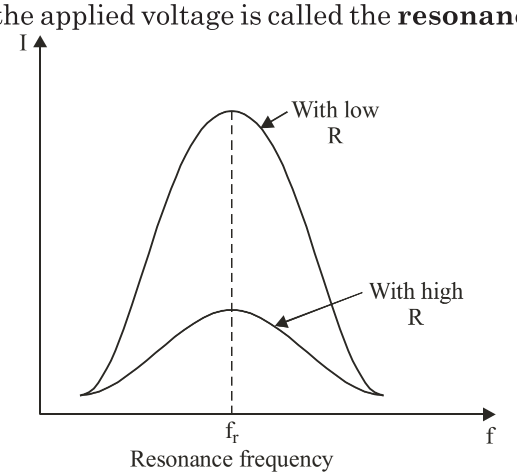
It series circuits, Q-factor provides the **voltage magnification**, whereas in parallel circuits, it provides **current magnification.**

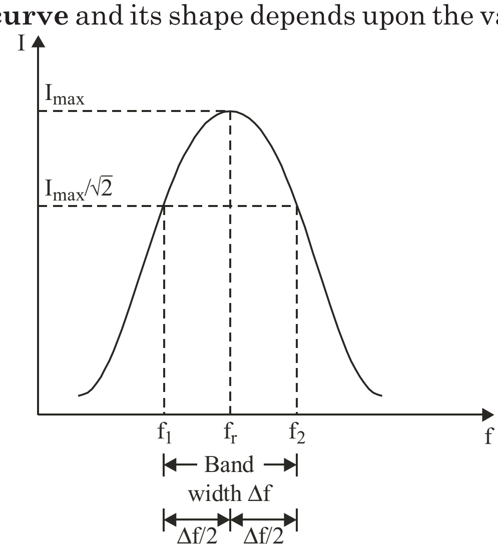
Q. 20. Explain the frequency curve (resonance curve) in a series $R - L - C$ circuit with proper labeling. ***[2014-15]***

Give the expression for bandwidth and show the result, $fr = \sqrt{f_1 f_2}$

[2014-15, 2011-12, 2013-14]

Sol. Resonance Curve : The curve drawn between circuit current and the frequency of the applied voltage is called the **resonance curve** and its shape depends upon the value





of circuit resistance R, as shown in fig. For **smaller values of R**, the resonance curve is **sharply peaked,** but for **larger values of R,** the curve is **flat**.

Band-Width, Δf The bonds of frequencies which is lies between half power frequency $(f_1$ and $f_2)$ is known as the **band-width, Δf**

$$\Delta f = f_2 - f_1, \Delta f = f_H - f_L \text{ Hz}$$

where, $\Delta f \rightarrow$ Band width

f_2 or $f_H \rightarrow$ High power frequency

f_1 or $f_L \rightarrow$ Low power frequency

Points regarding half-power frequencies are

- Current will be $\frac{1}{\sqrt{2}}$ of its max. value
- Impedance will be $\sqrt{2}$ times of its $Z_{\min} = \sqrt{2}R$
- Power will be $\frac{1}{2}$ of its maximum, $P_1 = P_2 = \frac{P_{\max}}{2}$
- **Expression for Band-Width**

Impedance for series $R - L - C$ ckt

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

at half power frequency (point)

$$Z \rightarrow \sqrt{2}Z_{\min} \rightarrow \sqrt{2}R$$

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

$$2R^2 = R^2 + (X_L - X_C)^2$$

$$R^2 = (X_L - X_C)^2$$

$$\left(\omega L - \frac{1}{\omega C}\right) = \pm R$$

For higher power cut-off frequency $\omega_1 L - \frac{1}{\omega_2 C} = R$ ...(1)

For lower power cut-off frequency $\omega_1 L - \frac{1}{\omega_2 C} = -R$ ...(2)

Adding eqn. (1) and (2)

$$(\omega_2 + \omega_1)L - \left(\frac{1}{\omega_2} + \frac{1}{\omega_1}\right)\frac{1}{C} = 0$$

$$(\omega_1 + \omega_2)L - \left[\frac{(\omega_1 + \omega_2)}{\omega_1 \omega_2}\right]\frac{1}{C} = 0$$

$$(\omega_1 + \omega_2)\left\{L - \frac{1}{\omega_1 \omega_2} \cdot \frac{1}{C}\right\} = 0$$

$$L - \frac{1}{\omega_1\omega_2} \cdot \frac{1}{C} = 0$$

$$L = \frac{1}{\omega_1\omega_2} \cdot \frac{1}{C} \Rightarrow \frac{1}{\omega_1\omega_2} = LC$$

$$\omega_1\omega_2 = \frac{1}{LC} \qquad \ldots(3)$$

$$(2\pi f_1)(\pi f_2) = \frac{1}{LC}$$

$$f_1 f_2 = \frac{1}{(2\pi)^2 LC}$$

$$f_1 f_2 = fr^2 \qquad \left\{\because fr = \frac{1}{2\pi\sqrt{LC}}\right\}$$

$$\boxed{fr = \sqrt{f_1 f_2}}$$

By subtracting eqn. (2) from (1)

$$(\omega_2 - \omega_1)L + \left(\frac{1}{\omega_1} - \frac{1}{\omega_2}\right) \cdot \frac{1}{C} = +2R$$

$$(\omega_2 - \omega_1)L + \left[\frac{(\omega_2 - \omega_1)}{\omega_1\omega_2} \cdot \frac{1}{C}\right] = 2R$$

$$(\omega_2 - \omega_1)\left[L + \frac{1}{\omega_1\omega_2} \cdot \frac{1}{C}\right] = 2R$$

$$(\omega_2 - \omega_1)\left[L + LC \cdot \frac{1}{C}\right] = 2R \qquad \left\{\text{From eqn. (3) } \frac{1}{\omega_1\omega_2} = LC\right\}$$

$$2\pi(f_2 - f_1)[L + L] = 2R$$

$$(2\pi) \cdot (2L) \cdot (f_2 - f_1) = 2R$$

$$f_2 - f_1 = \frac{2R}{2\pi \cdot 2L}$$

Bond width, $$\boxed{\Delta f = \frac{R}{2\pi L}}$$

Relations Between f_1, f_2, fr and Δf *[2015-16]*

From fig of resonance curve

(1) $$f_2 = fr + \frac{1}{2} \cdot \Delta f \text{ or } f_H = fr + \frac{\Delta f}{2}$$

(2) $$f_1 = fr - \frac{1}{2}\Delta f \text{ or } f_L = fr - \frac{\Delta f}{2}$$

Relations Between fr, Q and Δf *[2011-12]*

We know that

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

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

$$\Delta f = \frac{R}{2\pi L}$$

Quality factor Q can also be define as the ratio of resonance frequency, fr to the bandwidth, Δf.

$$\Delta f = \frac{fr}{Q} \Rightarrow Q = \frac{fr}{\Delta f}$$

Proof

$$\Delta f = \frac{\frac{1}{2\pi\sqrt{LC}}}{\frac{1}{R}\sqrt{\frac{L}{C}}} \Rightarrow \frac{fr}{Q}$$

$$= \frac{R\sqrt{C}}{2\pi\sqrt{LC}\cdot\sqrt{L}}$$

$$\Delta f = \frac{R}{2\pi L}$$

Proved.

Q. 21. Define following factor terms :

(i) Active or Real or True or watt full power. ***[2015-16]***

(ii) Reactive power

(iii) Apparent power

(iv) Power factor

(v) Quality factor

Sol. Active power Product of apparent power and power factor, is known as active power, denoted by P and measured in watt or KW.

$$P = VI\cos\phi$$

Reactive power Product of apparent power and sine of phase angle (ϕ), is known as reactive power, denoted by Q and measured in VAR or KVAR.

$$Q = VI\sin\phi$$

Apparent power Product of supply voltage and supply current, is known as apparent power, denoted by S and measured in VA or KVA.

$$S = VI$$

Power factor Cosine of the phase angle (ϕ) between supply voltage and supply current, is known as power factor, $\cos\phi$. It is unit less.

$$\cos\phi = \frac{R}{Z} \text{ (by impedance triangle)}$$

$$\cos\phi = \frac{P}{S} \text{ (by power triangle)}$$

$$\cos\phi = \frac{V_R}{V} \text{ (by voltage triangle)}$$

Quality factor Reciprocal of power factor is define as a quality factor.

$$Q\text{-factor} = \frac{1}{\text{Power factor}} = \frac{1}{\cos\phi}$$

$$= \frac{1}{(R/Z)} = \frac{Z}{R}$$

When reactive (X) is very much greater than resistance (R) inimpedance

$$X >> R$$

$$Q\text{-factor} = \frac{X}{R}$$

X may be X_L or may be X_C.

Q. 22. A 46 mH inductive coil has a resistance of 10 Ω. How much current will it draw, if connected across 100 V, 50 Hz source? Also determine the value of capacitance that must be connected across the coil to make the power factor of the circuit to be unity. ***[2016-17]***

Sol. Given that

$$L = 47 \text{ mH} = 46 \times 10^{-3} \text{ H}, R = 10\ \Omega$$

$$V = 100 \text{ V}, f = 50 \text{ Hz}$$

(i) $X_L = \omega L = 2\pi f L = 2\pi \times 50 \times 46 \times 10^{-3}$

$$= 14.451\ \Omega$$

Circuit impedance, $Z = \sqrt{R^2 + X_L^2} = \sqrt{(10)^2 + (14.451)^2}$

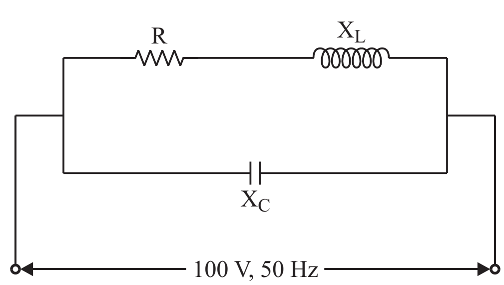
$$= \sqrt{308.83}$$

$$= 17.574\ \Omega$$

Current, $I = \frac{V}{Z} = \left(\frac{100}{17.574}\right)$

$$= 5.69 \text{ Amp.}$$

(ii) $C = ?, \cos\phi = 1 \Rightarrow \phi = 0°$



In this combination, power factor unity, $(\phi = 0^\circ)$ when $B_L = B_C$.

Now, inductive susceptance, $B_L = \dfrac{X_L}{R^2 + X_L^2} = \dfrac{14.4}{308}$

$$= 0.0468 \text{ S}$$

$$B_L = B_C \Rightarrow 0.0468 = \omega C$$

$$C = \frac{0.0468}{(2\pi f)} = \left(\frac{0.0468}{314}\right)$$

$$C = 0.0001490445 \text{ farad}$$

$$C = 149.0445 \ \mu\text{F}$$

Q. 23. A resistance and inductance are connected in series across a voltage $v = 283 \sin 314t$. An expression of current is found to be $i = 4 \sin (314t - 45^\circ)$. Find the values of resistance, inductance and power factor. ***[2012-13]***

Sol. Given that,

$$v = 283 \sin 314t$$

$$i = 4 \sin (314t - 45^\circ)$$

Instantaneous form

$$\omega = 314 \Rightarrow f = \frac{314}{2\pi} = 50 \text{ Hz}$$

Phase difference, $\phi = 45^\circ$ (voltage leads)

Circuit resistance, $R = Z \sin \phi$

Circuit reactance, $X = Z \sin \phi$ (Inductive)

Now $$Z = \frac{V_{\max}}{I_{\max}} \text{ or } \frac{V_{\text{rms}}}{I_{\text{rms}}} = \frac{283}{4} = 70.75 \ \Omega$$

$$R = Z \cos \phi$$

$$= 70.75 \cos (45^\circ) = 50 \ \Omega$$

$$X_L = Z \sin \phi$$

$$= 70.75 \sin (45^\circ) = 50 \ \Omega$$

We know that $$X_L = \omega L \Rightarrow L = \frac{X_L}{\omega}$$

$$= \frac{50}{314}$$

$$= 0.159 \text{ Henery}$$

Power factor of circuit $= \cos \phi$

$$= \cos 45^\circ$$

$$= 0.707 \text{ (Logging)}$$

Q. 24. The voltage and current of an $R - L - C$ series circuit are $v = 141.4 \sin (314 + 45^\circ)$ volt

$i = 28.28 \sin (314 - 15^\circ)$ Amp.

Find (i) V_{rms} and I_{rms}, (ii) Power factor, (iii) Power (iv) T (v) Value of R, L and C in a circuit. ***[2013-14]***

Sol. Phase difference, $\phi = 45° - (-15°) = 60°$

(i) $$V_{rms} = \frac{V_{max}}{\sqrt{2}}, I_{rms} = \frac{28.28}{\sqrt{2}} = \frac{I_{max}}{\sqrt{2}}$$

$$= 100 \text{ volt} = 20 \text{ Amp}$$

(ii) Power factor, $\cos\phi = \cos 60° = 0.5$ (lagging)

(iii) Power or Active Power, $$P = VI\cos\phi = \frac{V_{max}}{\sqrt{2}} \cdot \frac{I_{max}}{2} \cos 60°$$

$$= 1000 \text{ Watt}$$

(iv) Time period, $$T = \frac{1}{f} = \frac{1}{(\omega/2\pi)} = \frac{2\pi}{\omega}$$

$$= \frac{2\pi}{314} = 0.02001 \text{ sec}$$

(v) Circuit resistance, $$R = Z\cos\phi = \left(\frac{V_{rms}}{I_{rms}}\right) \times \cos 60°$$

$$= 2.5\ \Omega$$

Circuit reactance, $$X = X_L - X_C = Z\sin\phi$$

$$= 4.33\ \Omega$$

Q. 25. A series ac circuit has a resistance of 15 Ω and inductive reactance of 10 Ω. Calculate the value of a capacitor which is connected across this series combination so that system has unity power factors. The frequency of ac supply is 50 Hz. ***[2016-17]***

Sol. Given that

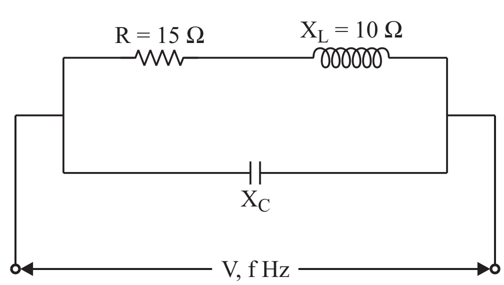
$$R = 15\ \Omega, X_C = 10\ \Omega, C = ?$$

$$\cos\phi = 1 \Rightarrow \phi = 0°$$

[It means either $\underbrace{X_L = X_C}_{\text{Series}}$ or $\underbrace{B_L = B_C}_{\text{Parallel}}$]

Conductance of coil, $$G = \frac{R}{R^2 + X_L^2} = \frac{15}{15^2 + 10^2}$$

$$= 0.04615$$

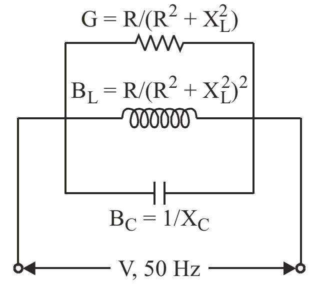


Inductive susceptance of coil, $B_L = \dfrac{X_L}{R^2 + X_L^2} = \dfrac{10}{15^2 + 10^2}$

$$= 0.0307\,\text{S}$$

Now, circuit becomes

Capacitive susceptance of capacitance $C, B_C = \dfrac{1}{X_C}$



$$B_C = 2\pi f C$$

Now by $B_L = B_C \Rightarrow 0.0307 = 2\pi f C$

$$C = \frac{0.0307}{2\pi f} = \frac{0.0307}{314}$$

$$= 9.7770 \times 10^{-5}$$

$$C = 97.77\,\mu\text{F}$$

Q. 26. An inductive coil of resistance 10 Ω and inductance 0.1 H is connected in parallel with a 150 μF capacitor to a variable frequency 200 V supply. Find the frequency at which the total current taken from the supply is in phase with the supply voltage. Also find the magnitude for this current.

Sol. Given that

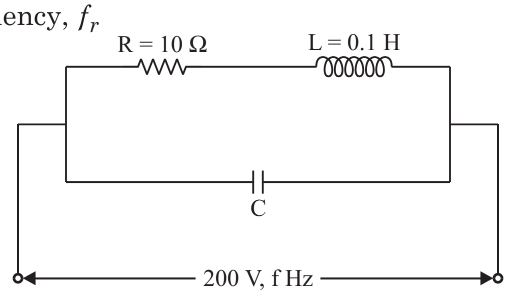
$$R = 10\ \Omega,\ L = 0.1\ \text{H},\ C = 150\ \mu\text{F} = 150 \times 10^{-6}\ \text{F}$$

$$V = 200\ \text{V}$$

When supply current is in phase with supply voltage, hence phase diff. is zero.

It means circuit is in resonant condition.

Now resonant frequency, f_r



$$f_r = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{L^2}} \qquad \text{(For above circuit)}$$

$$f_r = \frac{1}{2\pi}\sqrt{\frac{1}{(0.1 \times 150 \times 10^{-6})} - \frac{(10)^2}{(0.1)^2}}$$

$$f_r = \frac{1}{2\pi}\sqrt{66666.667 - 10000}$$

$$f_r = \frac{1}{2\pi}\sqrt{56666.667}$$

$$f_r = 37.886 \text{ Hz}$$

Q. 27. Two impedances $Z_1 = (5 + i10)\ \Omega$ and $Z_2 = (10 - i15)\ \Omega$ are connected in parallel. If total current is 20 A then find (i) current taken by each branch (ii) power factor (iii) Total power consumed. *[2013-14]*

Sol. Given that

$$Z_1 = (5 + i10)\ \Omega = 11.18\ \angle 63.435°$$

$$Z_2 = (19 - i15)\ \Omega = 18.03 - \angle -56.31°$$

$$Z_{\text{Total}} = Z_1 \,||\, Z_2 = \frac{Z_1 Z_2}{Z_1 + Z_2} = \frac{(11.18\ \angle 63.435°)(18.03 - \angle -56.31)}{(5 + i10) + (10 - i15)}$$

$$= \frac{201.556\angle 7.1250°}{15.811\angle -18.435°} = 12.748\ \angle 25.56°$$

Current, $I = 20 = (20 + i0) = 20\ \angle 0°$ Amp

Total $V = IZ_{\text{total}} = (20\ \angle 0°)(12.48\ \angle 25.56°)$

$$= 254.96\ \angle 25.56°$$

(i) Current through Z_1, $I_1 = \dfrac{V}{Z_1} = 254.96\ \angle 25.56°$

$$= 22.804\ \angle -37.45° \text{ Amp}$$

$$= (18.0 - i14) \text{ Amp}$$

Current through Z_2, $I_2 = \dfrac{V}{Z_2} = 254.96\ \angle 25.56°$

$$= 14.142\ \angle 81.87° \text{ Amp}$$

$$= (2 + i15) \text{ Amp}$$

(ii) Power factor, $\cos\phi = \cos(25.56°)$ Angle of $Z_{\text{Total}} = 0.9$

(iii) Total Power consumed, $P = VI\cos\phi$

$$= 254.96 \times 20 \times \cos(25.56°) = 4600.16 \text{ Watt}$$

Q. 28. In series-parallel circuit A and B are in series with C. The impedances are : $Z_A = (4 + 13)\ \Omega$, $Z_B = (4 - i5)\ \Omega$, $Z_C = (2 + i8)$. If the current $I_C = (25 + i0)$, calculate :

(i) Branch currents I_A and I_B

(ii) Branch voltages V_A, V_B and V_C,

(iii) Total power

(iv) Phasor diagram *[2015-16]*

Sol.

$$Z_A = (4 + i3)\ \Omega$$

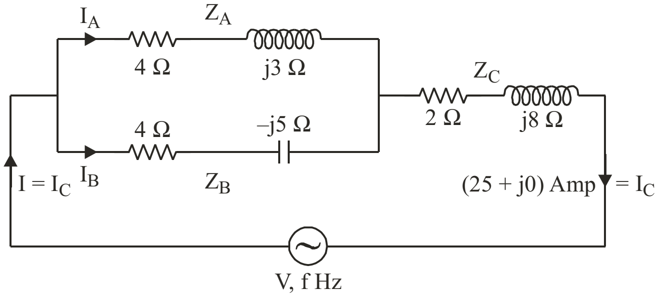
$$= 5\ \angle 36.87°\ \Omega$$

$$Z_B = (4 - i5)\ \Omega$$

$$= 6.4\ \angle -51.34°\ \Omega$$

$$Z_C = (2 + i8)\ \Omega$$

$$= 8.246\ \angle 75.96°\ \Omega$$



$$Z_{A-B} = Z_A \parallel Z_B = \frac{Z_A Z_B}{Z_A + Z_B} = \frac{(5\angle 36.87^\circ)(6.4\angle -51.34^\circ)}{(4+i3)+(4-i5)}$$

$$Z_{A-B} = 3.88\angle 0^\circ\ \Omega$$

(i) Branch Current, $I_A = I \times \dfrac{Z_B}{Z_A + Z_B} = 19.4\angle -37.3^\circ$ Amp

Branch Current, $I_B = I \times \dfrac{Z_A}{Z_A + Z_B} = 15.1588\angle 50.9^\circ$

(ii) Branch Voltage, $V_A = V_B = V_{AB}$ (Because Parallel)

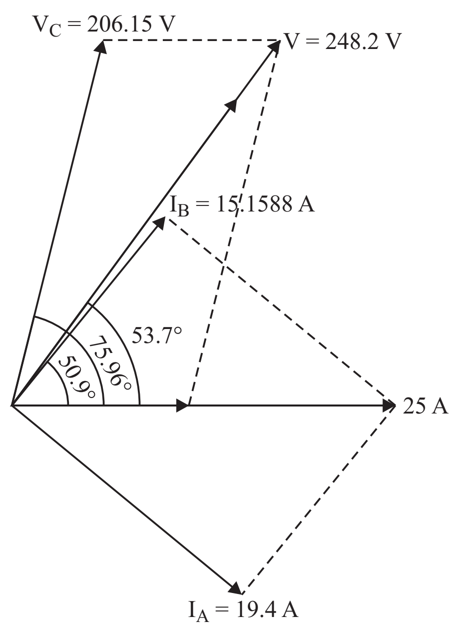
$V_{AB} = I \times Z_{A-B} = 97\angle 0^\circ$ volt

Branch voltage $V_C = IZ_C = 206.15\angle 75.96^\circ$

(iii) Total power, $P = I_A^2 R_A + I_B^2 R_B + I_C^2 R_C$

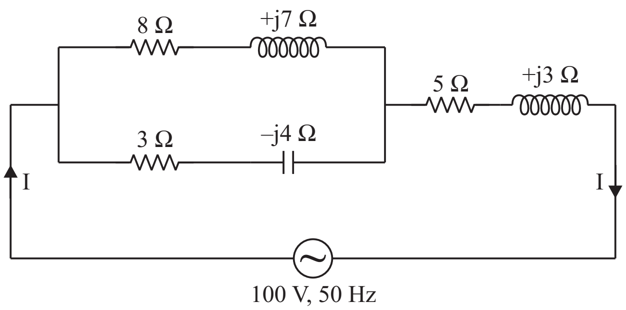
$= 3674.6$ watt

Total voltage, $V = V_{AB} + V_C = 248.2\angle 53.7^\circ$ volt



Q. 29. An impedance of (8 + *i*7) is connected with (3 – *i*4) in parallel, than further is connected with (5 + *i*3) in series with supply of 100 V, 50 Hz. Draw the circuit diagram and hence find the current in circuit and total impedance of the circuit. ***[2014-15]***

Sol.



$$Z_1 = (8 + i7) = 10.63 \angle 41.18°$$
$$Z_2 = (3 - i4) = 5 \angle -53.13°$$
$$Z_3 = (5 + i3) = 5.83 \angle 30.96°$$
$$Z_{1-2} = Z_1 \,||\, Z_2 = \frac{Z_1 Z_2}{Z_1 + Z_2}$$
$$= \frac{(10 \angle 41.18°)(5 \angle -53.13°)}{(8 + i7) + (3 - i4)}$$
$$Z_{1-2} = (50 \angle -11.95°)/(11.40 \angle 15)$$
$$Z_{1-2} = 4.386 \angle -27.2°$$
$$= (3.9 - i2)$$

Circuit impedance, Z_{Total}

$$Z_{\text{Total}} = Z_{1-2} + Z_3 = (4 - i2) + (5 + i3)$$
$$= (9 + i1)\ \Omega = 9.055 \angle 6.34°\ \Omega$$

Circuit current,
$$I = \frac{V}{Z} = \frac{100 \angle 0°}{9.055 \angle 6.34°} = 11.04 \angle -6.34° \text{Amp.}$$

Q. 30. Obtain the power factor of a two branch parallel circuit where the first branch has $Z_1 = (2 + i4)\ \Omega$ and second $Z_2 = (6 + i0)$. To what value must the 6 Ω resistor be changed to result in the overall power factor 0.9 lagging? ***[2012-13]***

Sol. Given that

$$Z_1 = (2 + i4)\ \Omega = 4.47 \angle 63.435°\ \Omega$$
$$Z_2 = (6 + i0)\ \Omega = 6 \angle 0°\ \Omega$$

(i)
$$Z_{\text{Total}} = Z_1 \,||\, Z_2 = \frac{Z_1 Z_2}{Z_1 + Z_2} = \frac{(4.47 \angle 63.435°)(6 \angle 0°)}{(2 + i4) + (6 + i0)}$$
$$= \frac{26.82 \angle 63.435°}{(8 + i4)} = \frac{26.82 \angle 63.435°}{8.94 \angle 26.565°}$$

$$= 3\ \angle 36.86^\circ$$

Now, $\phi = 36.87^\circ$ (Angle of Z_{Total})

Power factor, $\cos\phi = \cos(36.87^\circ)$

$$= 0.7999 \approx 0.8 \text{ (lagging)}$$

(ii) Let the resistance of the resistor of Z_2 be changed to R ohms so as to maks the power factor of whole circuit 0.9 (lagging).

When $\cos\phi = 0.9 \Rightarrow \phi = \cos^{-1}(0.9) = 25.842^\circ$

$$= 25.842^\circ$$

Now, $Z_1 = (2 + i4)\ \Omega = 4.47\ \angle 63.435^\circ\ \Omega$ (Same as Ist condition)

$Z_2 = (R + i0) = R = R\ \angle 0^\circ\ \Omega$ (In 2nd condition)

$$Z_{\text{Total}} = Z_1 \,||\, Z_2 = \frac{Z_1 Z_2}{Z_1 + Z_2} = \frac{(2 + i4)R}{(2 + i4) + (R + i0)}$$

$$Z_{\text{Total}} = \frac{2R + i4R}{(R + 2) + i4}$$

To break in Real and I_m part using complex conjugate method

$$Z_{\text{Total}} = \frac{2R + i4R}{(R + 2) + i4} \times \frac{(R + 2) - i4}{(R + 2) - i4}$$

$$Z_{\text{Total}} = \frac{2R(R + 2) + 16R + i4R(R + 2) - i8R}{(R + 2)^2 + 16}$$

$$Z_{\text{Total}} = \frac{(2R^2 + 20R) + i[4R^2 + 8R - 8R]}{(R + 2)^2 + 16}$$

$$Z_{\text{Total}} = \frac{2R^2 + 20R}{(R + 2)^2 + 16} - i\,\frac{(-4R^2)}{(R + 2)^2 + 16}$$

We know that, $\tan\phi = \dfrac{Y}{X} = \dfrac{I_m \text{ Part}}{\textit{Real} \text{ Part}}$

$$\tan(25.8242^\circ) = \frac{[-4R^2\{(R + 2)^2 + 16\}]}{[(2R^2 + 20R)/\{(R + 2)^2 + 16\}]}$$

$$0.4843 = \frac{-4R^2}{2R(R + 10)}$$

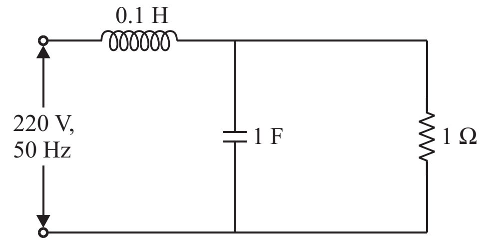
$$0.4843 = \frac{2R}{R + 10} \Rightarrow R + 10 = \left(\frac{-2}{0.4843}\right)$$

$$3.13R = 10$$

$$R = 3.19483 \approx 3.2\ \Omega$$

Q. 31. Calculate the resonance frequency of the circuit shown in fig.

[2011-12]



Sol. (1) Calculate total impedance from source side

(2) Break total impedance in real and imaginary

(3) By equating imaginary part to zero

We get resonance frequency

$$f_r = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{1}{R^2C^2}}$$

$$= \frac{1}{2\pi}\sqrt{\frac{1}{(0.1)(1)} - \frac{1}{(1)^2(1)^2}}$$

$$= \frac{1}{2\pi}\sqrt{10-1}$$

$$= \frac{1}{2\pi}\sqrt{9}$$

$$= \frac{3}{2\pi}$$

$$f_r = 0.4777 \text{ Hz}$$

Q. 32. A circuit of a resistance of 20 Ω, and inductance of 0.3 H and a variable capacitance in series across a 220 V, 50 Hz supply. Calculate :

(i) The value of capacitance to produce resonance

(ii) The voltage across the capacitance and inductance

(iii) The *Q*-factor of the circuit. ***[2014-15]***

Sol. (i) Let resonance produce at 50 Hz frequency

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

$$2\pi f_r = \frac{1}{\sqrt{LC}} \Rightarrow LC = \left[\frac{1}{(2\pi f_r)}\right]^2$$

$$C = \left(\frac{1}{314}\right)^2 \times \frac{1}{0.3} = 3.3808 \times 10^{-5} \text{ F}$$

$$C = 33.808\ \mu\text{F}$$

(ii) At resonance $V_L = V_C \Rightarrow IX_L = IX_C$

$$I = \frac{V}{R} \text{ (at resonance)} = \frac{220}{20} = 11$$

$$V_L = V_C = IX_L = 11(\omega_r L) = 11(314 \times 0.3)$$
$$= 1036.2 \text{ volt}$$

(iii) Q-factor at resonance

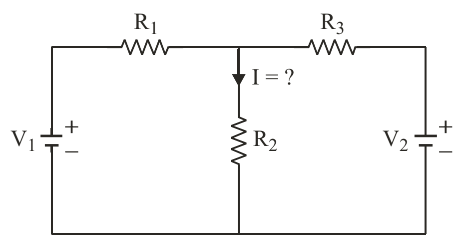
$$Q\text{-factor} = \frac{1}{R}\sqrt{\frac{L}{C}} = \frac{1}{20}\sqrt{\frac{0.3}{33.808 \times 10^{-6}}}$$
$$= 50 \times 0.0942$$
$$= 4.71$$

Q. 33. Write statement of superposition theorem. Explain if with an example.

[2015-16, 2014-15, 2011-12]

Sol. Superposition Theorem : Superposition theorem states that "In a linear resistive network containing two or more voltage or current sources, the current through any element (resistance) may be determine by adding together algebraically the current produced by each source acting alone, when all other sources are replaced by their internal resistance."

The general steps are following to solve the ckt. by superposition find I by superposition?



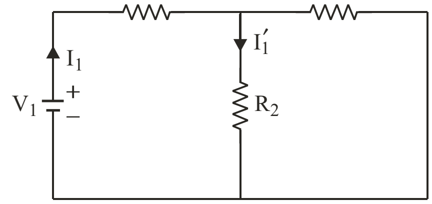
Step 1. Active One Source at a time and deactive all the other sources.

If $\frac{v}{g}$ source → Short. ckt (s.c)
Current source → Open ckt. (oc)
} (For deactive)

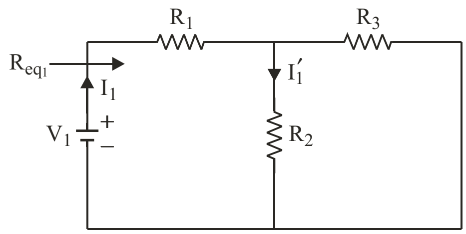
Let this time I_1 An current flow from V_1 source and in R_2 branch I_1 Amp current flow.

Step 2. Find R_{eq_1} from active source side.

$$R_{eq_1} = R_1 + (R_2 \,||\, R_3)$$



$$= \ldots\ \Omega$$



Step 3. Find Current from active voltage source

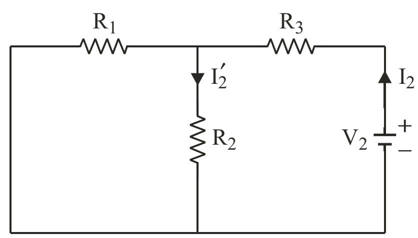
$$I_1 = \frac{V_1}{R_{eq_1}} = \ldots \text{Amp.}$$

Step 4. Find current I_1' in R_2 branch by using current divider rule

$$I_1' = I_1 \times \frac{R_3}{R_2 + R_3}$$

$$= \ldots \text{Amp.}$$

Step 5. Now, active 2nd source and deactive all other source.



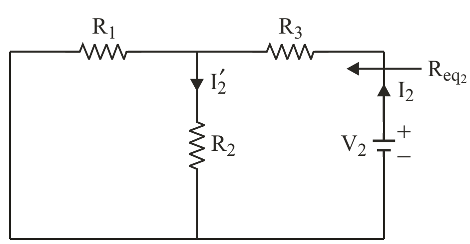
Let this time I_2 Amp current flow from 2nd voltage source and I_2' Amp. Current flow in R_2 branch.

Step 6. Repeat process from **Step 2** to **Step 4** for find I_2' in R_2 branch when 2nd source active.

$$R_{eq_2} = R_3 + (R_1 \,||\, R_2)$$

$$= \ldots \Omega$$

$$I_2 = \frac{V_2}{R_{eq_2}} = \ldots \text{Amp.}$$



$$I_2' = I_2 \times \frac{R_1}{R_1 + R_2}$$

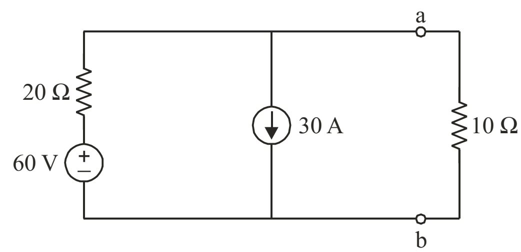
$$= \ldots \text{Amp.}$$

Step 7. Total current in R_2 branch $= I_1' \pm I_2'$

– ve direction of current $(I_1'$ and $I_2')$ if opposite.

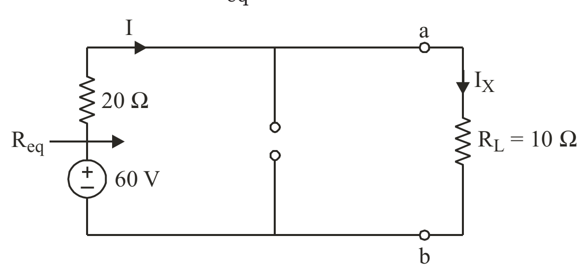
If any **one of the source is current source** then don't apply step 2 and step 3, **directly apply current divider rule.**

Q. 34. Find the current flowing through 10 Ω resistance in the following circuit using superposition theorem. ***[2011-12]***



Sol. Active 60 V source and deactive 30 A source

$$R_{eq} = 20 + 10 = 30\ \Omega \text{ [From Active Source]}$$

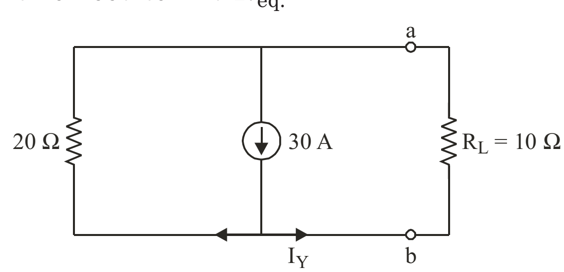


$$I = \frac{V}{R_{eq}} = \frac{60}{30} = 2 \text{ Amp.}$$

$$I_x = I = 2 \text{ Amp. (from fig.)}$$

Active 30 A source and deactive 60 V source.

Note. With current no need to find $R_{eq.}$



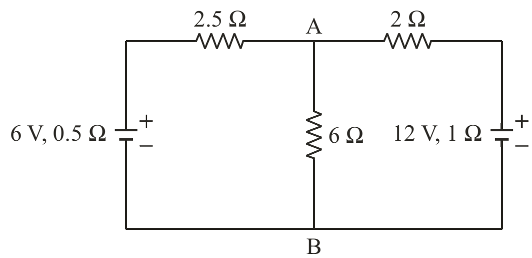
Current in 10 Ω

$$I_y = I \times \frac{20}{20+10} \text{ [By current divider Rule]}$$
$$= 30 \times \frac{20}{30}$$
$$= 20 \text{ Amp.}$$

Total current in 10 Ω resistance

$$I_{10\,\Omega} = I_y - I_x = 20 - 2 = 18 \text{ Amp.}(\uparrow)$$
$$= 18 \text{ Amp.}(\uparrow) \text{ (b to a)}$$

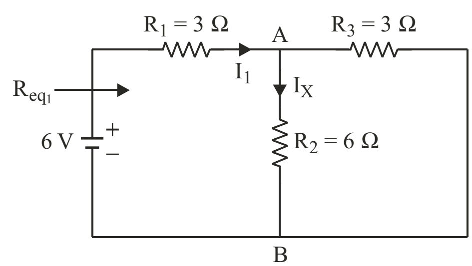
Q. 35. Using superposition theorem, calculate the current in *AB* branch in the circuit shown in below fig. ***[2012-13]***



Sol. $R_1 = 2.5 + 0.5 = 3\ \Omega$ and $R_3 = 2 + 1 = 3\ \Omega$

Active 6 V source and deactive 12 V source

$$R_{eq_4} = [3 + (6 \,||\, 3)] \text{ [Active source side]}$$
$$= 5\ \Omega$$

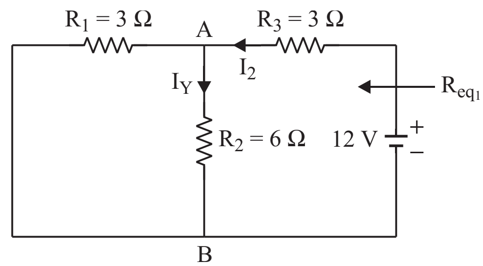


$$I_1 = \frac{V}{R_{eq_1}} = \frac{6}{5} = 1.2 \text{ Amp.} \qquad \text{(By OHM's Law)}$$

$$I_X = I_1 \times \frac{3}{3+6} = 1.2 \times \frac{3}{9} \qquad \text{(By current divider Rule)}$$
$$= 0.4 \text{ Amp.}$$

Active 12 V source and deactive 6 V source

$$R_{eq} = [3 + (6113)] \qquad \text{[From active source side]}$$
$$= 5\ \Omega$$
$$I_2 = \frac{V}{R_{eq_2}} = \frac{12}{5} = 2.4 \text{ Amp.}$$



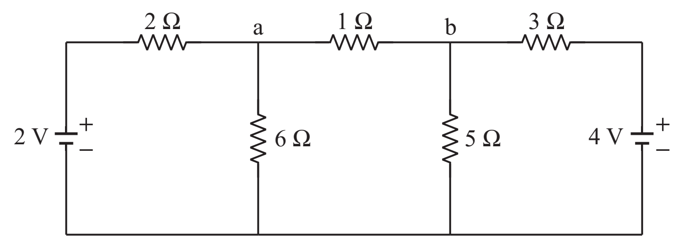
$$I_y = I_2 \times \frac{3}{3+6} = 2.4 \times \frac{3}{9} \text{ [By current divider Rule]}$$

$$= 0.8 \text{ Amp.}$$

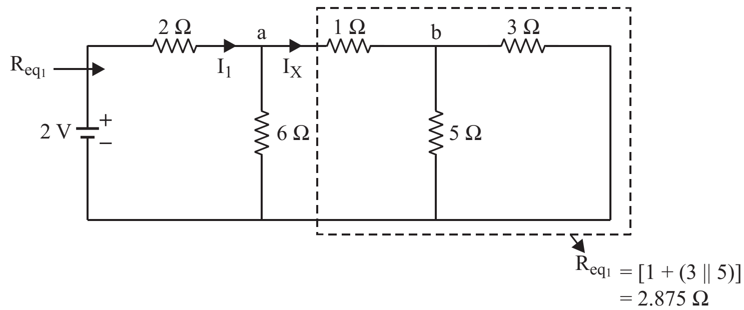
Total current in AB branch (6 Ω resistance)

$$I_{AB} = I_{6\,\Omega} = I_x + I_y = 0.4 + 0.8$$
$$= 1.2 \text{ Amp.}(\downarrow)(A \text{ to } B)$$

Q. 36. Use superposition theorem to compute the current through 1 Ω resistor of fig.



Sol. Active 2 V source and deactive 4 V source



From active source side

$$R_{eq_1} = 2 + [6 \,||\, \{1 + (3 \,||\, 5)\}]$$
$$= 2 + [6 \,||\, 2.875]$$
$$= 3.943\ \Omega$$

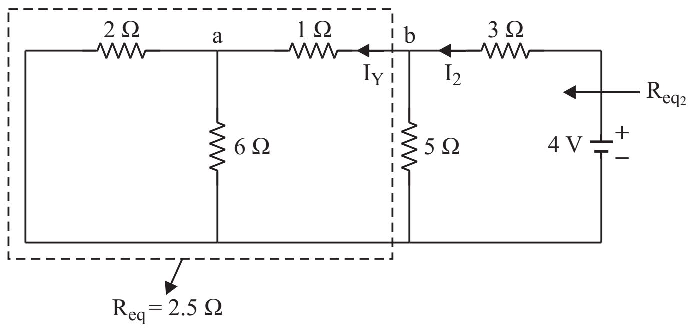
$$I_1 = \frac{V}{R_{eq.1}} = \frac{2}{3.943} = 0.507 \text{ Amp} \qquad \text{[By OHM's law]}$$

$$I_x = I_1 \times \frac{6}{6+2.875} = 0.507 \times \frac{6}{8.875} = 0.343 \text{ Amp.}$$

[By current divider rule]

Active 4 V source and deactive 2 V source

From active source side



$$R_{eq.2} = 3 + [5 \,||\, \{1 + (2 \,||\, 6)\}]$$
$$= 3 + [5 \,||\, 25]$$
$$= 4.667\ \Omega$$

$$I_2 = \frac{V}{R_{eq_2}} = \frac{4}{4.667} = 0.857 \text{ Amp.}$$

$$I_y = I_2 \times \frac{5}{5+2.5} = 0.857 \times \frac{5}{7.5} = 0.571 \text{ Amp. [By current divider rule]}$$

Total current 1 Ω resistor

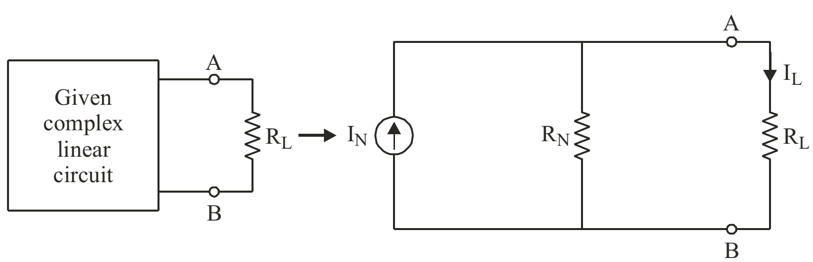
$$I_{1\Omega} = I_y - I_x = 0.571 - 0.343$$
$$= 0.228 \approx 0.23 \text{ Amp.} (\leftarrow)(b \text{ to } a)$$

Q. 37. Write the statement of norton's theorem with an example.

[2016-17, 2015-16, 2014-15]

Sol. Norton's Theorem : Norton's theorem states that any given complex linear circuit can be reduced to a single current source with a parallel resistance.

Where



$I_N \rightarrow I_N(I_{SC})$ is Norton current,

$$I_L = I_N \frac{R_N}{R_N + R_L}$$

i.e., also known as short circuit current (I_{SC}).

It is the current flow through the short circuit (S.C.) terminal when all sources are active and load resistance (R_L) replaced by S.C.

R_N → Norton's equivalent resistance, it is same as R_{th}, which is equivalent resistance from load resistance (R_L) side when all sources deactive and load resistance (R_L) open.

R_L → Load resistance, through which current to be measure.

I_L → Load current, flow through load resistance. It is calculated by following formula

$$I_L = I_N \times \frac{R_N}{R_N + R_L}$$

The **General Steps** are following to solve the ckt. by Norton's theorem.

Step 1. Find R_N $(R_{eq.})$

For this deactive all sources and open load resistance, and find $R_{eq.}$ from open load resistance (R_L) side.

Step 2. Find I_N (I_{SC})

For this active all source and load resistance (R_L) replaced by short circuit (S.C.) and find Norton or short circuit current (I_{SC} or I_N) through short-circuit terminal. By using any one method by

(1) By KVL/KCL

(2) By loop/Mesh Analysis

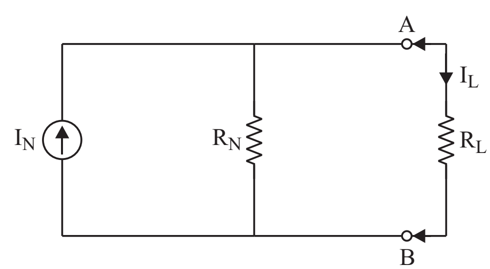
(3) By Nodal Analysis

(4) By Superposition Method

Step 3. Draw Norton's Equivalent circuit.

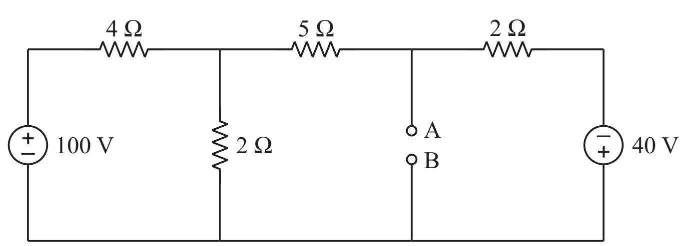
Step 4. Find I_L By following formula

$$I_L = N_N \times \frac{R_N}{R_N + R_L}$$



Q. 38. Obtain the Norton's equivalent circuit across $A - B$ terminals.

[2012-13]

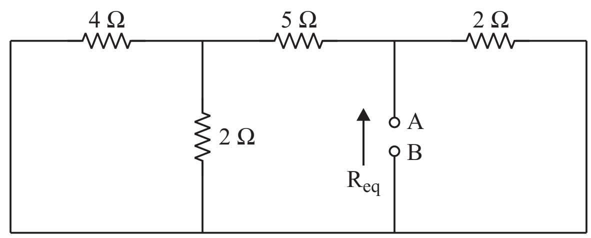


Sol. For R_N

$R_{eq.}$ from (across $A - B$)

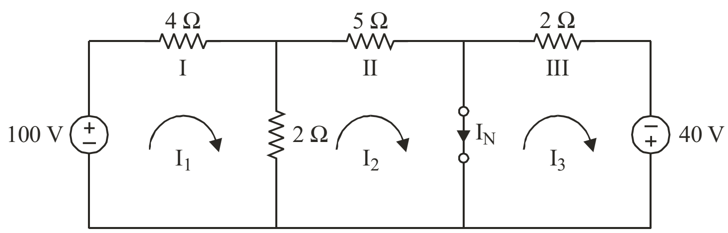
(↑) Side

$$R_N = R_{eq.}\ [2 \,||\, \{5 + (2 \,||\, 4)\}] = [2 \,||\, 6.33]$$
$$= 1.52\ \Omega$$



For I_N

Using mesh method in all three meshes



where, $I_N = I_2 - I_3$ (from Fig.)

Applying KVL in Mesh I

$$6I_1 - 2I_2 = 100 \quad \ldots(i)$$

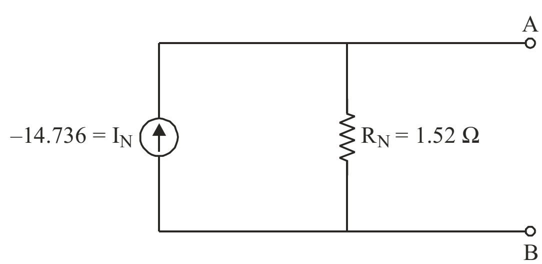
Applying KVL in Mesh II $-2I_1 + 7I_2 = 0$ ...(ii)

Applying KVL in Mesh (III) $I_3 = \dfrac{40}{2} = 20$ Amp.

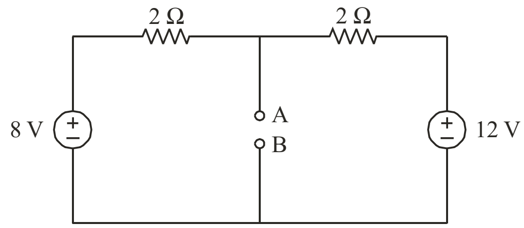
On solving eqn. (i) and (ii), we get $I_2 = \dfrac{100}{19} = 5.26$ Amp.

Now, $I_N = I_{SC} = I_2 - I_3 = -14.736$ Amp. (↓) (A to B)

Norton's equivalent ckt



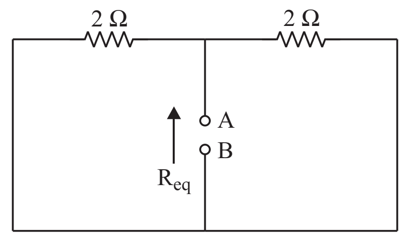
Q. 39. Calculate Norton's equivalent of the network shown in fig. at terminal *AB*. Determine the current through 4 Ω resistor across *AB*. ***[2011-12]***



Sol. For R_N

$R_{eq.}$ from (across $A - B(\uparrow)$ Side)

$R_N = R_{eq.} = (2 \,||\, 2) = 1\ \Omega$

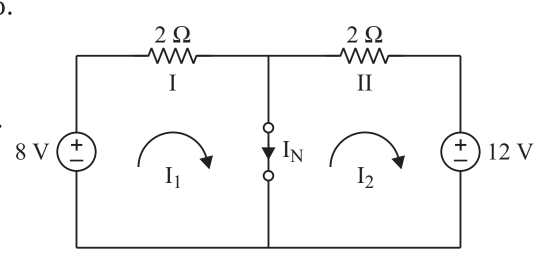


For I_N or I_{SC} Using mesh analysis method

Where, $I_N = I_1 - I_2$ (From fig.)

Applying KVL in mesh I

$$I_1 = \frac{8}{2} = 4 \text{ Amp.}$$



Applying KVL in mesh II.

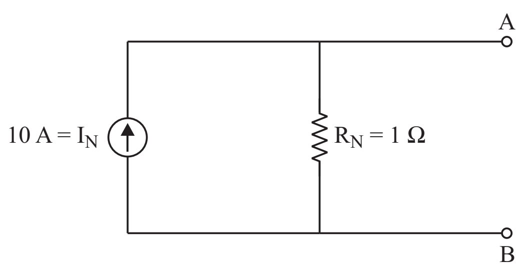
$$I_2 = -\frac{12}{2} = -6 \quad \text{Amp.}$$

Now, $I_N = I_1 - I_2$

I_N or $I_{SC} = 4 - (-6)$

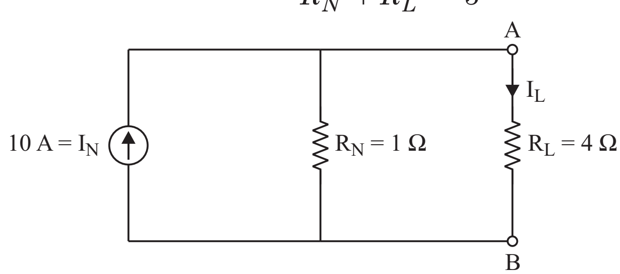
$= 10$ Amp.

Norton's Equivalent ckt



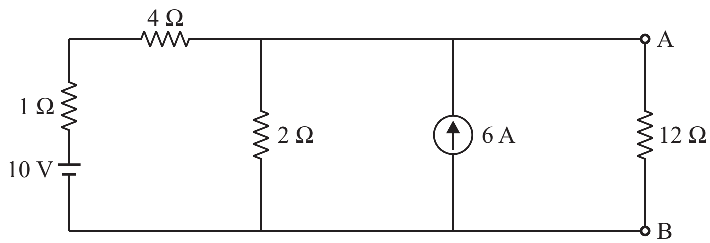
Current through $R_L = 4\ \Omega$ (across $A - B$)

$$I_L = I_N \times \frac{R_N}{R_N + R_L} = \frac{10}{5}$$



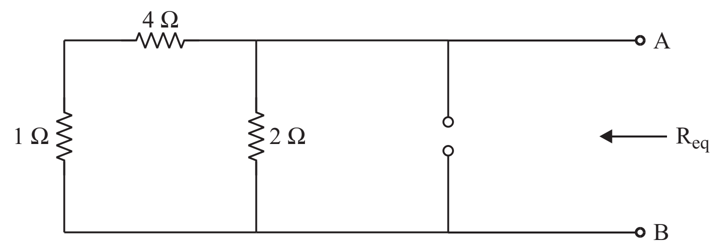
$$I_{4\,\Omega} = I_L = 2 \text{ Amp.}$$

Q. 40. Draw the Norton's equivalent circuit across $A-B$, and determine current flowing through 12 Ω resistor for the network. *[2013-14]*



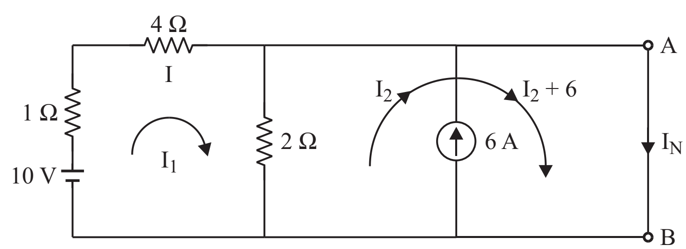
Sol. For R_N: $R_{eq.}$ from (across $A-B$)

(←) side = (Load side)



$$R_N = R_{eq.} = [2 \,||\, (4+1)]$$
$$= [2 \,||\, 5]$$
$$= 1.43\ \Omega$$

For I_N: Using mesh analysis method where, $I_N = I_2 + 6$ (From Fig.)



Applying KVL in Mesh I.

$$7I_1 - 2I_2 = 10 \quad \text{...(i)}$$

Applying KVL in Mesh II [Loop]

$$-2I_1 + 2I_2 = 0 \quad \text{...(ii)}$$

$$[I_1 = I_2]$$

Solving eqn. (i) and (ii), we get

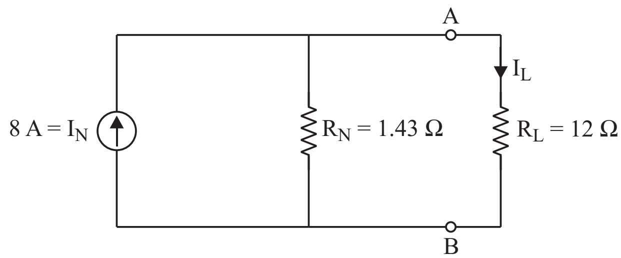
$$I_2 = \frac{10}{5} = 2 \text{ Amp.}$$

Now I_N or I_{SC}

$$I_N = I_2 + 6$$
$$= 8 \text{ Amp.}$$

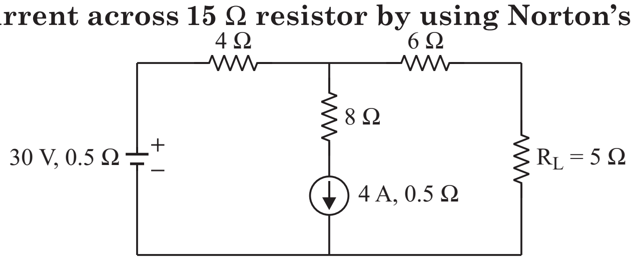
Current in 12 Ω resistor, (across $A - B$)

Norton's equivalent ckt



$$I_L = \frac{I_N \times R_N}{R_N + R_L}$$
$$I_L = 0.85 \text{ Amp.}$$

Q. 41. Find current across 15 Ω resistor by using Norton's Theorem. ***[2013-14]***

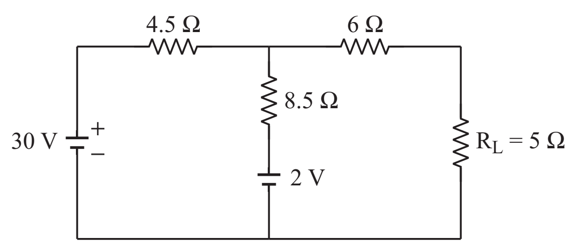


Sol. 4 Ω and 0.5 Ω internal resistance of 30 v are in series hence total resistance $= 4 + 0.5 = 4.5\ \Omega$

4A Current source are replaced by voltage source with their internal resistance 0.5 Ω and total resistance of that branch

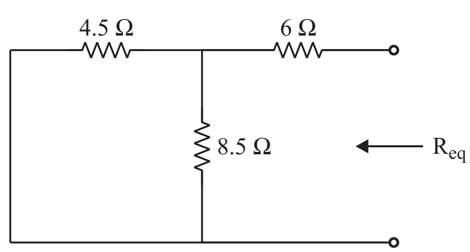
$= 8 + 0.5 = 8.5\ \Omega$

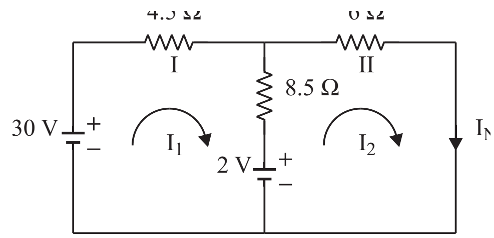
Now, circuit becomes



For R_N : $R_{eq.}$ from (←) side (Load side)

$$R_N = R_{eq.} = [6 + (8.5 \,||\, 4.5)]$$
$$= 8.942\ \Omega$$





For I_N or I_{SC} : Using mesh analysis method where $I_N = I_2$

Applying KVL in Mesh I

$$13I_1 - 8.5I_2 = 28 \quad \ldots(i)$$

$$-8.5I_1 + 14.5I_2 = 2 \quad \ldots(ii)$$

Applying KVL in Mesh II

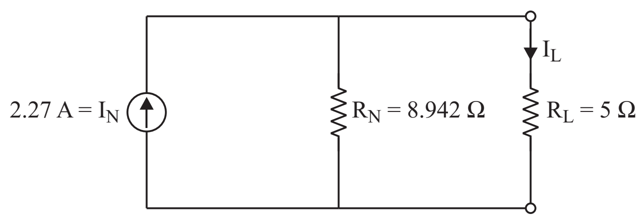
On solving eqn. (i) and (ii), we get $I_2 = 2.27$ Amp.

Now, I_N or $I_{SC} = I_2 = 2.27$ Amp. (↓)

$$I_L = I_N \times \frac{R_N}{R_N + R_L}$$

$$= 1.45 \text{ Amp.} (\downarrow)$$

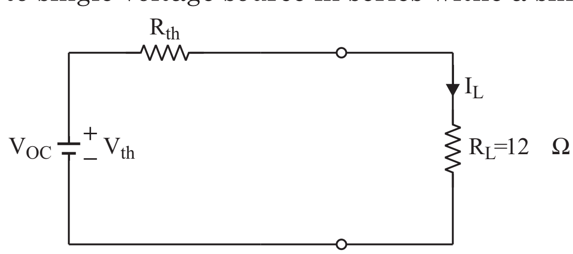
Norton's equivalent ckt



Q. 42. Write the statement of thevenin's theorem with an example.

[2015-16, 2016-17, 2011-12, 2012-13]

Sol. Thevenin's Theorem : The thevenin's theorem states that any complex linear circuit can be reduced to single voltage source in series withe a single resistance.



where $V_{th} \rightarrow$ thevenin's equivalent voltage.

i.e., also known as open circuit (V_{OC}) voltage which voltage across open load resistance (R_L), when all source active.

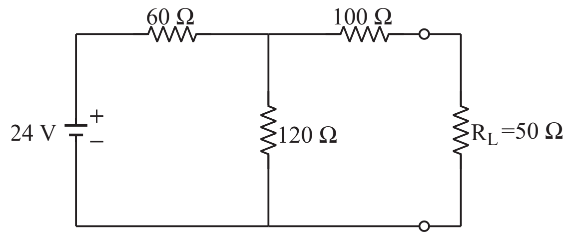
$$I_L = \frac{V_{th}}{R_{th} + R_L}$$

$\boldsymbol{R}_{th} \rightarrow$ Thevenin's equivalent resistance, i.e., known as internal resistance (R_{in}), which equivalent resistance from load resistance side when all sources deactve and load resistance (R_L) open.

$R_L \rightarrow$ Load resistance, through which current measure.

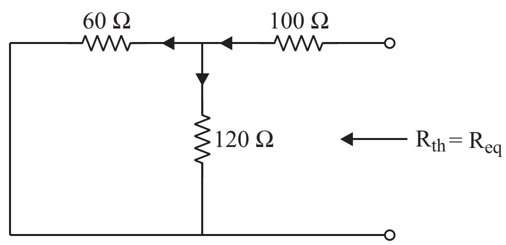
The general steps are following to solve the ckt. by thvenin's theorem.

Find current I through 50 Ω by thevenin theorem.



Step 1. Find $R_{th.}$

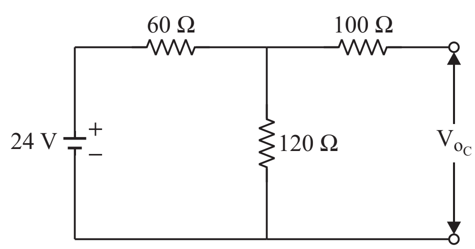
For this deactive all sources and open load resistance and find $R_{eq.}$ from open load side.



$$R_{eq.} = 100 + (60 \,||\, 120) = 100 + \frac{60 \times 120}{60 + 120} = 100 + \frac{7200}{180}$$

$$R_{th.} = 140\ \Omega$$

Step 2. Find V_{th}



For this active all sources and measure open ckt. voltage (V_{OC}) across open R_L.

Here 100 Ω resistor is open (not in ckt) so it may be neglect then we can see here 24 V divide in 60 Ω and 120 Ω because these resistance in series.

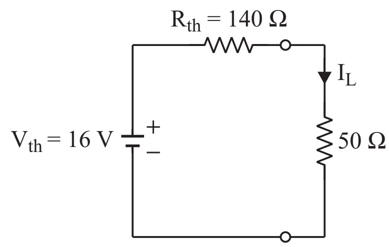
By voltages diver rule

$$\text{Voltage across } 120\ \Omega = 24 \times \frac{120}{60 + 120} = 16\ \text{V}$$

$$V_{th} = V_{OC} = \frac{V}{g} \text{ across } 120\ \Omega \qquad (V/g = \text{Voltage})$$

$$V_{th} = 16\ \text{V}$$

Step 3. Draw thevenis equivalent ckt.

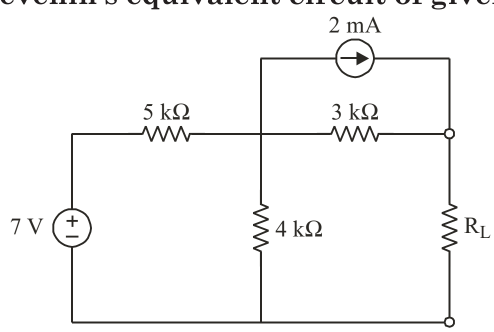


Step 4. Now find load resistance (R_L) current I_L by apply KVL in mesh

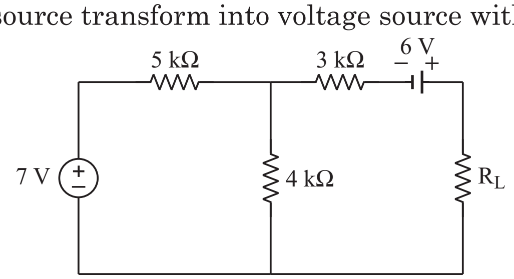
$$I_L = \frac{V_{th}}{R_{th} + R_L} = \frac{16}{140 + 50} = \frac{16}{190}$$

$$I_L = \frac{16}{190} \text{ Amp.}$$

Q. 43. Draw the thevenin's equivalent circuit of given fig. *[2015-16]*

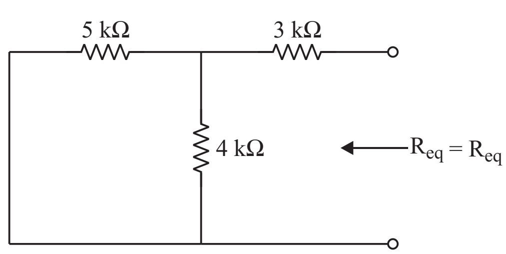


Sol. 2 mA current source transform into voltage source with 3 kΩ.



$$R_{th} = R_{eq.} = [3 + (4 \,||\, 5)] \text{ k}\Omega$$
$$= 5.22 \text{ k}\Omega$$

For R_{th}



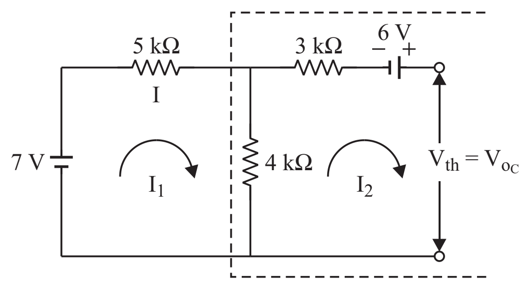
For V_{th}. Applying KVL in Mesh III

$$I_1 = \frac{7}{9 \times 10^3} = 0.77 \text{ mA}$$

Applying KVL in dotted section for V_{th} ($I_2 = 0$)

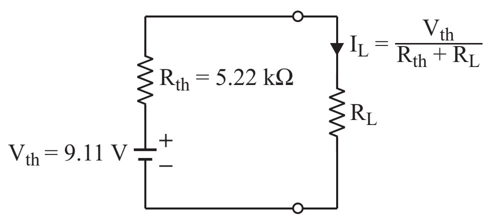
$$-(4 \times 10^3) \times I_2 + (4 \times 10^3) \times I_1 - (3 \times 10^3) I_2 + 6 - V_{th} = 0$$

$$-(4 \times 10^3) \times 0 + (4 \times 10^3) \times (0.77 \times 10^{-3}) - (3 \times 10^3) \times 0 + 6 - V_{th} = 0$$

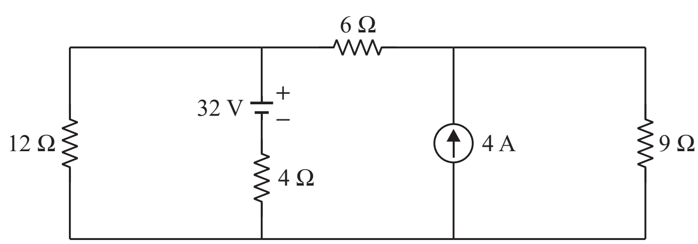


$$V_{th} = V_{OC} = 9.11 \text{ volt}$$

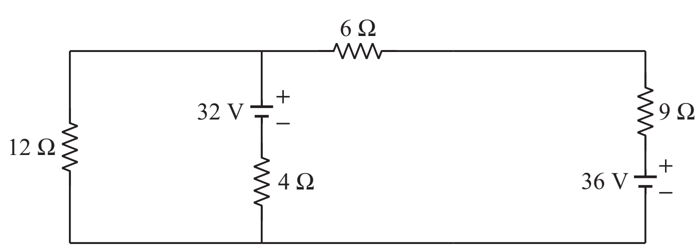
Now, **Thevenin's equivalent** ckt.



Q. 44. Find current in 6 Ω using thevenin's theorem. ***[2013-14]***

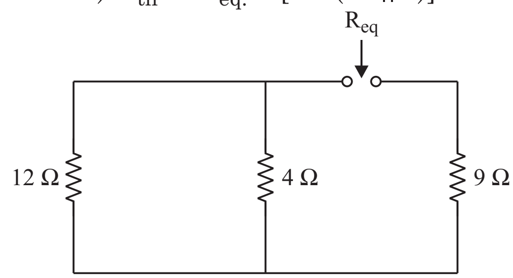


Sol. 4 A current source transform into voltage source with 9 Ω

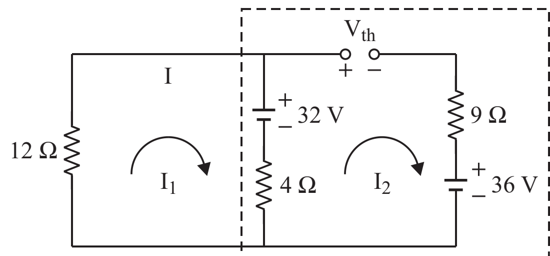


For R_{th}

$R_{eq.}$ from (↓) side (load side) $R_{th} = R_{eq.} = [9 + (12 \| 4)] = 12\ \Omega$



For V_{th} or V_{OC} : Applying KVL in Mesh I



$$I_1 = \frac{-32}{16} = -2 \text{ Amp.}$$

Applying KVL in dotten section for $V_{th.}$ $(I_2 = 0)$

$$-4I_2 + 4I_1 + 32 - V_{th} - 9I_2 - 36 = 0$$

$$-4 \times 0 + 4(-2) - 4 - V_{th} - 9 \times 0 = 0$$

$$V_{th} = -12 \text{ volt}$$

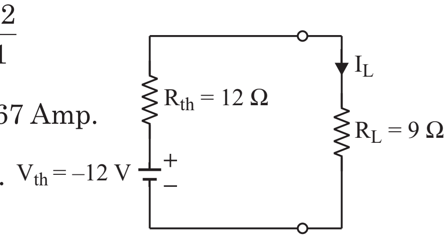
Now, **thevenin's equivalent** ckt.

$$I_L = \frac{V_{th}}{R_{th} + R_L} = \frac{-12}{21}$$

$$= \frac{-2}{3} \text{ Amp.} = -0.667 \text{ Amp.}$$

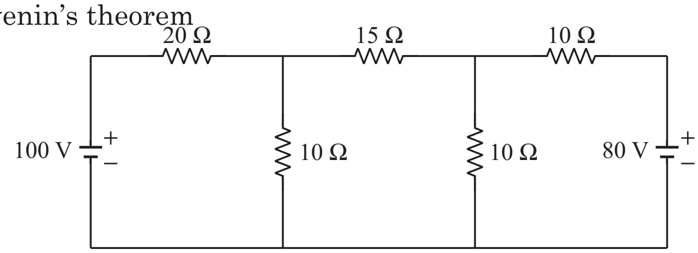
$$I_L = -0.667(\downarrow) \text{ Amp.}$$

$$= 0.667(\uparrow) \text{ Amp.}$$



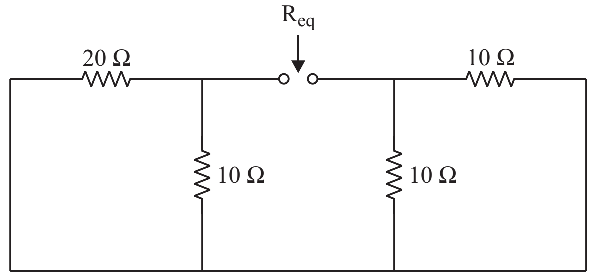
Q. 45. Determine current in 15 Ω resistance using thevenin's theorem and verify the same by Norton's theorem shown in fig. *[2014-15]*

Sol. By thevenin's theorem



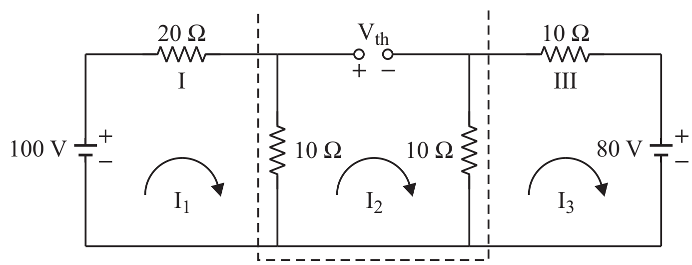
For R_{th} :

For R_{th} : $R_{eq.}$ from (↓) side (Load side)



$$R_{th} = R_{eq.} = [(20 \,||\, 10) + (10 \,||\, 10)]$$
$$= [6.667 + 5]$$
$$= 11.667\ \Omega$$

For V_{th} : Applying KVL in Mesh I.



$$I_1 = \frac{100}{30} = 3.33 \text{ Amp.}$$

Applying KVL in Mesh III.

$$I_3 = -\frac{80}{30} = -4 \text{ Amp.}$$

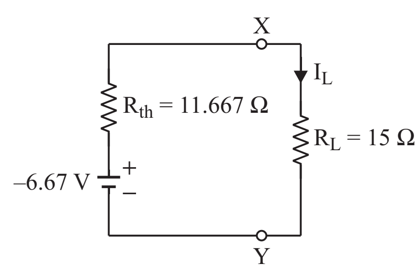
Applying KVL in dotted section [where, $I_2 = 0$]

$-10I_2 + 10I_1 - V_{th} - 10I_2 + 10I_3 = 0$

$-10 \times 0 + 10 \times 3.33 - V_{th} - 10 \times 0 + 10 \times (-4) = 0$

$$V_{th} = -6.67 \text{ volt}$$

Now, **thevenin's equivalent** ckt



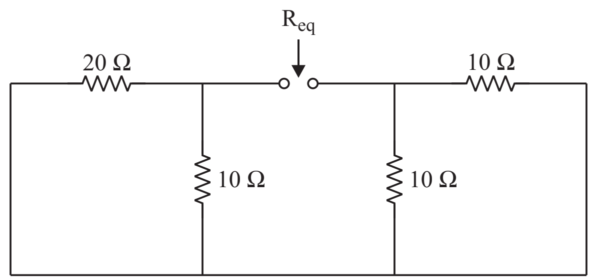
$$I_L = \frac{V_{th.}}{R_{th} + R_L} = \frac{-6.67}{26.667} = -0.25$$

$I_L = -0.25$ (↓) Amp. (X to Y)

$= 0.25$ (↑) Amp. (Y to X)

By Norton's theorem

For R_N :

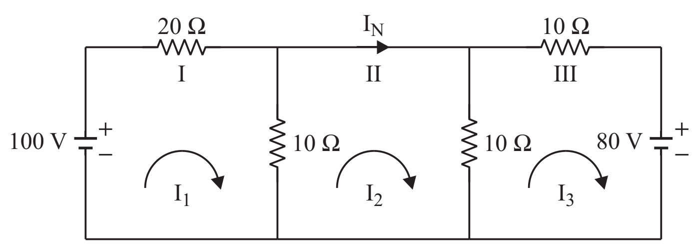


$R_{eq.}$ from (↓) side [Load side]

$$R_N = R_{eq.} = [(20 \,||\, 10) + (10 \,||\, 10)]$$
$$= [6.667 + 5]$$
$$= 11.667\ \Omega$$

R_N and R_{th} both will be equal in respective cases Norton's and thevenin's theorem. [**Note** → calculated by same procedure]

For I_N: Using mesh analysis method where, I_N or $I_{SC} = I_2$



Applying KVL in Mesh I.

$$30I_1 - 10I_2 = 100 \quad \text{...(i)}$$

Applying KVL in Mesh II.

$$-10I_3 - 10I_1 + 20I_2 = 0 \quad \text{...(ii)}$$

Applying KVL in Mesh III

$$-10I_2 + 20I_3 = -80 \quad \text{...(iii)}$$

On solving eqn. (i), (ii) and (iii), we get

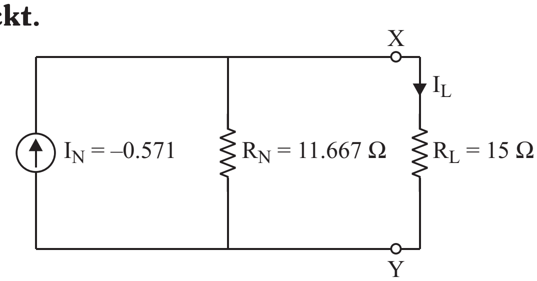
$$I_1 = 3.143 \text{ Amp.}$$
$$I_2 = -0.571 \text{ Amp.}$$

and $I_3 = -4.285$ Amp.

Now, I_N or $I_{SC} = I_2$

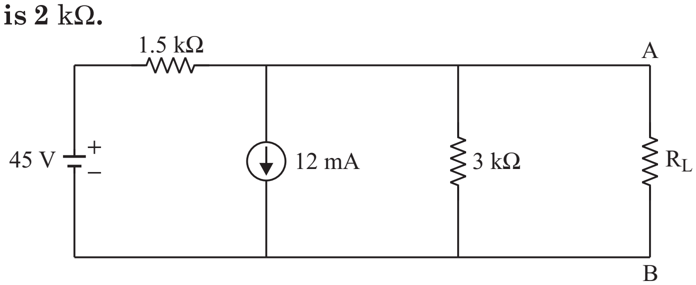
$$I_N = -0.571 \text{ Amp.}$$

Norton's equivalent ckt.



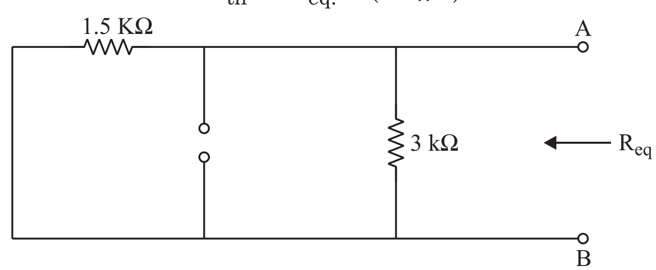
$$I_L = I_N \times \frac{R_N}{R_N + R_L} = -0.25 \text{ Amp.}$$
$$= -0.25 (\downarrow) \text{ Amp. } (X \text{ to } Y)$$
$$= 0.25 (\uparrow) \text{ Amp. } (Y \text{ to } X)$$

Q. 46. Find voltage across load resistance R_L using thevenin's theorem when load resistance is 2 kΩ. *[2015-16]*



Sol. For R_{th} : $R_{eq.}$ from (←) side (across $A - B$)

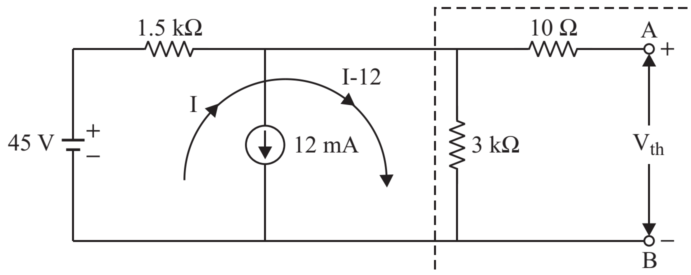
$$R_{th} = R_{eq.} = (1.5 \,||\, 3)$$



$$= \frac{(1.5 \times 3)}{1.5 + 3} = \frac{4.5}{4.5}$$
$$= 1 \text{ k}\Omega$$

For V_{th} : Apply KVL in loop

$$45 - 1.5I - 3(I - 12) = 0$$
$$I = \frac{45 + 36}{(4.5)} = \frac{81}{4.5}$$
$$= 18 \text{ mA}$$

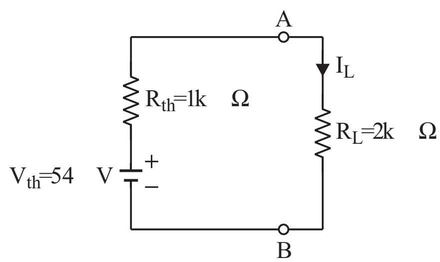


V_{th} from dotted section

$$V_{th} = (3 \times 10^3) \times (18 \times 10^{-3})$$
$$= 54 \text{ volt}$$

Theoremin's equivalent ckt

$$I_L = \frac{V_{th}}{R_{th} + R_L} = \frac{54}{(1+2) \times 10^3}$$



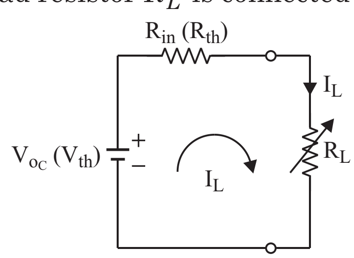
$$= 18 \times 10^{-3} \text{ Amp.}$$
$$= 18 \text{ mAmp} (\downarrow) (A \text{ to } B)$$

Q. 47. State and prove maximum prover transfer theorem. Illustrate the theorem, its efficiency is 50%. ***[2015-16, 2014-15]***

Sol. Maximum Power Transfer Theorem (MPT) : Maximum power transfer theorem states that maximum power will be delivered to the load resistance (R_L) when circuit load resistance (R_L) is equal to the circuit internal resistance (R_{in})

$$R_{in} = R_L$$

Proof of MPT Theorem As shown in fig. the variable load resistor R_L is connected to the open circuit voltage V_{OC} (V_{th}) of a power source.



Load current,

$$I_L = \frac{V_{OC}}{R_{in} + R_L}$$

Power in the load,

$$P = I_L^2 \cdot R_L = \frac{V_{OC}^2 \cdot R_L}{(R_{in} + R_L)^2}$$

P will be maximum when differentiate of P w.r.t. R_L equals to zero.

$$\frac{dP}{dR_L} = 0 \Rightarrow \frac{d}{dR_L}\left[\frac{V_{OC}^2}{(R_{\text{in}} + R_L)^2} \cdot R_L\right] = 0$$

$$V_{OC}^2 \frac{d}{dR_L}\left[\frac{R_L}{(R_{\text{in}} + R_L)^2}\right] = 0$$

$$\frac{(R_{\text{in}} + R_L)^2 \cdot 1 - 1R_L(R_{\text{in}} + R_L)}{(R_{\text{in}} + R_L)^4} = 0 \Rightarrow \frac{(R_{\text{in}} + R_L)[R_{\text{in}} + R_L - 2R_L]}{(R_{\text{in}} + R_L)^4} = 0$$

$$R_{\text{in}} - R_L = 0 \Rightarrow R_{\text{in}} = R_L$$

So, max power

$$P_{\max} = \frac{V_{OC}^2 \cdot R_L}{(R_{\text{in}} + R_L)^2}$$

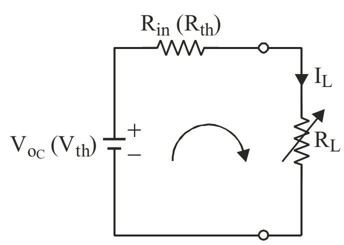
$$= \frac{V_{OC}^2}{(R_L + R_L)^2} \cdot R_L = \frac{V_{OC}^2}{4R_L^2} \cdot R_L$$

Max. power, $$P_{\max} = \frac{V_{OC}^2}{4R_L} = \frac{V_{th}^2}{4R_L}$$

Efficiency of Max. Power Transfer (MPT) Circuit *[2013-14]*

Output power at load,

$$P_{\text{out}} = I_L^2 \cdot R_L$$



Input power for the MPT ckt.

$$P_{\text{in.}} = I_L^2\,(R_{\text{in}} + R_L)$$

We know that efficiency,

$$\eta = \frac{O/P \text{ Power}}{I/P \text{ Power}} = \frac{I_L^2 \cdot R_L}{I_L^2(R_{\text{in}} + R_L)}$$

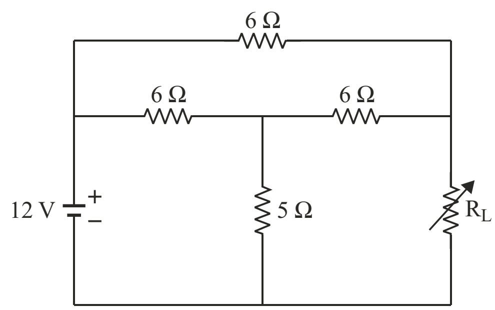
Fat max. power circuit $(R_{\text{in}} = R_L)$

$$\eta = \frac{R_L}{R_L + R_L} = \frac{1}{2}$$

$$\eta = 0.5$$

Efficiency in %, $\eta = 50\%$

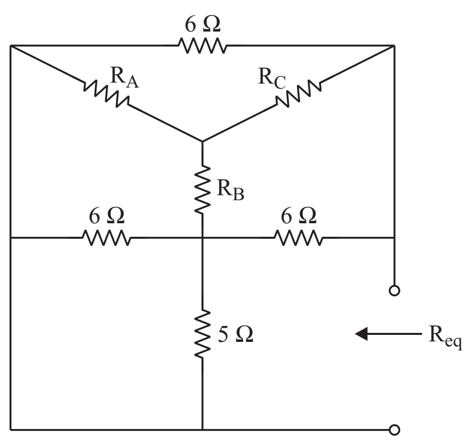
Q. 48. Find R_L and power by maximum power transfer theorem. *[2013-14]*



Sol. For maximum power transfer $R_L = R_{th}$

For R_{th} : By using (Δ to Y) transformation 6 Ω in Δ transform in to R_A , R_B and R_C in Y.

$$R_A = R_B = R_C = \frac{R^2 \text{ (in } \Delta)}{(R + R + R)}$$

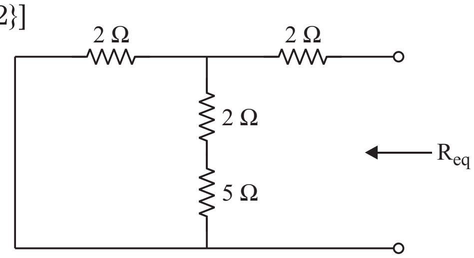


$$= \frac{6^2}{6+6+6} = \frac{36}{18} = 2\ \Omega$$

$$R_A = R_B = R_C = 2\ \Omega \text{ (in } Y)$$

R_{eq} from (←) side (load side)

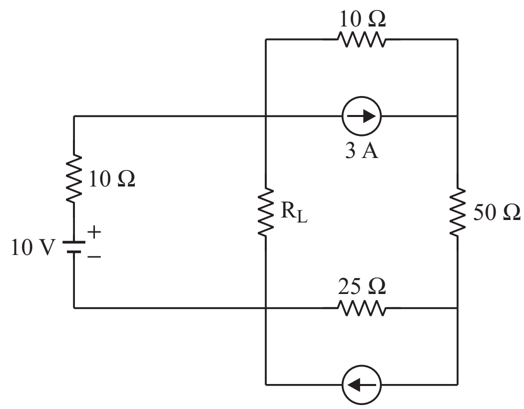
$$R_{th} = R_{eq.} = [2 + \{(512)112\}]$$
$$= [2 + (7 \,||\, 2)]$$
$$= 2 + (14/9)$$
$$= 3.55\ \Omega$$



For maximum power transfer

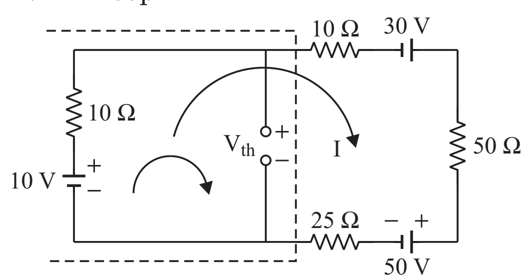
$$R_L = R_{th} = 3.55\ \Omega$$

Q. 49. In the circuit shown below, determine value of R_L for maximum power transfer condition and also obtain maximum power transferred to the load. *[2015-16]*



Sol. 3 A and 2 A current source transformed into voltage source with their respective resistance 10 Ω and 29 Ω.

For V_{th} : Applying KVL in loop



$$I = \frac{(10 + 30 + 50)}{(10 + 10 + 50 + 25)}$$

$$I = 0.947 \text{ Amp.}$$

Apply KVL in dotted section

$$10 - 10I - V_{th} = 0 \Rightarrow V_{th} = 10 - 10(0.947)$$
$$= 0.5263 \text{ volt}$$

For R_{th} : $R_{eq.}$ from (↑) side (load-side)

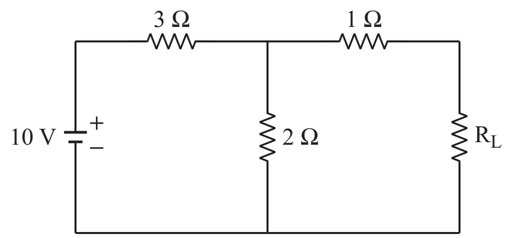
$$R_{th} = R_{eq.} = [10 \,||\, (10 + 50 + 25)]$$
$$R_{th} = R_{eq.} = 8.947\ \Omega$$

For max. power transfer $R_L = R_{TH} = 8.947\ \Omega$

Max. power to R_L, $\quad P_{max} = \dfrac{V_{th}^2}{4R_L} = \dfrac{(0.5263)^2}{4 \times 8.947}$

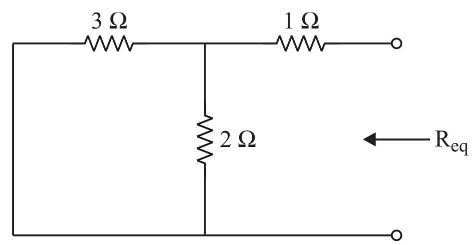
$$= 7.74 \times 10^{-3} = 7.74 \text{ m watt}$$

Q. 50. Find the value of R_L that we can transfer maximum power to it and also calculate the maximum power transferred as shown in fig. ***[2016-17]***



Sol. For R_{th} : $R_{eq.}$ from (←) side from load side

$$R_{th} = R_{eq.} = [1 + (3 \,||\, 2)]$$
$$= 2.2\ \Omega$$



For max. power transfer to R_L

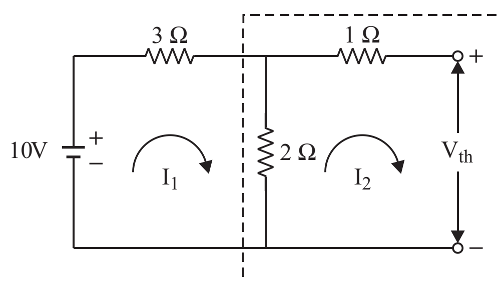
$$R_L = R_{th}$$
$$= 2.2\ \Omega$$

For V_{th} : Applying KVL in Mesh I

$$I_1 = \frac{10}{(3+2)} = 2 \text{ Amp.}$$

Applying KVL in dotted section (where, $I_2 = 0$)

$$2I_1 - 2I_2 - 1I_2 - V_{th} = 0$$



$$2(2) - (2 \times 0) - (1 \times 0) = V_{th}$$
$$V_{th} = 4 \text{ Volt}$$

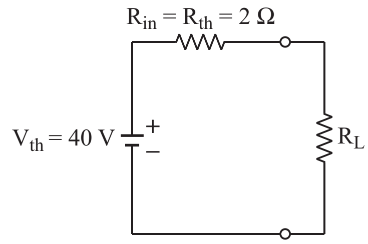
Maximum power transferred to R_L

$$P_{max} = \frac{V_{th}^2}{4R_L} = \frac{(4)^2}{(4 \times 2.2)} = \frac{16}{8.8}$$
$$= 1.8181 \text{ Watt}$$

Q. 51. A 40 V d.c. Source has internal resistance of 2 Ω and supplies a resistive load. What can be maximum power drawn by the load? ***[2015-16]***

Sol. For maximum power transfer

$$R_L = R_{th} = 2\ \Omega$$



$$P_{max} = \frac{V_{th}^2}{4R_L} = \frac{(40)^2}{4 \times 2}$$
$$= 200 \text{ Watt}$$

Q. 52. A voltage source of 100 V has an internal impedance 2 Ω and supplies a load having that same impedance. How mush power is absorbed by the load?

[2012-13]

Sol. When internal impedance 2 Ω supplies and load having that same impedance $Z_{in} = Z_L = 2\ \Omega, V_{th} = 100$ V

Then max. power absorbed by load

$$P_{max} = \frac{V_{th}^2}{4R_L} = \frac{(100)^2}{4 \times 2}$$
$$= 1250 \text{ watt.}$$

❑

Unit-3

3-ϕ Circuit, Measuring Instruments

Q. 1. What do you mean by measurement and measuring instrument? Also write the characteristics of instrument?

Ans. Measurement : It is a process of comparison between a standard and unknown (quantity to be measured), resulting is knowing the unknown magnitude in terms of standard.

Measuring Instrument : It is a device that allows us to make this comparison.

Characteristics of Instrument

(i) Opeational power consumption of instrument should be negligible.

(ii) Instrument should not alter the ambient condition of ckt in which it has been introduced.

Q. 2. What do you mean by following?

(i) Accuracy

(ii) Error

(iii) Sensitivity

Ans. Accuracy : It is defined as the closeness with which measured value approach to the true value.

Accuracy is always specified in terms of error.

Error : Error can be defined as the deviation of measured value from the true value.

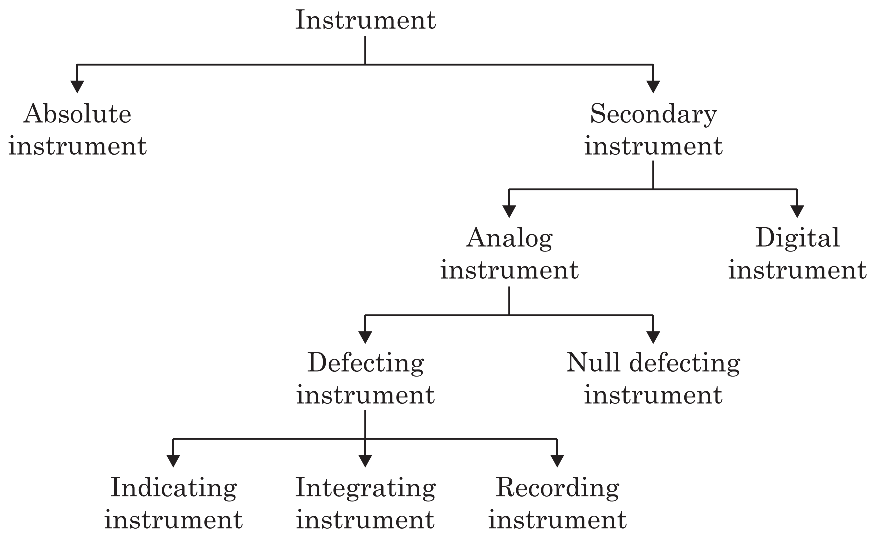
Sensitivity : It is the ratio of o/p signal to a change of *i*/*P* signal.

OR

It is the ratio of response of an instrument to a change in measured variable.

Q. 3. Write the classification of instrument.

Ans. Instruments are bradly classified on the basis of their methodlogy of their measurement.



Q. 4. Write the difference between absolute (Primary) and secondary instrument.

Ans.

	Absolute	**Secondary**
1.	Absolute inst. are those which gives O/P interms of physical constant of the inst.	Secondary inst. are those which give their O/P directly in terms of the parameter under measurement.
2.	These inst. based their operation on the indirect methodology of measurement.	They based their operation on the direct methodology of measument.
3.	Due to the less no. of moving mechanical part, resulting in a lower operational power consumption, these inst. are highly accurate.	Due to a large no. of moving mechanical parts, resulting in a higher operational power consumption, these inst. are relatively less accurate.
4.	They are generally used as standard inst. in the calibrating laboratories.	They are generally used for the day to day measurement in the industry.
5.	Typical exp. tangent galvanometer Rayleigh's current balance.	Exp. ● ammeter ● Voltmenter ● Mathematers

Q. 5. Explain all types of deflecting type instrument.

Ans. There are 3 types of deflecting instrument.

(1) Indicating instrument : This Inst. which gives the instantaneous value of the parameter under measurement. exp Ammeter, Voltmeter etc.

(2) Integrating Inst. : It gives the sum OR total of electrical parameters consumed over a specified period of time. **exp :** Energy meter.

(3) Recording inst. : This inst. maintained a continuous record of past measurement over a specified period of time. **exp :** Recording Voltmeter, null balance recorder etc.

Q. 6. Explain the essentials torques of an indicating instrument in detail.

[UPTU 2013]

OR

Explain various torques as damping, deflecting and controlling.

Ans. An indicating inst. would essentially requires torques to indicate the value of parameter under measurement. They are

(1) Defecting Torque (Operating Torque) : It is required to move the moving system i.e., move the pointer away from the zero position.

It is produced by parameter under measurement due to one of those effect electric current i.e. Heating, magnetic, electromagnetic induction etc.

Deflecting system of inst. converts the electrical energy in to mechanical energy i.e., called deflecting torque.

Magnitude of deflecting torque is proportional to magnitude of parameter under measurement.

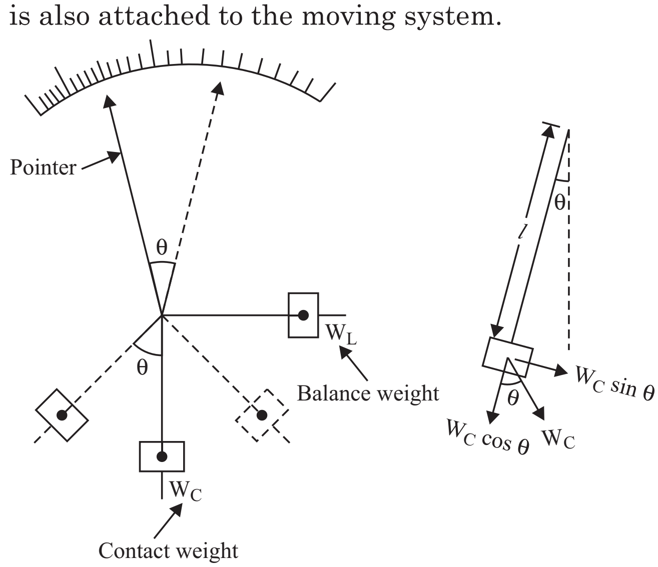
(2) Controlling Torque : Controlling torque has two utility.

(i) It tries to stop the pointer at steady state position.

(ii) It brings the pointer back to the zero position when parameter under measurement is removed from terminals of inst.

The controlling torque is produced by control mechanism and two most. common used control mechanism are

(a) Gravity control : In gravity control inst., a small adjust weight is attached to the moving system shown in fig. In order to counter balance the weight of moving system, another weight W_b is also attached to the moving system.



Controlling Torque

$$T_c = W_c \sin\theta \times l$$
$$T_c \propto \sin\theta$$

We know that

Defecting Torque

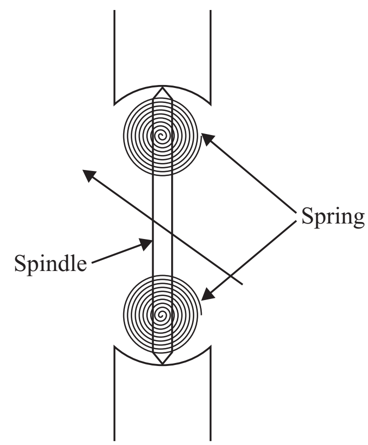
$$T_d \propto I$$

at steady state pontoon OR equilibrium position

$$T_d = T_c$$
$$\boxed{I \propto \sin\theta}$$

$\Rightarrow$ Non-uniform scale.

(b) Spring Control : In spring control method there are one OR two spiral hair spring are attached to the moving spindle.



When current is passed then pointer is deflected, the spring gets twisted in the opposite direction. This twisted produces restoring force, whose magnitude is proportional to the angle of deflection of the pointer.

$$T_c \propto \theta \Rightarrow T_c = k\theta$$

at steady state

$$T_d = T_c$$
$$\theta \propto I \Rightarrow \text{Uniform scate}$$

Spring is made of a non-magnetic alloy such as phaspor-bronze.

No. of turn per unit length should be larger to reduce deformity.

Advantages of spring control over gravity control.

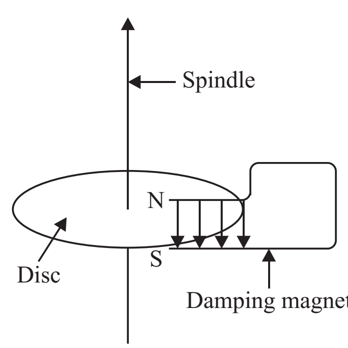
- Uniform scale
- Need not to be kept in vertical position of these inst. for measurement

(3) Damping Torque : The utility of the damping torque is to damp the oscillations of the pointer at the steady state position.

It is produced by a damping mechanism and various damping mechanism used are

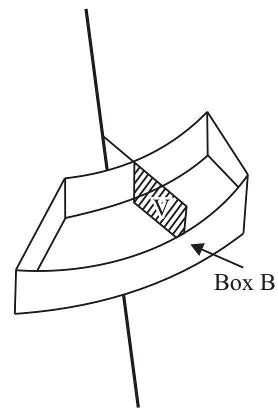
(a) Eddy Current Damping : This mechanism is used in instances where the field that produces the deflection torque is large.

- In this system a disc of conducting but non-magnetic material (Copper, Aluminum) attached to the moving spindle is allowed to pass between a permanent magnet pales.



- When the pointer moves the disc also moves between poles of magnet. So disc cuts the flux and eddy currents are induced in the disc, Hence a force is extered on the disc.
- This force always acts in opposite direction to that of motion according to Lenz's law and provide damping torque.
- It is a most efficient and convenient method.

(b) Air Friction Damping : In this method, one or two light aluminum vanes are attached to the moving system.



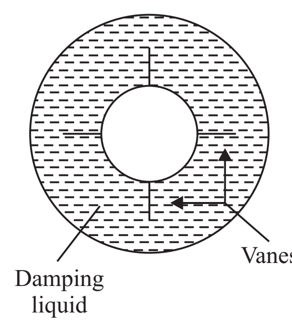
- The vane moves in metal box *B* which is shield.
- The gap between vane and box inner wall is very small.
- The air pressure inside the chamber restrict the movement of the vane in either side and provides the required damping torque.
- This mechanism is used in instances where the field that produces the deflecting torque is weak.

(c) Fluid Friction Damping : In this method, vanes or disc are diped in to a pot containing liquid of high viscosity.

When pointer moves the friction between vanes and liquid oppose the motion of the pointer and then necessary damping is provided.

It is specifically in instrument which have low sensitivity.

This method is not suitable for portable instrument.



Q. 7. Discuss the constructional detail and working principle of PMMC type of voltmeter. What are the advantages and disadvantages of PMMC type of voltmeters? Explain why PMMC type of instruments belongs to linear scale instrument.

Or

Describe the working principle of PMMC instrument why is the scale linear.

Or

Describe the construction and working principle of PMMC instrument and also derive the equation for deflection if the instrument is spring controlled.

Or

Explain with neat diagram, working principle of PMMC type electrical measuring instruments.

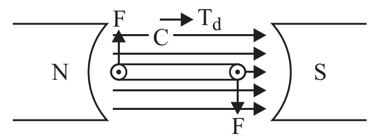
Ans.PMMC is stands for permanent magnet moving coil or moving coil instrument.

PMMC is also known as D'Arsonvals galvanometer. ***[UPTU 06, 12, 14, 15, 17]***

- This instrument is more accurator very sensitive.
- This instrument either as a ammeter or voltmeter.
- It is suitable for d.c. only.

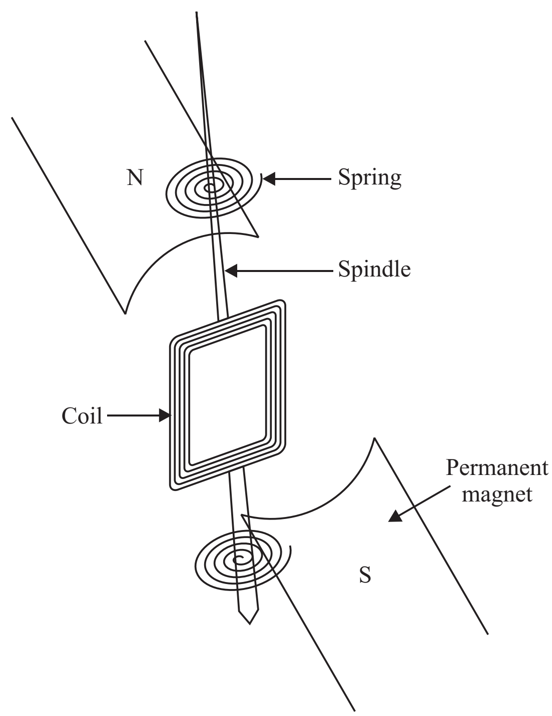
Principle

Operation of PMMC is based on that when the current carrying conductor is placed in a magnetic field, a mechanical force is exerted on the conductor.



Construction

- It consists of a powerful permanent magnet.
- A light rectangular coil with may turns wound on a light aluminum or copper former inside.

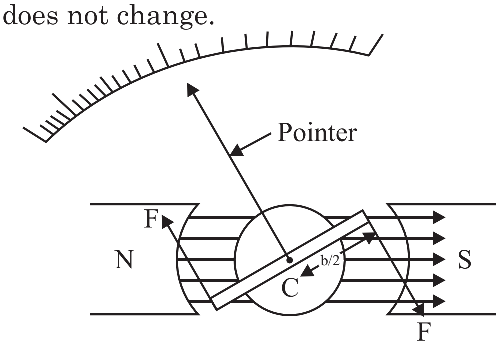


- The coil is mounted on the spindle and acts as the moving element.
- Two spiral hair-springs are connected to the spindle. These spring provide the controlling torque T_C.
- Damping torque provided by eddy currents induced in the aluminum former.

Working

When the instrument is connected in the ckt to measure the current OR voltage, the operating current flows through the coil; then a mechanical force acts on it. As a result the pointer moves over the graduate scale to indicate the value of current OR voltage being measured.

The deflecting torque is reversed if the current is reversed because field produced by the permanent magnets does not change.



Hence it cannot be used for a.c. measurement.

Deflecting Torque

When the current is passed through the coil, force acts upon the bothe sides are produce a deflecting torque

$B \rightarrow$ Flux density in the air gap

$I \rightarrow$ Current passing through the coil in amp.

$l \rightarrow$ Effective length of coil in meter.

$b \rightarrow$ Bredth of the coil.

$N \rightarrow$ No. of turns in the moving coil.

Force experienced by the each side of coil is

$$F = NBIl$$

and Deflecting Torque = Force × Perpendicular distance

$$T_d = F \times b$$
$$= NBIlb$$
$$T_d = NBIA$$

$NBA \rightarrow$ Constant

$$T_d \propto I$$

Controlling Torque

$$T_c \propto \theta \qquad [\theta \rightarrow \text{angle of deflection}]$$

At equilibrium

$$T_c = T_d$$
$$\theta \propto I \text{ uniform scale}$$

∵ Deflection is directly proportional to current passing through coil.

∴ Scale of this inst. **will be uniform.**

Advantages

- Uniform scale.

- Sensitivity of this inst. is very high.
- This is free from hystersis loss.
- Very accurate, reliable and low power consumption (25 μw –200 μw)

Disadvantages

- Can not be used for a.c.
- This is costly inst.
- Error may be introduced due to ageing of permanent magnet and control spring.

Q. 8. Discuss the concept of use of shunt and multiplier with the basic circuit diagram.

OR

Discuss the concept of extension of PMMC with the basic circuit diagram.

[UPTU 2010-11]

Ans.

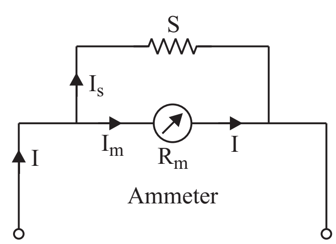
Extension of Range

These instruments can carry maximum current of near about 50 mA and potential drop is 50 mV.

In practice, heavy currents and voltages are required to be measured.

Extension of Ammeter Range

The range of a PMMC ammeter can be extended by connecting a low resistance (called shunt) in parallel with moving coil of the inst.



This shunt provides a path for extra current.

$R_m \rightarrow$ meter resistance

$S \rightarrow$ shunt resistance

$I_m \rightarrow$ full scale deflection current

$I \rightarrow$ full range of current

Voltage across shunt = Voltage across meter

$$(I - I_m)S = I_m R_m$$

$$S = \frac{I_m R_m}{I - I_m}$$

$$SI - SI_m = I_m R_m$$

$$IS = I_m(R_m + S)$$

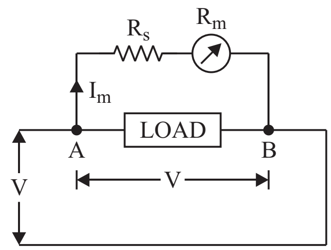
$$\text{Multiplying factor} = \frac{I}{I_m} = \frac{R_m + S}{S}$$

$$\frac{I}{I_m} = 1 + \frac{R_m}{S}$$

it is clear that lower value of S gives greater value of multiplying factor.

Extension of Voltmeter Range

The range of a PMMC voltmeter can be increased by connecting high resistance R_s in series with it as shown in fig.



$R_m \rightarrow$ meter resistance

$R_s \rightarrow$ series resistance

$I_m \rightarrow$ full scale deflection

$V \rightarrow$ full range voltage of the meter

Voltage across meter = Voltage across AB

$$I_m(R_s + R_m) = V$$

$$I_m R_s + I_m R_m = V$$

$$R_s = \frac{V - I_m R_m}{I_m} = \frac{V}{I_m} - R_m$$

$$R_s + R_m = \frac{V}{I_m}$$

$$R_m \left(\frac{R_s}{R_m} + 1\right) = \frac{V}{I_m}$$

$$\frac{R_s}{R_m} + 1 = \frac{V}{I_m R_m}$$

$$\frac{V}{V_m} = 1 + \frac{R_s}{R_m}$$

$$\frac{\text{Voltage across entier ckt}}{\text{Voltage across inst.}} = 1 + \frac{R_s}{R_m}$$

Multiplying factor $\quad m = 1 + \dfrac{R_s}{R_m}$

OR

Volt. magnification

$R_s \rightarrow$ is high, $m \rightarrow$ high

Q. 9. Explain the construction and working principle of moving iron type instruments and also explain their types.

OR

Explain the principle of operation of attraction type of moving iron type instruments.

OR

Enlist the various type of moving iron instruments. ***[UPTU 2005, 11, 13, 16]***

Ans. Moving-iron instruments are generally used to measure alternating voltages and currents. In moving-iron instruments the movable system consists of one or more pieces of specially-shaped soft iron, which are so pivoted as to be acted upon by the magnetic field produced by the current in coil.

There are two general types of moving-iron instruments namely :

1. Repulsion (or double iron) type (figure 1)
2. Attraction (or single-iron) type (figure 2)

Construction

The brief description of different components of a moving-iron instrument is given below :

- **Moving Element :** A small piece of soft iron in the form of a vane or rod.
- **Coil :** To produce the magnetic field due to current flowing through it and also to magnetize the iron pieces.
- In repulsion type, a fixed vane or rod is also used and magnetized with the same polarity.
- Control torque is provided by spring or weight (gravity).
- Damping torque is normally pneumatic, the damping device consisting of an air chamber and a moving vane attached to the instrument spindle.
- Deflecting torque produces a movement on an aluminum pointer over a graduated scale.

Working

The deflecting torque in any moving-iron instrument is due to forces on a small piece of magnetically 'soft' iron that is magnetized by a coil carrying the operating current. In repulsion type moving-iron instrument consists of two cylindrical soft iron vanes mounted within a fixed current-carrying coil. One iron vane is held fixed to the coil frame and other is free to rotate, carrying with it the pointer shaft.

Current in the coil induces both vanes to become magnetized and repulsion between the similarly magnetized vanes produces a proportional rotation. The deflecting torque is proportional to the square of the current in the coil hairspring that produces the restoring torque.

Moving iron instruments having scales that are nonlinear and somewhat crowded in the lower range of calibration.

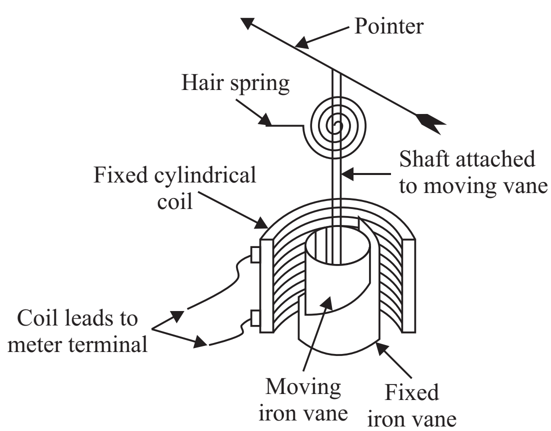


Fig. 1

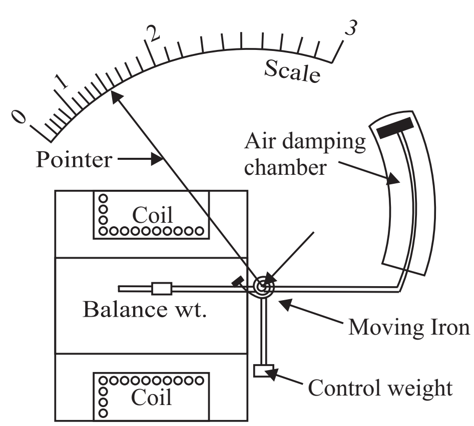


Fig. 2

Advantages

- The instruments are suitable for use in AC and DC circuits.
- The instruments are robust, owing to the simple construction of the moving parts.
- The stationary parts of the instruments are also simple.
- Instrument is low cost compared to moving coil instrument.
- Torque/weight ratio is high, thus less frictional error.

Q. 10. Derive the expression of torque for moving iron type instrument.

Ans. **Torque Equation of moving iron instruments**

Consider a small increment in current supplied to the coil of the instrument, due to this current let $d\theta$ be deflection under the deflecting torque T_d. Due to such deflection, some mechanical work will be done.

$$\therefore \quad \text{Mechanical Work} = T_d \; d\theta$$

There will be a change in the energy stored *i* the magnetic field due to the change in inductance. This is becan the vane tries to occupy the position of minimum reluctance. The inductance is inversely proportional to reluctance of the magnetic circuit of coil.

Let

I = initial current

L = instrument inductance

θ = deflection

dI = increase in current

$d\theta$ = change in deflection

dL = change in inductance

In order to effect in increment dL in the current, there must be an increase in the applied voltage given by,

$$e = \frac{d(LI)}{dt}$$

$$= I\,\frac{dL}{dt} + L\,\frac{dI}{dt} \text{ as both } I \text{ and } L \text{ are changing.}$$

The electrical energy supplied is given by

$$eI\;dt = \left(I\,\frac{dL}{dt} + L\,\frac{dl}{dt}\right) l\;dt$$

$$= I^2\;dL + IL\;dI$$

The stored energy increases from $\frac{1}{2}\,LI^2$ to $\frac{1}{2}(L + dL)(I + dI)^2$

Hence the change in stored energy is given by

$$= \frac{1}{2}(L + dL)(I + dI)^2 - \frac{1}{2}\,LI^2$$

Neglecting higher order terms, this becomes, $IL\;dI + \frac{1}{2}\,I^2\;dL$

The energy supplied in nothing but increase in stored energy plus the energy required for mechanical work done.

$$\therefore \qquad I^2\ dL + IL\ dI = IL\ dI + \frac{1}{2} I^2\ dL + T_4 \cdot d\theta$$

$$\therefore \qquad T_d \cdot d\theta = \frac{1}{2} I^2\ dL$$

$$\therefore \qquad T_d = \frac{1}{2} I^2 \frac{dL}{d\theta}$$

While the controlling torque is given by

$$T_c = K\theta$$

where K = spring constant

$$\therefore \qquad K\theta = \frac{1}{2} I^2 \frac{dL}{d\theta} \text{ under equilibrium}$$

$$\therefore \qquad \theta = \frac{1}{2} \frac{I^2}{K} \frac{dL}{d\theta}$$

Q. 11. Discuss the contraction and Principe of single phase dynamometer wattmeter and also the advantages.

OR

Derive the torque equation of dynamometer wattmeter and also list the error in it.

OR

What are the major differences between PMMC and dynamomenter instruments? ***[UPTU 2009-10]***

Ans. Dynamometer type watt meter works on very simple principle and this principle can be state when any current carrying conductor is placed inside a magnetic field, it experiences a mechanical force and due this mechanical force deflection of conductor takes place.

Construction and Working Principle of Electrodynamometer Type Wattmeter : Now let us look at constructional detail of electrodynamometer. It consists of following parts. There are two types of coils present in the electrodynamometer. They are :

Moving Coil

Moving coil moves the pointer with the help of spring control instrument. A limited amount of current flows through the moving coil so as to avoid heating. So in order to limit the current we have connect the high value resistor in series with the moving coil. The moving is air cored and is mounted on a pivoted spindle and can moves freely. In electrodynamometer type wattmeter, moving coil works as pressure coil. Hence moving coil is connected across the voltage and thus the current flowing through this coil is always proportional to the voltage.

Fixed Coil

The fixd coil is divided into two equal parts and these are connected in series with the load, therefore the load current will flow through these coils. Now the reason is very obvious of using two fixed coil instead of one, so that it can be constructed to carry considerable amount of electric current. These coils are called the current coils of electrodynamometer type wattmeter. Earlier these fixed coils are designed to carry the current of about 100 amperes but now the modern wattmeter are designed to carry current of about 20 amperes in order to save power.

Control System

Out of two controlling systems i.e.

Gravity control and Spring control, only spring controlled systems are used in these types of wattmeter. Gravity controlled system cannot be employed because they will appreciable amount of errors.

Damping System

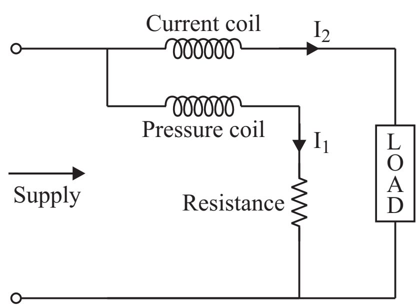
Air friction damping is used, as eddy current damping will distort the weak operating magnetic field and thus it may leads to error.

Scale

There is uniform scale is used in these types of instrument as moving coil moves linearly over a range of 40 degrees to 50 degrees on either sides.

Now let us derive the expressions for the controlling torque and deflecting torques.

In order to derive these expressions let us consider the circuit diagram given below :



We know that instantaneous torque in electrodynamic type instruments is directly proportional to product of instantaneous values of currents flowing through both the coils and the rate of change of flux linked with the circuit.

Let I_1 and I_2 be the instantaneous values of currents in pressure and current coils respectively.

$$T = I_1 \times I_2 \times \frac{dM}{dx}$$

So the expression for the torque can be written as : Where, x is the angle. Now let the applied value of voltage across the pressure coil be

$$v = \sqrt{2}V \sin \omega t$$

Assuming the **electrical resistance** of the pressure coil be very high hence we can neglect reactance with respect to its resistance. In this the impedance is equal to its **electrical resistance** therefore it is purely resistive.

The expression for instantaneous current can be written as

$$I_2 = \sqrt{2} \times \frac{V \sin \omega t}{R_p}$$

$$I_2 = \frac{v}{R_p} \quad \text{where } R_p \text{ is the resistance of pressure coil.}$$

If there is phase difference between voltage and electric currrent, then expression for instantaneous current through current coil can be written as

$$I_1 = I(t) = \sqrt{2} I \sin(\omega t - \phi)$$

As current through the pressure coil in very very small compare to current through current coil hence current through the current coil can be considered as equal to total load current.

Hence the instantaneous value of torque can be written as

$$\sqrt{2} \times \frac{V \sin \omega t}{R_p} \times \sqrt{2} \times I \times \sin(\omega t - \phi) \times \frac{dM}{dx}$$

Average value of deflecting torque can be obtained by integrating the instantaneous torque from limit 0 to

$$T_d = \text{deflecting torque} = \frac{VI}{R_p} \cos\phi \times \frac{dM}{dx}$$

T, where T is the time period of the cycle.

Controlling torque is given by

$$T_c = Kx$$

where K is spring constant and x is final steady state value of deflection.

Advantages of Electrodynamometer Type Watt meter

Following are the advantages of electrodynamometer type watt meters and they are written as follows :

1. Scale is uniform upto certain limit.
2. They can be used for both to measure ac as well dc quantities as scale is calibrated for both.

Q. 12. Why can we not measure a.c. quantity by PMMC? ***[UPTU 2009-10]***

Ans. In PMMC, as the direction of the magnetic field of permanent magnet does not change with the change in polarity of ac parameter under measurement, therefore pointer oscillates over calibrated scale for low frequency and staitionary at zero position for high frequency.

∴ This inst. are not suitable to measure ac quantity.

Q. 13. Write down the differences between PMMC and moving coil inst.

OR

Write down the differences between moving coil and moving iron type inst.

[UPTU 2009-10]

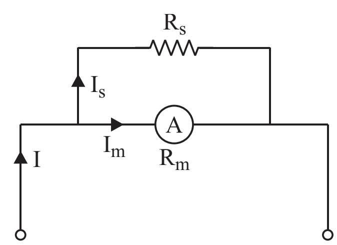
Ans.

	Moving Coil (PMMC)	Moving Iron
1.	It is used only for DC.	It is used for DC as well as AC.
2.	It has uniform scale	It has non-uniform scale
3.	It has low operational power. Consumption	It has higher operational power consumption
4.	No effect of stray magnetic field due to presence of strong magnet	Error may occur due to stray magnetic field
5.	It is costlier	It is cheaper.

Q. 13. If the meter has a resistance of 4.5 Ω and requires 12 mA for full scale deflection. In order that meter may read 1.2 mP. Then the value of shunt will be

[UPTU 2012-13]

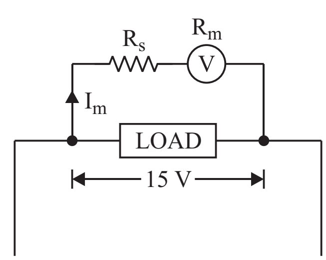
Sol.



$$R_m = 4.5\ \Omega$$
$$I_m = 12\ \text{mA} = 12 \times 10^{-3}\ \text{A}$$
$$I = 1.2\ \text{A}$$
$$I_s = I - I_m = 1.2 - 12 \times 10^{-3} = 1.188$$
$$I_s S = I_m R_m$$
$$1.188 \times S = 12 \times 10^{-3} \times 4.5$$
$$S = 0.04545\ \Omega$$
$$\text{Multiplying factor} = \frac{I}{I_m} = \frac{1.2}{12 \times 10^{-3}} = 100$$

Q. 14. If the meter has a resistance of 4.5 Ω and required 18 mA for full scale deflection in order that the meter reads 15 V, find the value of series resistance and voltage amplification.

Sol.



$$R_m = 4.5\ \Omega$$
$$I_m = 18\ \text{mA} = 18 \times 10^{-3}\ \text{A}$$
$$15 = I_m \times R_s + I_m \times R_m = 18 \times 10^{-3}\,(R_s + 4.5)$$
$$R_s = 828.83\ \Omega$$

$$m = 1 + \frac{R_s}{R_m} = 1 + \frac{828.83}{4.5} = 185.18$$

Q. 15. How will you use a PMMC inst. which gives full scale deflection at 60 mV p.d. and 12 mA current as

(i) Ammeter 0 – 10 A (ii) Voltmeter 0 – 200 V *[UPTU 2010]*

Sol. Resistance of inst. $= \frac{V_m}{I_m}$

$$R_m = \frac{60 \times 10^{-3}}{12 \times 10^{-3}} = 5\ \Omega$$

(i) Full range of current $I = 10$ A

$$I_s = I - I_m = 10 - 12 \times 10^{-3} = 0.988$$

$$S = \frac{I_m R_m}{I_s} = \frac{60 \times 10^{-3}}{0.988} = 0.060\ \Omega$$

(ii) Full range of volt $V = 200$ V

$$R_s = \frac{V}{I_m} - R_m$$

$$= \frac{200}{12 \times 10^{-3}} - 5 = 16661.66\ \Omega$$

Q. 16. The full scale deflection current of a meter is 1 mA and its internal resistance is 100 Ω. This meter is to have full deflection when 1 mA is measured. What is the value of series resistor to be used?

Sol. $I_m = 1\text{ mA} = 1 \times 10^{-3}$ A

$$R_m = 100\ \Omega$$

$$V = 100\text{ V}$$

$$V_m = I_m R_m = 1 \times 10^{-3} \times 100 = 0.1\text{ Volt}$$

$$\text{Multiplying factor} = \frac{V}{V_m} = \frac{100}{0.1} = 1000$$

$$R_s = \frac{V}{I_m} - R_m$$

$$= \frac{100}{1 \times 10^{-3}} - 100 = 99900\ \Omega$$

Q. 17. A current galvanometer has the follow parameter

$$\boldsymbol{B = 9.8 \times 10^{-3}\ \text{Wb / m}^2}$$

$$\boldsymbol{N = 200\ \text{turns}}$$

$$\boldsymbol{l = 14\ \text{mm},\ b = 14\ \text{mm}}$$

Controlling spring const.

$$\boldsymbol{k = 12 \times 10^{-9}\ \text{N/rad}}$$

Calculate deflection of the galvanometer when a current of 1 μA flows through it.

Sol. $$T_d = NBAI$$

$$= 200 \times 0.8 \times 10^{-3} \times (14 \times 10^{-3} \times 14 \times 10^{-3}) \times 1 \times 14$$

$$= 384.16 \times 10^{-12} \text{ N-m}$$

$$T_c = k\theta = 12 \times 10^{-9} \times \theta$$

At equilibrium $$T_c = T_d$$

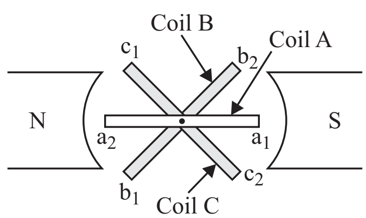
$$12 \times 10^{-9} \times \theta = 384.16 \times 10^{-12}$$

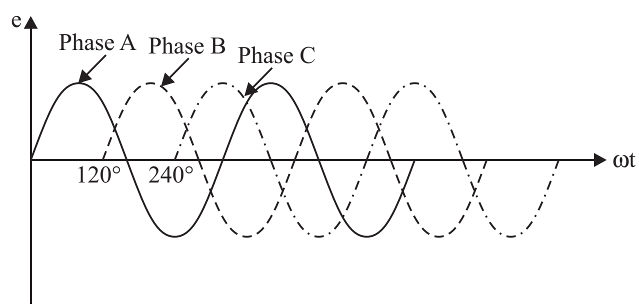
$$\theta = 0.0320 \text{ rad.}$$

Q. 18. What is a three phase (3 – ϕ) system? ***[UPTU 2009-10]***

Ans.

- 3 – ϕ A.C. supply is generated by 3 – ϕ generator has three sperate but identical winding that are 120° electrical apart and rolate in a common magnetic field.
- A three phase generator will produce 3 voltage of some magnitude and frequency but displaced 120° electrical from one another.
- 3 coils *ABC* rotates in anticlockwise direction with angular velocity ω in 2-pates field.
- e.m.f. in coil *B* will be 120° behind that of coil *A*
- e.m.f. in coilc will be 240° behind OR 120° ahead that of coit *A*.





Q. 19. Give the necessity and advantages of 3-ϕ system.

OR

What are the reasons for use of 3-ϕ system?

Ans. **Reasons for the use of 3-ϕ system**

- Electric power is generated , transmitted and distributed in the form of 3-ϕ power.
- Homes and small establishments are wired for single phase power but this merely represents a tap-off from the basic 3-ϕ system.
- 3-ϕ power has a constant magnitude whereas 1-ϕ power pulsates from zero to peak value at twice the supply from.
- 3-ϕ system can set up a rotating magnitude field in stationary windings.
- This connect be done with 1-ϕ current.

- for the same rating, 3-ϕ machine are smaller, simpler in construction and have better operating characteristics than 1-ϕ machines.
- To transmit the same amount of power over a fixed distance at a given voltage, the 3-ϕ system requires only $\frac{3}{4}$ the wright of copper that is required by the 1-ϕ system.
- The voltage regulation of a 3-ϕ transmission line is better than that of a 1-ϕ line.
- 3-ϕ maters are self starting and more efficient than 1-ϕ motor.

Q. 20. Write the EMF equations, its phasor representation and complex notation which are produced by 3-ϕ system and what is the resultant of these 3 EMF?

Sol. The eqs. of 3 emf can be represented as

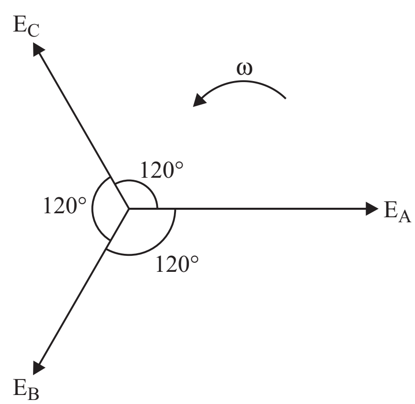
$$e_{a_1a_2} = E_m \sin \omega t$$
$$e_{b_1b_2} = E_m \sin(\omega t - 120°)$$
$$e_{c_1c_2} = E_m \sin(\omega t - 240°)$$

Or

$$e_{c_1c_2} = E_m \sin(\omega t + 120°)$$

Or

$$e_A = E_m \sin \omega t$$
$$e_B = E_m \sin(\omega t - 120°)$$
$$e_c = E_m \sin(\omega t + 120°)$$



Phasor representation

E_A, E_B and E_C are rms value.

Resultant

$$= e_A + e_B + e_C$$
$$= E_m \sin \omega t + E_m \sin(\omega t - 120°) + E_m \sin(\omega t + 120°)$$
$$= E_m [\sin \omega t + \sin(\omega t - 120°) + \sin(\omega t + 120°)]$$
$$= E_m[\sin \omega t + 2 \sin \omega t \cos 120°]$$
$$= E_m[\sin \omega t + 2 \sin \omega t (-1/2)]$$

$$= 0$$

Complex notation of 3 emfs.

$$E_A = E\angle 0° = E(1 + j0)$$
$$E_B = E\angle -120° = E(-0.5 - j0.866)$$
$$E_C = E\angle +120° = E(-0.5 + j0.866)$$
$$E = \frac{E_m}{\sqrt{2}}$$
$$\text{Resultant} = E_A + E_B + E_C$$
$$= E[1 + j0 - 0.5 - j0.866 - 0.5 + j0.866]$$
$$= 0$$

If resultant will be zero.

It is called Balanced 3-ϕ system.

Q. 4. What is the meaning of phase sequence and write the name of 3 phases in 3-ϕ system?

Ans.

- The three coils *A*, *B* and *C* are producing voltages. It is easy to see that voltage in coit *A* attains maximum +ve value 1st, next coil-*B* and then coil-*C*.
- Hence the phase sequence is *ABC*.
- If the direction of rotation of alternator is reversed then phase sequence becomes *ACB*.

PHASE Sequence

- The order in which the voltages in the three phases OR coils reach their maximum +ve values is called the phase sequence OR phase order.

NAMING the PHASES

- The three phases OR windings may be numbered OR lettered.
  It is usual practice to name the three phases by 3 natural colours

  Red (R)

  Yellow (Y)

  Blue (B)
- In this case phase sequence is RYB.
- By convention phase sequence RYB is taken as +ve and RBY as –ve.

  RYB → +ve

  RBY → –ve

Q. 5. What is the importance of double script notation in 3-ϕ system?

Ans. **DOUBLE-Subscript Notation**

- The double-subscript notation is very useful concept in the analysis of 3-ϕ.
- In this notation, two letters are placed at the foot of the symbol for voltage and current.

- The two letters indicate the two points between which voltage OR current exists.
- V_{RY} with R being +ve w.r.t. paint Y.
- V_{YR} means point Y is +ve w.r.t. R

$$V_{RY} = -V_{YR}$$

- I_{RY} indicates current I between points R and Y and that its direction is from R to Y.

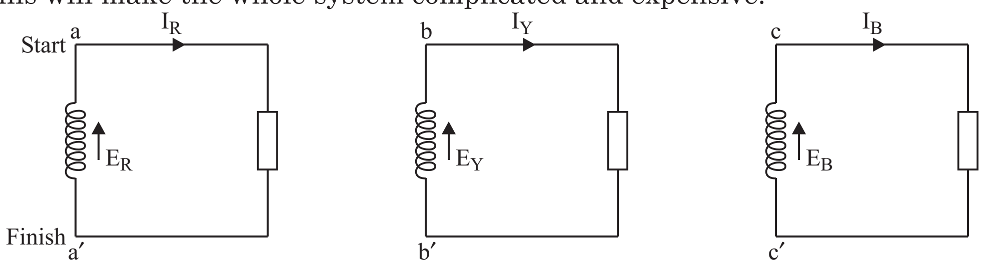
Q. 6. Explain different types of interconnections and need of it in 3-ϕ system?

Ans. **Interconnection of 3-ϕ system**

- If 3-ϕ are not interconnected then we ned two seperate conductor for each phase then.

$$\text{Total no. of conductors} = 2 \times 3 = 6$$

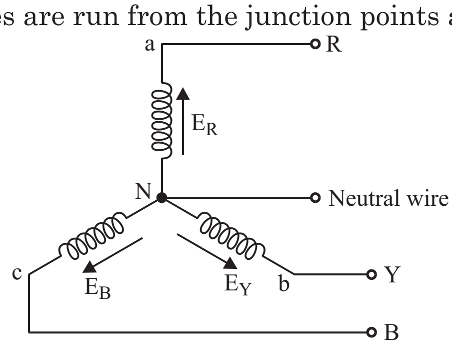
This will make the whole system complicated and expensive.

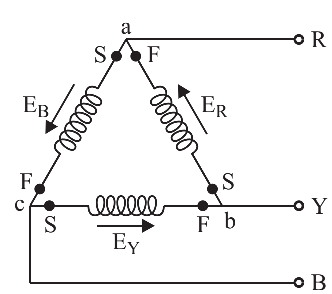


- To overcome this there are 2 methods for interconnection of 3-ϕ system.
  (i) Star connection (Y-connection)
  (ii) Delta connection

Star Connection

- In star connection, similar ends (start or finish) of the three phases are joined together and 3 lines are run from the other free ends as shown in fig.
- The common point N is called neutral point.
- Neutral conductor (shown dotted) may or may not be brough out.
- If a neutral conductor exists the system is called 3-phase 4 wire system.
- If there is no neutral conductor. It is called 3 phase, 3 wire system.
- In Δ-connection, dissimilar ends of phases are joint to form a closed mesh and 3 lines are run from the junction points as shown in fig.



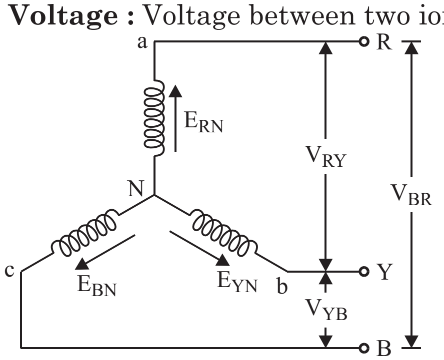


- No neutral point exists.
- Only 3-phase 3 wire system can be formed.
- Need of it is 3-ϕ system
- Star and Delta connection serves substantially all the function of 3 seperate 1-ϕ ckts but with on important advantage that the no. of conductors required is reduced.
- Saving of conductor materials and hence leads to economy.

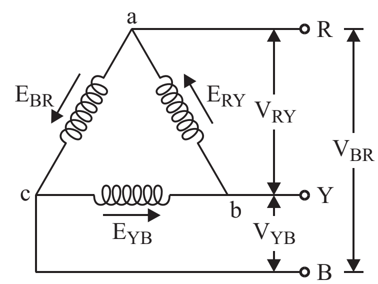
Q. 7. Define Phase voltage, Line voltage, Phase current, Line current in star and delta connected system?

Ans. Phase Voltage : Voltage between any line and neutral point is called phase voltage. It is the voltage across each winding.

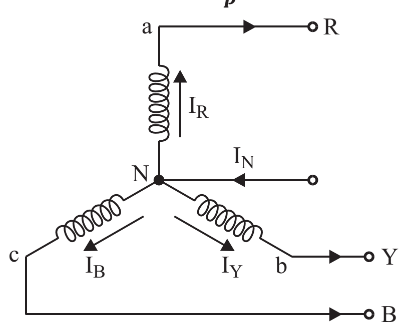
Line Voltage : Voltage between two ions is called line voltage.



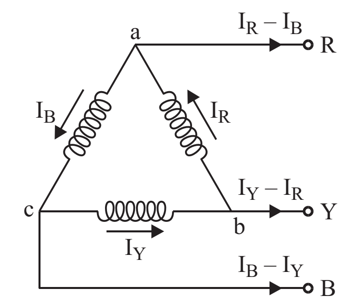
$\underbrace{E_{RN}, E_{YN}, E_{BN}}$ **Phase Voltage** V_p



$\underbrace{V_{RY}, V_{YB}, V_{BR}}$ **Line Voltage** V_L



$\underbrace{I_R, I_Y, I_B}$ **Phase Current** I_p



$\underbrace{I_R - I_B, I_Y - I_R, I_B - I_V,}$ **Line Current** I_L

Phase Current : Currents flowing in the phases are called phase current.

Line Current : Currents flowing in the lines are called the line voltage.

Q. 8. Prove the voltage relation in Y-connected in 3-ϕ system.

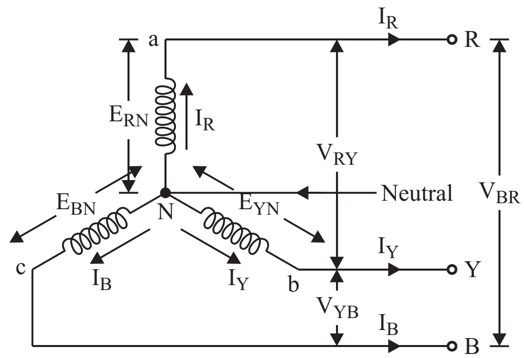
OR

Prove that the line voltage is $\sqrt{3}$ times to that of phase voltage in case of star connection 3-ϕ system.

OR

Derive $V_L = \sqrt{3}V_{ph}$ in star connection 3-φ system. *[UPTU 2008, 09, 10, 13, 14, 16]*

Sol.



$$\left.\begin{matrix} E_{RN} \\ E_{YN} \\ E_{BN} \end{matrix}\right\} \text{Phase voltage } V_P \quad \left.\begin{matrix} V_{RY} \\ V_{YB} \\ V_{BR} \end{matrix}\right\} \text{Line voltage } V_L \quad \left.\begin{matrix} I_R \\ I_Y \\ I_B \end{matrix}\right\} \text{Phase voltage } I_P$$

From above fig.

$$\text{Line current} = \text{Phase current}$$

$$I_L = I_P$$

I_N = Phasor Sum of I_R, I_Y and I_B

$$I_N = I_R + I_Y + I_B$$

For balanced load

$$I_N = 0$$

The 3 phase voltages E_{RN}, E_{YN} and E_{BN} are equal in magnitude but displaced 120° electrical from each other.

The same is true for line voltages such a supply system is called Balanced Supply System.

$$E_{RN} = V_P\angle 0° = V_P(1 + j0)$$

$$E_{YN} = V_P\angle -120° = V_P(-0.5 - j0.866)$$

$$E_{BN} = V_P\angle 120° = V_P(-0.5 + j0.866)$$

$$V_{RY} = E_{RN} - E_{YN}$$

$$= V_P(1 + j0) - V_P(-0.5 - j0.866)$$

$$= V_P(1.5 + j0.866)$$

$$= V_P(1.732\angle 30°)$$

$$V_{RY} = \sqrt{3}V_P\angle 30°$$

Similarly

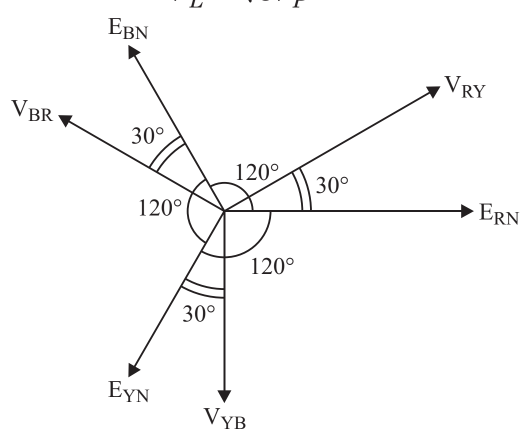
$$V_{YB} = E_{YN} - E_{BN}$$

$$= V_P(-0.5 - j0.866) - V_P(-0.5 + j0.866)$$

$$= V_P[0 - j1.732]$$
$$= V_P(1.732\angle -90^\circ)$$
$$V_{YB} = \sqrt{3}V_P\angle 90^\circ$$
$$V_{BR} = E_{BN} - E_{RN}$$
$$= V_P[-0.5 + j0.866] - V_P[1 + j0]$$
$$= V_P[-1.5 + j0.866]$$
$$= V_P(1.732\angle 150^\circ)$$
$$V_{BR} = \sqrt{3}V_P\angle 150^\circ$$

Hence

$$V_L = \sqrt{3}V_P$$



$$\text{Line voltage} = \sqrt{3} \times \text{Phase voltage}$$

Line voltages are 30° ahead of its respective phase voltage.

Q. 9. Explain current-voltage phase relation in star connection 3-ϕ system.

Ans. For inductive load I_P logs by ϕ of its V_P p.f. $\rightarrow$ lagging

I_R, I_Y and I_B are equal in magnitude but 120° displaced from one another.

In star system

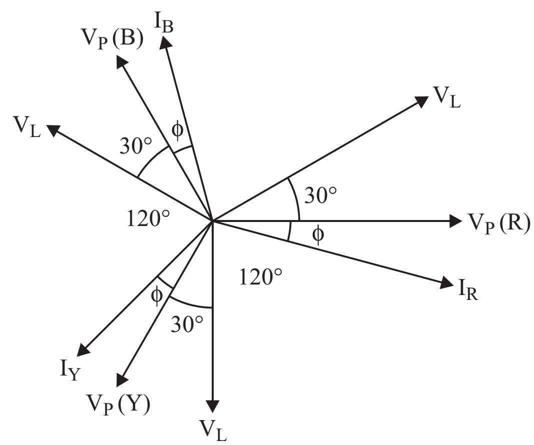
$$I_L = I_P$$

both are equal in magnitude and direction.

Angle between line currents and the corresponding line voltage is

$$30 + \phi \xrightarrow{\text{for}} \text{lagging p.f.}$$

$$30 - \phi \xrightarrow{\text{for}} \text{leading p.f.}$$



Q. 10. Write the equation of instantaneous voltage and current in star connection 3-ϕ system.

Ans. **Instantaneous phase voltage and current**

$$e = E_m \sin \omega t$$

$E_m \rightarrow$ maximum value

$E \rightarrow$ rms value $\rightarrow$ Phase voltage V_P

$$\therefore \quad E = \frac{E_m}{\sqrt{2}}$$

$$V_P = \frac{E_m}{\sqrt{2}} \Rightarrow E_m = \sqrt{2}V_P$$

$$\left.\begin{aligned} e_R &= \sqrt{2}V_P \sin \omega t \\ e_Y &= \sqrt{2}V_P \sin(\omega t - 120^\circ) \\ e_B &= \sqrt{2}V_P \sin(\omega t + 120^\circ) \end{aligned}\right\} \text{Instantaneous phase voltage}$$

Instantaneous phase currents for lagging p.f.

$$i_R = \sqrt{2}I_P \sin(\omega t - \phi)$$

$$i_Y = \sqrt{2}I_P \sin(\omega t - 120^\circ - \phi)$$

$$i_B = \sqrt{2}I_P \sin(\omega t + 120^\circ + \phi)$$

For leading p.f. ϕ is replaced by $-\phi$

Q. 11. Derive the expression for power in star connection 3-ϕ system and why dose power not pulsate with frequency?

Ans. **Instantaneous Power**

$$p = e_R i_R + - e_Y i_Y + e_B i_B$$

$$= 2V_P I_P \sin \omega t \sin(\omega t - \phi)$$

$$+ 2V_P I_P \sin(\omega t - 120^\circ) \sin(\omega t - 120^\circ - \phi)$$

$$+ 2V_P I_P \sin(\omega t + 120^\circ) \sin(\omega t + 120^\circ - \phi)$$

$$= V_P I_P [\cos\phi - \cos(2\omega t - \phi)]$$

$$+ V_P I_P [\cos\phi - \cos(2\omega t - 240^\circ - \phi)]$$

$$+ V_P I_P [\cos\phi - \cos(2\omega t + 240^\circ - \phi)]$$

$$= V_P I_P [3\cos\phi - \cos(2\omega t - \phi) - \cos(2\omega t - 240^\circ - \phi) - \cos(2\omega t + 240^\circ - \phi)$$

$$= V_P I_P [3\cos\phi - \cos(2\omega t - \phi) - 2\cos(2\omega t - \phi)\cos 240^\circ]$$

$$p = V_P I_P [3\cos\phi - \cos(2\omega t - \phi) - 2\cos(2\omega t - \phi)(-1/2)]$$

$$= V_P I_P 3\cos\phi$$

$$= 3V_P I_P \cos\phi$$

No term of wt is present

$\therefore$ 3-ϕ power does not pulsat with frequency its magnitude becomes constant.

Total power = Average of instantaneous power

$$= 3V_P I_P \cos\phi$$
$$= 3 \times \text{Power in each phase}$$

Average power is active OR read power

$$P_{avg} = 3V_P I_P \cos\phi$$

for star connection

$$V_L = \sqrt{3}V_P \text{ and } I_L = I_P$$

$$\therefore \quad P_{avg} = 3\frac{V_L}{\sqrt{3}} I_L \cos\phi$$

$$P_{avg} = \sqrt{3}V_L I_L \cos\phi$$

$$\text{Active Power} = 3V_P I_P \cos\phi = \sqrt{3}V_L I_L \cos\phi$$

$$\text{Reactive Power} = 3V_P I_P \sin\phi = \sqrt{3}V_L I_L \sin\phi$$

$$\text{Apparent Power} = 3V_P I_P = \sqrt{3}V_L I_L$$

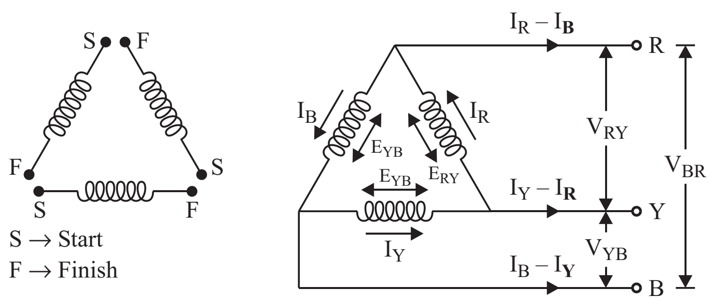
Q. 12. Prove the voltage and current relationship for 3-ϕ delta connected system.

OR

Prove that the line current is $\sqrt{3}$ times to that of phase current in case of for 3-ϕ delta connected system. ***[UPTU 2008, 2009, 12, 13, 14]***

Ans. $\left.\begin{matrix} E_{RY} \\ E_{YB} \\ E_{BR} \end{matrix}\right\}$ Phase voltage V_P $\left.\begin{matrix} V_{RY} \\ V_{YB} \\ V_{BR} \end{matrix}\right\}$ Line voltage V_L $\left.\begin{matrix} I_R \\ I_Y \\ I_B \end{matrix}\right\}$ Phase voltage I_P

$$\left.\begin{matrix} I_R - I_B \\ I_Y - I_R \\ I_B - I_Y \end{matrix}\right\} \text{Line current } I_L$$



- 3-ϕ voltages are equal in magnitude and displaced 120° electrical from one another.
- $\underbrace{\vec{E}_{RY} + \vec{E}_{YB} + \vec{E}_{BR}}_{\text{Phasor Sum}} = 0$
- No current flow round the mesh when the terminals are open.
- From the fig.

$$E_{RY} = V_{RY}, E_{YB} = V_{YB}, E_{BR} = V_{BR}$$

Line voltage = Phase voltage

$$V_L = V_P$$

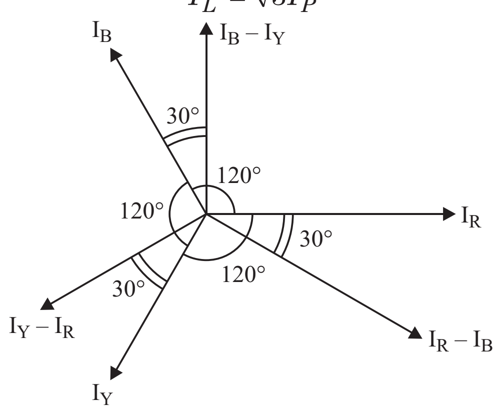
In balanced Δ system 3 phase currents I_R, I_Y and I_B are equal in magnitude is 120° displaced from one another.

$$I_R = I_P \angle 0°$$
$$I_Y = I_P \angle -120°$$
$$I_B = I_P \angle +120°$$
$$I_P = \frac{I_m}{\sqrt{2}}$$

Line Current

$$\begin{aligned}
I_R - I_B &= I_P \angle 0° - I_P \angle 120° \\
&= I_P(1 = j0) - I_P(-0.5 + j0.866) \\
&= I_P(1.5 - j0.866) \\
&= I_P(1.732 \angle -30°) \\
I_R - I_B &= \sqrt{3} I_P \angle -30° \\
I_Y - I_R &= I_P \angle -120° - I_P \angle 0° \\
&= I_P(-0.5 - j0.866) - I_P(1 + j0) \\
&= I_P(-1.5 - j0.866) \\
&= I_P(1.732 \angle -150°) \\
I_Y - I_R &= \sqrt{3} I_P \angle -150° \\
I_B - I_Y &= I_P \angle +120° - I_P \angle -120° \\
&= I_P(-0.5 + j0.866) - I_P(-0.5 - j0.866) \\
&= I_P(0 + j1.732) \\
&= I_P(1.732 \angle 90°) \\
I_B - I_Y &= \sqrt{3} I_P \angle 90°
\end{aligned}$$

∴ $$I_L = \sqrt{3} I_P$$



Line currents are 30° behind the respective phase current.

Q. 13. Write the equation for all power 3-φ delta connected system.

Sol. **Power in Delta System**

Total power = 3 × power per phase

$$= 3V_P I_P \cos\phi$$

For delta $V_L = V_P$ and $I_L = \sqrt{3} I_P$

$$P_{avg} = 3V_L \frac{I_L}{\sqrt{3}} \cos\phi$$

$$= \sqrt{3} V_L I_L \cos\phi$$

$$\text{Active power} = 3V_P I_P \cos\phi = \sqrt{3} V_L I_L \cos\phi$$

$$\text{Reactive power} = 3V_P I_P \sin\phi = \sqrt{3} V_L I_L \sin\phi$$

$$\text{Apparent power} = 3V_P I_P = \sqrt{3} V_L I_L$$

Q. 14. If the phase of 3-phase connected system is 200 volt, what will be the line voltage

(a) When phases are correctly connected?

(b) When connections of the one of phases are reversed? ***[UPTU 2001, 03]***

Sol. (a) Given $V_P = 200 = V_R = V_Y = V_B$

$$\vec{V}_R = 200\angle 0°$$

$$\vec{V}_Y = 200\angle -120°$$

$$\vec{V}_B = 200\angle +120°$$

When phase are correctly connected then

$$\vec{V}_{RY} = \vec{V}_L - \vec{V}_Y$$

$$= 200\angle 0° - 200\angle -120°$$

$$= 200\sqrt{3}\angle 30°$$

Similarly $\vec{V}_{YB} = \vec{V}_Y - \vec{V}_B$

$$= 200\sqrt{3}\angle -90°$$

$$\vec{V}_{BR} = \vec{V}_B - \vec{V}_R$$

$$= 200\sqrt{3}\ \angle 150°$$

(b) When V_R is reversed then it becomes

$$\vec{V}_R = 200\angle 180°$$

$$\vec{V}_{RY} = \vec{V}_R - \vec{V}_Y$$

$$= 200\ \angle 180° - 200°\angle 120°$$

$$= 200[1\angle 180^\circ - 1 - 102^\circ]$$
$$= 200[-1 + j0 - (-0.5 - j0.866)]$$
$$= 200[0.5 + j0.86]$$
$$= 200\ \angle 120^\circ$$
$$\vec{V}_{YB} = \vec{V}_Y - \vec{V}_B$$
$$= 200\ \angle -120^\circ - 200\angle 120^\circ$$
$$= 200\sqrt{3}\ \angle -90^\circ$$
$$\vec{V}_{BR} = \vec{V}_Y - \vec{V}_B$$
$$= 200\ \angle 120^\circ - 200\angle 180^\circ$$
$$= 200[0.5 + j0.866] - 200[-1 + j0]$$
$$= 200\,[0.5! + j0.866]$$
$$= 200\ \angle 60^\circ$$

Note : If phase of any quantity is moversed then its phase angle is changed by +180° or –180°.

Q. 15. 3-coils, each having a resistance of 20 Ω and an inductive reactance of 15, are connected in star to a 400 V, 50 Hz supply calculate

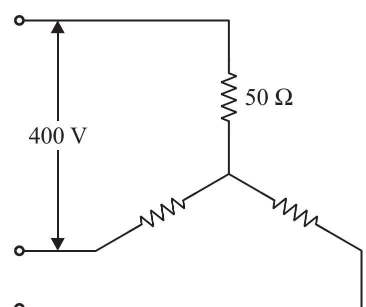
(i) Line current

(ii) Power factor

(iii) Power supplied ***[UPTU 2002]***

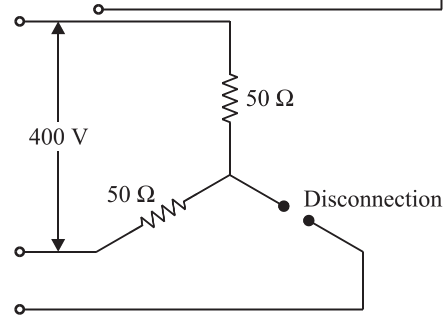
Sol. (i)

$$V_L = 400$$
$$V_P = \frac{400}{\sqrt{4}} = 231$$
$$I_P = \frac{V_P}{R_P} = \frac{231}{30}$$
$$= 4.62 \text{ amp}$$
$$I_L = I_P = 4.62 \text{ amp}$$
$$P = \sqrt{3} V_L I_L \cos\phi$$
$$= \sqrt{3} \times 400 \times 4.62 \times 1$$
$$= 3200 \text{ W}$$



(ii) Where one resistors is disconnected

Two resistor of save will be in series across the 400 line voltage



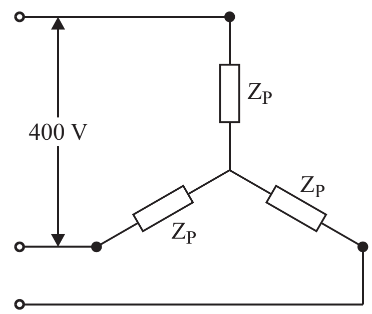
$$\therefore \qquad I_L = P_P = \frac{400}{50 + 10}$$
$$= 4 \text{ amp}$$

Power $= V_L I_L \cos\phi = 400 \times 4 \times 1 \times 1600$ W

Q. 16. A balance stare connected load of 8 + *j*6/phase is connected to a balanced 3-ϕ 400 V supply. Find the line current, power factor and power.

[UPTU 2012-13, 2016-17]

Ans. Given



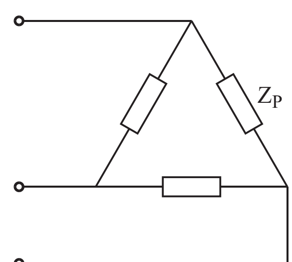
$$\text{Supply} = 400 \text{ volt}$$
$$\Downarrow$$
$$\text{Line voltage}$$
$$\therefore \quad V_L = 400 \text{ V}$$
$$\therefore \quad V_P = \frac{V_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} \text{ volt}$$
$$Z_P = 8 + j6 = 10\angle 36.87°$$
$$\therefore \quad \text{Phase current } I_P = \frac{V_P}{Z_P}$$
$$= \frac{400\sqrt{3}}{10} = 23 \text{ A}$$
$$\therefore \quad \text{Line current} = \text{Phase current}$$
$$= 23 \text{ A}$$

From $Z_P \; \phi = 36.87°$

$$\therefore \quad \text{p.f.} = \cos 36.87° = 0.8 \text{ (logging)}$$
$$\text{Power} = 3V_P I_P \cos\phi = 3 \times \frac{400}{\sqrt{3}} \times 23 \times 0.$$
$$= 12748 \text{ Watt}$$

Q. 17. A balanced delta-connected load of impedance 16 + *j*12 Ω/phase is connected to a 3-ϕ 400 V supply. Find the phase current, line current, power factor, power, reactive VA. ***[UPTU 2008-09]***

Ans. Given



Line voltage

$$V_L = 400 \text{ L}$$
$$V_P = V_L = 400 \text{ volt}$$

∴ Phase current

$$I_P = \frac{V_P}{Z_P}$$
$$= \frac{400}{20} = 20 \text{ amp}$$
$$Z_P = 16 + j12$$
$$= 20 \angle 37°$$

In delta

Line Current

$$I_L = \sqrt{3} I_P = \sqrt{3} \times 30 = 34.64 \text{ amp}$$

$$\text{P.F.} = \cos\phi = \cos 37° = 0.8 \text{ (logging)}$$

$$\text{Active power} = 3V_P I_P \cos\phi$$

$$= 3 \times 400 \times 20 \times 0.8 = 19.2 \text{ kW}$$

$$\text{Reactive power} = 3V_P I_P \sin\phi$$

$$= 3 \times 400 \times 20 \times \sin 37°$$

$$= 14.5 \text{ k VAR}$$

Q. 18. A 3-ϕ voltage source has a phase voltage of 120 V and supplies star connected load having impedance 36 + *j*48 Ω/phase. Calculate :

(i) The line voltage

(ii) The line current

(iii) The power factor

(iv) The total 3-phase power supplied to the load. *[UPTU 2008-09]*

Ans. Given

Phase voltage

$$V_P = 120 \text{ volt}$$

$$Z_P = 36 + j48$$

$$= 60\angle 53°$$

(i) Line voltage $V_L = \sqrt{3} V_P$

$$= \sqrt{3} \times 120$$

$$= 208 \text{ volt}$$

(ii) Phase current

$$\text{e}I_P = \frac{V_P}{Z_P} = \frac{208}{60}$$

$$= 3.47 \text{ amp}$$

∴ Line current $= I_L = I_P$

$$= 3.47 \text{ amp}$$

(iii) Power factor $= \cos\phi$

$$\cos 53° = 0.60 \text{ (lagging)}$$

(iv) Power supplied $= 3V_P I_P \cos\phi$

$$= 3 \times 120 \times 3.47 \times 0.6$$

$$= 749.52 \text{ watt}$$

Q. 19. A balanced 3-phase star connected load of 18 kW taking a leading current of 60 A when connected across a 3-phase 440 V, 50 Hz supply. Find the values and nature of load. *[UPTU 2007-08, 2012-13]*

Ans. Given

$$\text{Power} = 18 \text{ kW}$$

$$I_L = I_P = 60 \text{ A leading}$$
$$V_L = 440 \text{ volt}$$

⇒ Load is capacitive nature

⇒ $$P = 18 \text{ kw}$$
$$3V_P I_P \cos\phi = 8 \times 10^3$$
$$3\frac{V_L}{\sqrt{3}} I_P \cos\phi = 8 \times 10^3$$
$$3 \times \frac{440}{\sqrt{3}} \times 60 \times \cos\phi = 8 \times 10^3$$
$$\cos\phi = 0.39$$
$$\phi = 67°$$
$$Z_P = \frac{V_P}{T_P} = \frac{440\sqrt{3}}{60}$$
$$= 4.23\ \Omega$$

Complex form of Z_P

$$Z_P = 4.23\angle -\phi$$
$$= 4.23\angle -67°$$
$$= 1.65 - j3.9$$

∴ $$R_P = 1.65\ \Omega$$
$$X_P = 3.9\ \Omega$$

Q. 20. 3 similar coils each having a resistance of 8 Ω and an inductance of 191 H in series, is connected across a 400 V, 3-φ, 50 hz supply. Calculate the line current, power input, KVA and kVAR taken by the load. ***[UPTU 2006-07]***

Sol. Given

$$R_P = 8\ \Omega$$
$$L_P = 0.191 \text{ H}$$

∴ $$X_P = 2\pi f L_P$$
$$= 2 \times 3.14 \times 50 \times 101$$
$$= 6\ \Omega$$

∴ $$Z_P = R_P + jX_P$$
$$= 8 + j6 = 10\angle 36.87°$$
$$V_L = 400 \text{ V}$$
$$V_P = \frac{V_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 231 \text{ V}$$
$$I_P = \frac{V_P}{Z_P} = \frac{231}{10} = 23.1 \text{ amp}$$

∵ $$I_L = I_P$$

$\therefore \qquad I_P = 23.1 \text{ amp}$

Power $\frac{i}{P}$

$$= 3V_P I_P \cos\phi$$
$$= 3 \times 231 \times 23.1 \times \cos 36°$$
$$= 12.8 \text{ kw}$$
$$\text{KVA} = 3V_P I_P$$
$$= 3 \times 231 \times 23.1$$
$$= 16 \text{ KVA}$$
$$\text{KVAR} = 3V_P I_P \sin\phi$$
$$= 3 \times 231 \times 23.1 \times \sin 30°$$
$$= 9.6 \text{ KVAR}$$

Q. 21. What is the use of single phase watt-meter and how is it connect to measure the power?

Ans. A 1-ϕ watt meter consists of two coils

1. Fixed coil i.e., called current coil having low resistance is inserted in series with the line so that it carries the line current.
2. Movable coil i.e., called potential coil having high resistance is connected like a voltmeter across the line. The small current in the potential coil

$$= \frac{\text{Input voltage}}{\text{Resistance of potential coil}}$$

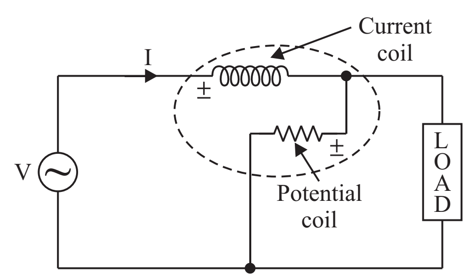
Movable coil carrying a pointer which moves over a scale.

Watt meter deflection $\propto$ Average power ($VI \cos\phi$) delivered to the ckt.

- It is clear that wattmeter has 4 terminals

2 for current coil

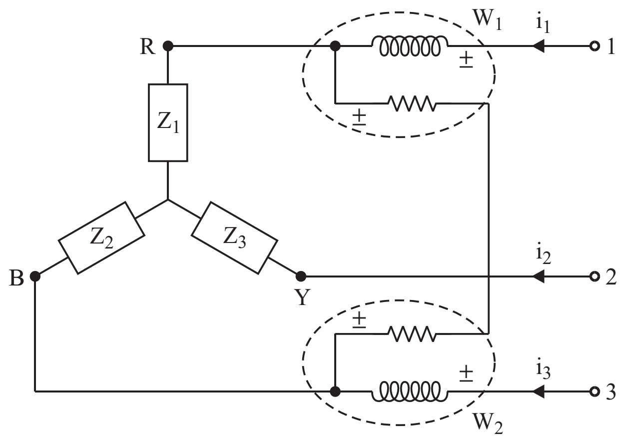
2 for potential coil.



- When connected in ckt to measure power, sometimes it gives backward deflection i.e., it reads down scale.
- This is due to improper connections.
- As shown in fig. one current coil and one potential terminal are marked usually ± on an actual instrument.
- To obtain upscale reading on meter ± terminal of current coil is connected to line side of ckt and ± terminal of potential coil is connected to the same line lead as current coil.
- A reversal of either coil connection will result in backward deflection.

Q. 23. Explain 2-wattmeter method for measurement of 3-phase power.

Ans. **Two-wattmeter Method**



In this method, current coils of the two wattmeters are connected in any two lines and the potential coil of each is joined to the third line as shown in fig.

Total Power = $W_1 + W_2$ algebraic sum.

It can be proved mothermatically

- 2-wathmeter can be used babnced as well as unbalanced load.
- Voltage coil is also called as pressure coil.
- 2-wattmeter method is a universal method of measuring power in a 3-ϕ ckt.
- Instantaneous power supplied to the load

$$p = p_1 + p_2 + p_3$$
$$= v_1 i_1 + v_2 i_2 + v_3 i_3$$

For star connection

$$i_1 + i_2 + i_3 = 0$$
$$i_2 = -(i_1 + i_3)$$

$\therefore$ $$p = v_1 i_1 + v_2[-(i_1 + i_3)] + v_3 i_3$$
$$= (v_1 - v_2) i_1 + (v_3 - v_2) i_3$$

$v_1 - v_2 \rightarrow$ Instantaneous voltage across voltage coil of w_1

$i_1 \rightarrow$ Instantaneous current through current coil of w_1

$v_3 - v_2 \rightarrow$ Instantaneous voltage across voltage coil of w_2

$i_3 \rightarrow$ Instantaneous current through current coil of w_2

Instantaneous power recorded by w_1

$$p_1 = (v_1 - v_3) i_1$$

Instanteneous power recorded by w_2

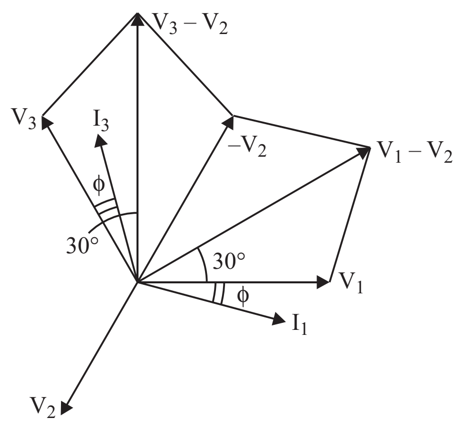
$$p_2 = (v_2 - v_3) i_3$$
$$p = p_1 + p_2$$
$$P_{avg} = P_{1\,avg} + P_{2\,avg}$$

$$\Downarrow \qquad \Downarrow$$
$$\text{reading of } w_1 \quad \text{reading of } w_2$$

Reading of $W_1 = (V_1 - V_2)I_1 \cos$ [Phase angle between $V_1 - V_3$ and I_1]

Reading of $W_2 = (V_3 - V_2)I_3 \cos$ [Phase angle between $V_3 - V_2$ and I_3]

for phase angle



$$V_3 - V_2$$
$$V_1 - V_2 \rightarrow \text{Line voltage}$$
$$I_1 \Rightarrow \text{Line current}$$

Phase angle between $V_1 - V_2$ and I_1

$$= 30 + \phi$$

Phase angle between $V_3 - V_2$ and I_3

$$= 30 - \phi$$

$$\text{Reading of } W_1 = V_2 I_2 \cos(30 + \phi)$$
$$\text{Reading of } W_2 = V_2 I_2 \cos(30 - \phi)$$

∴ Total power

$$P = V_2 I_2 \cos(30 + \phi) + V_2 I_2 \cos(30 - \phi)$$
$$= V_2 I_2 [2 \cos 30° \cos \phi]$$
$$= V_2 I_2 [\sqrt{3} \cos \phi]$$
$$= \sqrt{3} V_2 I_2 \cos \phi$$
$$P = \sqrt{3} V_2 I_2 \cos \phi \text{ True power}$$
$$W_1 + W_2 = \sqrt{3} V_2 I_2 \cos \phi$$
$$W_1 - W_2 = V_2 I_2 \cos(30 + \phi) - V_2 I_2 \cos(30 - \phi)$$
$$= V_2 I_2 [\cos(30 + \phi) - \cos(30 - \phi)]$$
$$W_1 - W_2 = V_2 I_2 \sin \phi$$
$$\frac{W_1 - W_2}{W_1 + W_2} = \frac{\sin \phi}{\sqrt{3} \cos \phi}$$

$$\tan\phi = \sqrt{3}\left(\frac{W_1 - W_2}{W_1 + W_2}\right)$$

Q. 24. How are varied 2-wattmeter readings with nature of load?

Ans. **Variation in wattmeter reading**

$$W_1 = V_2 I_2 \cos(30 + \phi)$$
$$W_2 = V_2 I_2 \cos(30 - \phi)$$

For Inductive load

$$W_1 = V_2 I_2 \cos(30 - \phi)$$
$$W_2 = V_2 I_2 \cos(30 + \phi)$$

For capacitive load $\phi \to -\phi$

Readings are exchanged

- If $\phi = 0$, unity p.f.

$$W_1 = V_2 I_2 \cos 30° = \frac{\sqrt{3}}{2} V_2 I_2 \to \text{Half of total power}$$
$$W_2 = V_2 I_2 \cos 30° = \frac{\sqrt{3}}{2} V_2 I_2 \to \text{Half of total power}$$

Both wattmeter indicate equal and +ve (Upscale) readings

- If $\phi = 60°$, P.F. $\to$ 0.5

$$W_1 = V_2 I_2 \cos 90° = 0$$
$$W_2 = V_2 I_2 \cos 30° = \frac{\sqrt{3}}{2} V_2 I_2 \to \text{Total power}$$

$\therefore$ Wattmeter W_2 measures total power alone.

- If $\phi = 90°$, P.F. $\to$ 0

$$W_1 = V_2 I_2 \cos 120° = -\frac{1}{2} V_2 I_2$$
$$W_2 = V_2 I_2 \cos 60° = \frac{1}{2} V_2 I_2$$

Two wattermeter will read equal and oppositive

$$\therefore \quad W_1 + W_2 = 0$$

- If $60° < \phi < 90°$, $0 < \text{P.F.} < 0.5$

$$W_1 = \text{–ve reading (down scale)}$$
$$W_2 = \text{+ve reading (up scale)}$$

$$\therefore \quad \text{Total power} = W_2 + (-W_1)$$
$$= W_2 - W_1$$

Q. 25. In 2-wattmeter method power measured was 30 kW at 0.7 p.f. lagging. Find reading of each wattmeter. *[UPTU 2007, 11-12]*

Sol. $\cos\phi = 0.7$

$$\phi = 45°$$

$$\text{Total power} = 30 \text{ kW}$$

$$\sqrt{3} V_2 I_2 \cos\phi = 30 \times 10^3$$

$$\sqrt{3} \times V_2 I_2 \times 0.7 = 30 \times 10^3$$

$$V_2 I_2 = 24743.6$$

1st wattmeter reading

$$W_1 = V_2 I_2 \cos(30° + \phi)$$
$$= 24743.6 \cos(30° + 45°)$$
$$= 24743.6 \cos 75°$$
$$= 6404 \text{ watt}$$

2nd wattmeter reading

$$W_2 = V_2 I_2 \cos(30° - \phi)$$
$$= 24743.6 \cos(30° - 45°)$$
$$= 23900 \text{ watt}$$

Q. 26. A 3-ϕ balanced load connected across 3-ϕ 400 V, ac supply draws a line current of 10 A. 2 wattmeter are used to measure *i/P* power The ratio of 2-wattmeter reading is 2 : 1, find the reading of the two wattmeter.

[UPTU 2002, 13-14]

Ans. Given $V_2 = 400$ volt

$$I_2 = 10 \text{ A}$$

Ratio $$\frac{W_2}{W_1} = \frac{2}{1}$$

$\because$ $$\tan\phi = \sqrt{3}\,\frac{\text{Higher Reading} - \text{Lower Reading}}{\text{NR.} + \text{L.R.}}$$

$$= \sqrt{3}\left(\frac{W_2 - W_1}{W_2 + W_1}\right)$$

$$= \sqrt{3}\left(\frac{W_2/W_1 - 1}{W_2/W_1 + 1}\right)$$

$$= \sqrt{3}\left(\frac{2-1}{2+1}\right) = \frac{1}{\sqrt{3}}$$

$\therefore$ $$\phi = 30°$$

1st wattmeter reading $$W_1 = V_2 I_2 \cos(30° + \phi)$$
$$= 400 \times 10 \cos(30° + 30°)$$
$$= 2000 \text{ watt}$$

2nd wattmeter reading $$W_2 = V_2 I_2 \cos(30° - \phi)$$
$$= 400 \times 10 \times \cos(30° - 30°)$$
$$= 4000 \text{ watt}$$

Q. 27. 2-mattmeters connected to measure power in a 3-ϕ ckt measures power in a 3-ϕ ckt measures 5 kw and 1 kw. The latter reading being obtained after reversing current coil connection, calculate p.f. of the load and the total power consumed. ***[UPTU 2001]***

Ans. Given,

$$\text{Higher reading} = 5 \text{ kw}$$
$$\text{Lower reading} = 1 \text{ kw}$$

if latter reading is obtained after reversing coil connection then it will be

$$\text{L.R.} = 1 \text{ kw}$$
$$\text{Total power} = \text{HR} + \text{LR}$$
$$5 + (-1) = 4 \text{ kw}$$

For p.f.

$$\tan\phi = \sqrt{3}\,\frac{\text{H.R.} - \text{L.R.}}{\text{H.R.} + \text{L.R.}}$$
$$= \sqrt{3}\,\frac{5-(-1)}{5+(-1)}$$
$$\phi = 68.9°$$

$\therefore$
$$\text{p.f. } \cos\phi = \cos 68.9°$$
$$= 0.36$$

Q. 28. Three equal impedances, each consisting of *R* and *L* in series, are connected in star and are supplied from a 400 volt, 50 Hz, 3-ϕ 3 wire supply system. The power input to the load is neasured by two wattmeters method and the two wattmeters read 3 kw and 1 kw, then determine the values of *R* and *L* connected in each phase.

Sol. In star connection $V_L = 400$ V, $f = 50$ Hz

$$V_P = \frac{V_L}{\sqrt{3}} = -231 \text{ volt}$$
$$W_1 = 3 \text{ kw},\ W_2 = 1 \text{ kw}$$

We know that

$$\phi = \tan^{-1}\left[\sqrt{3}\left(\frac{W_1 - W_2}{W_1 + W_2}\right)\right]$$
$$= \tan^{-1}\left[\sqrt{3}\left(\frac{2}{4}\right)\right] = 40.89°$$

We know that

$$W_1 = V_L I_L \cos(30 - \phi)$$
$$3 \times 10^3 = 400 \times I_L \cos(30 - 40.85°)$$
$$I_L = \frac{3000}{400 \times \cos(-10.85°)}$$
$$= 7.637 \text{ Amp}$$
$$I_P = I_L = 7.637 \text{ Amp (in } \gamma\text{-connection)}$$

Impedance of load, $Z = \frac{V_P}{I_P} = \frac{231}{7.637} = 30.245\ \Omega$

Resistance of load, $R = 2 \cos\phi = 29.69\ \Omega$

Inductive reactance of load, $X_L = 2 \sin\phi = 5.72\ \Omega$

$$L = \frac{X_L}{\omega} = \frac{5.72}{2\pi f} = 18.21 \text{ mH}$$

Q. 29. A balance star connected inductive load is connected to a 400 V, 50 Hz a.c. supply. Two wattmeter is used to measure supply power indicate 8000 W and 400 W respectively. Determine

(i) Line current

(ii) Impedance of each phase

(iii) Resistance and Inductance of each phase ***[UPTU 2009-10]***

Ans. In star connection $V_L = 400$ V, $f = 50$ Hz

$$V_P = \frac{V_L}{\sqrt{3}} = 231 \text{ volt}$$

$$W_1 = 8000 \text{ watt}$$

$$W_2 = 4000 \text{ watt}$$

$$\phi = \tan^{-1}\left[\sqrt{3}\left(\frac{W_1 - W_2}{W_1 + W_2}\right)\right]$$

$$= \tan^{-1}\left[\sqrt{3}\left(\frac{4000}{12000}\right)\right] = 30°$$

(i) Total power, $P = W_1 + W_2 = 12000$ watt

$$P = \sqrt{3} V_L I_L \cos\phi$$

$$\Rightarrow \quad I_L = \frac{P}{\sqrt{3} V_L \cos(30°)}$$

$$I_L = 20 \text{ Amp}$$

$$I_P = I_L = 20 \text{ Amp (in } \gamma\text{-connection)}$$

(ii) Impedance of each phase, $Z = \frac{V_P}{I_P} = \frac{231}{20}$

$$= 11.55\ \Omega$$

(iii) Resistance, $R = Z \cos\phi = 11.55 \cos(30°)$

$$= 10\ \Omega$$

Inductive reactance, $X_L = Z \sin\phi = 11.55 \sin(30°)$

$$= 5.775\ \Omega$$

$$L = \frac{X_L}{\omega} = 18.37 \text{ mH}$$

❑

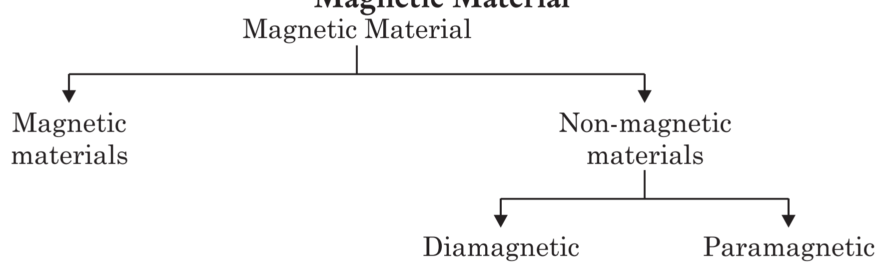
Unit-4

Magnetic Circuit 1-ϕ AC Transformer

Q. 1. Discuss about Magnetic materials and what do you mean by Magnetic fie ld.

Ans.

Magnetic Material



- All the materials in this universe may be classified either magnetic or non-magnetic.
- Magnetic materials are those which are affected by magnetic field and non magnetic materials are those which are not affected or slightly affected by magnetic field.
- Maximum types of materials fall under category of non-magnetic material. Non-magnetic material can further be classified as diamagnetic and paraagnetic materials.
- Some of the non magnetic materials exhibit very slight magnetic effect but it is extremely difficult to detect. Practically, all these materials are referred as totally non-magnetic.
- On the other hand, all the materials which exhibit magnetic effect strongly are referred as magnetic materials or ferromagnetic materials.

Magnetic fields

Magnetic fields can be created either by placing, a permanent magnet or by supplying current through a solenoid. Latter is electromagnet. A magnetic field is defined as the space surrounding a permanent magnet or electromagnet where the electric field is felt by other magnet or magnetic material.

Q. 2. What is the difference between a Permanent Magnet and an Electromagnet?

Ans. A permanent magnet does not require any external electric supply to produce the field. But their magnetic field is normally weaker than that of an electromagnet. Hence, permanent magnets are relatively bulky in size. The strength of the field cannot be varied as per requirement. The field of these magnets are also not everlasting, it will be loosened over a period of time. They also lose their magnetism, if they get subjected to physical shock or vibration. Because of these many disadvantages, the applications of permanent magnet in the field of engineering are quite limited.

Q. 3. What do mean by Magnetic flux and what are its properties?

[UPTU 2015]

Ans. Magnetic Flux or Magnetic Lines of Force

- Magnetic field is also represented by lines of force as static electric field.
- These lines of force are referred as magnetic flux. When a unit magnetic pole is placed inside a magnetic field, it will experience both repulsive and attractive force, from similar and opposite poles of the magnet, respectively.
- The unit pole travels due to resultant of the repulsive and attractive force. The path through which the unit pole travels in the magnetic field is referred as magnetic lines of force.
- There are numbers of magnetic lines of force in a magnetic field, and these lines of force are collectively called magnetic flux. These flux lines have some specific properties that are described below.
- The unit of this flux is the Weber (Wb). The unit was named in honor of German scientist Max Weber.

Properties of Magnetic Flux or Magnetic Lines of Force

- They always form complete closed loops, lines of magnetic flux exist all the way through the magnet.
- They behave as if they are elastic. That is, when distorted they try to return to their natural shape and spacing.
- The lines of force of magnetic field are radiated from the north (N) pole to the south (S) pole.
- Flux lines do not cross or interact to each other.

Q. 4. Define following terms as applied to magnetic ckt :

(i) Magnetic ckt (ii) Magnetic flux density (iii) mmf (iv) Magnetic field strength (v) Reluctance (vi) Permenance (vii) Permeability (viii) Relative Permeability

Ans. (i) Magnetic Circuit

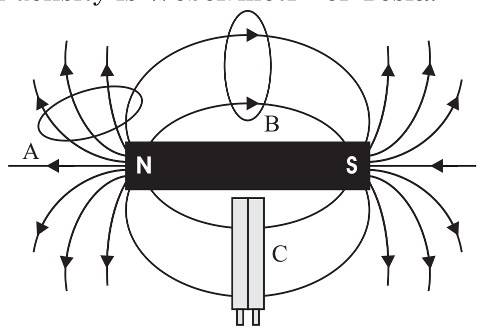
- When a magnetic flux is circulated or follow through a closed area or path, is called the magnetic circuit or when a magnetic field circulates in a closed path represented as lines of magnetic flux in a confined area is called Magnetic Circuit.

- This magnetic circuit forms with permanent magnets or electromagnets and confined to the path by magnetic cores consisting of ferromagnetic materials like iron etc.

(ii) Magnetic flux density *[UPTU 2015]*

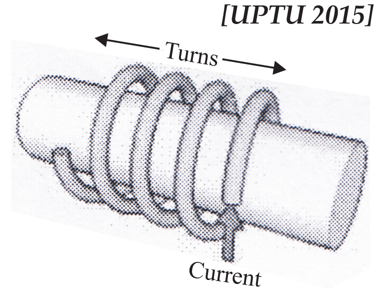
Magnetic flux density is defined as the amount of magnetic flux in an area taken perpendicular to themagnetic flux's direction.

Unit of Magnetic flux density is Weber/metr^2 or Tesla.



(iii) MMF *[UPTU 2015]*

A circulating force called Magneto Motive Force (MMF) or magnetic potential is responsible for establishing magnetic flux in a magnetic circuit.



The MMF is equivalent to a number of wire carrying an electric current and has units of ampere turns.

MMF is the property of certain substances or phenomena that gives rise to a magnetic field and is analogous to electromotive force or voltage of electricity.

(iv) Magnetic field strength *[UPTU 2015]*

Magnetic field strength signifies how strong the magnetic field is. Hence magnetic field strength is defined as the mmf per metre length of the magnetic circuit.

- The unit of H is ampere turn/metre.
- The symbol for magnetic field strength is H.
- For calculating magnetic field strength or H, we have to divide total ampere turns by mean length of a magnetic circuit. That is,

$$H = \frac{NI}{l}$$

where, I is the mean or average length of the magnetic circuit.

(v) Magnetic Reluctance *[UPTU 2010, 15]*

- The obstruction offered by a magnetic circuit to the magnetic flux is known as reluctance.

- As in electric circuit, there is resistance similarly in the magnetic circuit, there is a reluctance, but resistance in an electrical circuit dissipates the electric energy and the reluctance in magnetic circuit stores the magnetic energy.
- Also in an electric circuit, the electric field provides the least resistance path to the electric current. Similarly, the magnetic field causes the least reluctance path for the magnetic flux.

It is denoted by S.

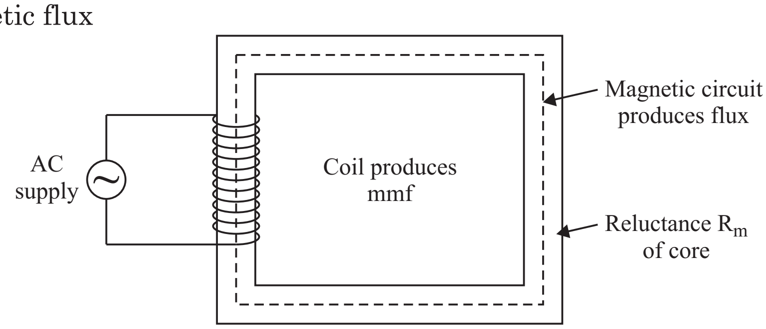
$$\text{Reluctance}\,(S) = \frac{\text{m.m.f}}{\text{flux}} = \frac{F}{\phi}$$

where,

S—reluctance in ampere-turns per weber.

F—magnetic motive force

ϕ—magnetic flux



The SI unit of magnetic reluctance is AT/Wb (ampere-turns/Weber).

The reluctance of the magnetic circuit is directly proportional the length of the conductor and inversely proportional to the cross-section area of the conductor.

$$S \propto l$$

$$S \propto \frac{1}{A}$$

$$\text{Reluctance}\,(S) = \frac{l}{\mu A} = \frac{l}{\mu_r \mu_0 A}$$

where,

l—the length of the conductor

μ—Permeability of the material

μ_0—permeability of vacuum which is equal to the $4\pi \times 10_7$ Henry/metre.

μ_r—relative permeability of the material.

A-cross-section area of the conductor.

(vi) Permeance

The reciprocal of the magnetic reluctance is known as the magnetic permeance. It is given by the expression

$$\text{P ermeance}\,(P) = \frac{1}{\text{Reluctance}} = \frac{1}{R}$$

(vii) Magnetic Permeability

- Magnetic permeability is the ability of a material to respond to how much electromagnetic flux it can support to pass through itself within an applied electromagnetic field. In other word magnetic permeability of a material is the degree of magnetization capability.
- Magnetic permeability is expressed in μ that is a Greek Letter. In 1885, Mathematician Oliver Heaviside had termed magnetic permeability as μ.
- The relation between B and H is directly proportional, i.e.,

$$B \propto H$$

$$B = \mu H$$

where, μ is the proportional constant of that material or medium and it is termed as magnetic permeability. Hence we can write

$$\mu = \frac{B}{H}$$

- So, in other word magnetic permeability is defined as the ratio of magnetic flux density (B) of a material to its electro-magnetizing force (H).
- The unit of Electromagnetic Permeability is Henry/meter or Newton/sq-ampere.
- Permeability in free pace is denoted as μ_0. Its value is $4 ? \times 10^{-7}$ H/m. This value of permeability is taken as standard value that is treated as permeability constant.
- Permeability of another medium or substance is denoted as μ only.

(viii) Relative Permeability

Relative permeability is the ratio of permeability of any substance to that of free space and it is denoted as μ_r, i.e.,

$$\mu_r = \frac{\mu}{\mu_0}$$

So, permeability of any medium or material is

$$\mu = \mu_r \mu_0$$

Q. 5. What is Faraday's laws of electromagnetic induction?

Ans.

First Law

First Law of Faraday's Electromagnetic Induction state that whenever a conductor are placed in a varying magnetic field emf are induced which is called induced emf, if the conductor circuit are closed current are also induced which is called induced current.

Second Law

Second Law of Faraday's Electromagnetic Induction state that the induced emf is equal to the rate of change of flux linkages (flux linkages is the product of turns, n of the coil and the flux associated with it).

$$e = -N \frac{d\phi}{dt}$$

Q. 7. What do you mean by static and dynamic induced emf?

Ans. **Statically Induced EMF**

The emf induced in a coil due to change of flux linked with it (change of flux is by the increase or decrease in current) is called statically induced emf.

Transformer is an example of statically induced emf. Here the windings are stationary, magnetic field is moving around the conductor and produces the emf.

Dynamically Induced EMF

The emf induced in a coil due to relative motion of the conductor and the magnetic field is called dynamically induced emf.

dc generator works on the principle of dynamically induced emf in the conductors which are housed in a revolving armature lying within magnetic field.

Q. 8. State the following

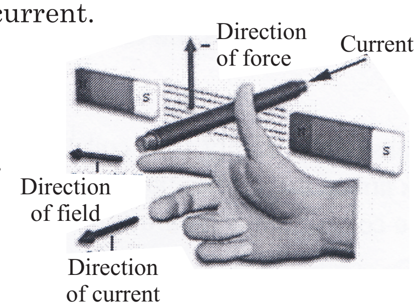
(i) Fleming's right hand rule

(ii) Fleming's left hand rule

(iii) Lenz's law

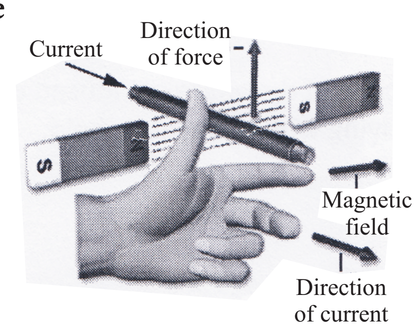
Ans. **Fleming's right hand rule**

- As per Faraday's law of electromagnetic induction, whenever a conductor moves inside a magnetic field, there will be an induced current in it. If this conductor gets forcefully moved inside the magnetic field, there will be a relation between the direction of applied force, magnetic field and the current.
- This relation among these three directions is determined by Fleming Right Hand Rule This rule states "Hold out the right hand with the first finger, second finger and thumb at right angle to each other. If forefinger represents the direction of the line of force, the thumb points in the direction of motion or applied force, then second finger points in the direction of the induced current.



Fleming's left hand rule

- It is found that whenever an current carrying conductor is placed inside a magnetic field, a force acts on the conductor, in a direction perpendicular to both the directions of the current and the magnetic field.
- Hold out your left hand with forefinger, second finger and thumb at right angle to one another. If the force finger represents the direction of the



field and the second finger that of the current, then thumb gives the direction of the force.

Lenz's Law

Lenz law states that induced current always develops a flux which opposes the very cause it is due to

Or

When an emf is induced in a circuit electromagnetically the current set up always opposes the motion or change in current which produces it.

Q. 9. What is the differentiate between Mutual Inductance and Self Inductance. What is Inductance?

Ans. Self Inductance is the property of a single isolated coil, to induce an emf in it, in accordance with the change in magnetic flux linked with it. The value of self inductance of a coil is given by,

$$L = \mu_0 \mu_r n^2 \frac{A}{l}$$

where, A is the area of cross section of the coil, n is the total number of turns of the coil and l is the length of the coil.

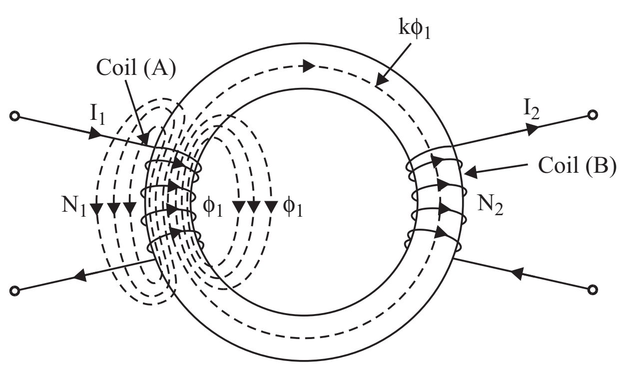
Mutual inductance of a pair is the ability one coil to produce an induced emf in a nearby coil, when the magnetic flux linked with it changes. It depends on the self inductances of each coils and the orientation of the coils and the separation between the coils.

Inductance is a property of an electric circuit or component which causes an e.m.f. to be generated in it (self inductance) or in the neighboring circuit (mutual inductance) due to the change in the current flowing through the circuit.

Q. 10. What is coefficient of coupling and derive the expression for coefficient of coupling between two coils.

Ans. The fraction of magnetic flux produced by the current in one coil that links with the other coil is called coefficient of coupling between the two coils. It is denoted by (k).

Two coils are taken coil A and coil B, When current flows through one coil it produces flux; the whole flux may not link with the other coil coupled, and this is because of leakage flux by a fraction (k) known as **Coefficient of Coupling**.



$k = 1$ when the flux produced by one coil completely links with the other coil and is called magnetically tightly coupled.

$k = 0$ when the flux produced by one coil does not link at all with the other coil and thus the coils are said to be magnetically isolated.

Consider two coils having self inductance L_1 and L_2 placed very close to each other. Let the number of turns of the two coils be N_1 and N_2 respectively. Let coil 1 carries current i_1 and coil 2 carries current i_2

$$N_1\phi_1/i_1 = \text{Self induced of coil } 1 = L_1$$

$$N_2\phi_2/i_2 = \text{Self induced of coil } 2 = L_2$$

Due to current i_1, the flux produced is ϕ_1 which links with both the coils. Then from the previous knowledge mutual inductance between two coils can be written as

$$Mi_1 = (k\phi_1)\, N_1$$

is the part of the flux ϕ_1 linking with coil 2.

$$\therefore \qquad M = N_2(k_1\phi_1)/i_1 \qquad \ldots(1)$$

Similarly due to current i_2, the flux produced is ϕ_2 which links with both the coils. Then the mutual inductance between two coils can be written as

$$Mi_2 = (k\phi_2)\, N_1 \qquad \ldots(2)$$

where $k\phi_2$ is the part of the flux ϕ_2 linking with coil 1.

$$\therefore \qquad M = N_1(k_2\phi_2/i_2)$$

Multiplying equations (1) and (2)

$$M^2 = \frac{N_2(k_1\phi_1)}{i_1}\cdot\frac{N_1(k_2\phi_2)}{i_2}$$

$$\therefore \qquad M^2 = k_1k_2\left[\frac{N_1\phi_1}{i_1}\right]\left[\frac{N_2\phi_2}{i_2}\right]$$

$$\therefore \qquad M^2 = k_1k_2L_1L_2$$

$$\therefore \qquad M = \sqrt{(k_1k_2)}\,\sqrt{(L_1L_2)}$$

Let $k = \sqrt{(k_1k_2)}$

$$\therefore \qquad M = k\sqrt{(L_1L_2)}$$

where k is called coefficient of coupling.

$$\therefore \qquad k = \frac{M}{\sqrt{(L_1L_2)}}$$

the mutual inductance between the two coils is maximum with $k = 1$. The maximum value of the mutual inductance is given by

$$M = \sqrt{(L_1L_2)}$$

Q. 11. Compare electric and magnetic ckts showing similarities and dissimilarities.

Or

Describe the analogies that can be made between electric and magnetic ckts regarding the following items.

Driving force, fiel intensity, impeance, drop, equivalent ckt. ***[UPTU 2013, 17]***

Ans. **Similarities**

Definition	Magnetic ckt	Electric ckt
	Closed path following by magnetic flux	Closed path followed by electric current
Driving force	MMF is required to establish magnetic flux measured in Ampere-turn	EMF is required to flow of current measured in Volt
Response	Flux $= \dfrac{\text{MMF}}{\text{Reluctance}}$	Current $= \dfrac{\text{EMF}}{\text{Reluctance}}$
Impedance	Reluctance $S = \dfrac{1}{\mu A}$	Resistance $R = \rho \dfrac{1}{A}$
Series connection	$S_{eq} = S_1 + S_2 + S_3 + \dots$	$R_{eq} = R_1 + R_2 + R_3 + \dots$
Parallel connection	$S_{eq} = \dfrac{1}{\dfrac{1}{S_1} + \dfrac{1}{S_2} + \dfrac{1}{S_3}}$	$S_{eq} = \dfrac{1}{\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}}$
Density	Flux density $B = \mu H$	Current Density $J = \sigma E$
Drop	MMF drop $F = \phi S$	Voltage drop $V = IR$

Dissimilarities

Magnetic ckt	Electric ckt
Flux does not flow in magnetic ckt	Current flow in magnetic ckt
Flux can pass through air	Air can not pass through air
Residual flux present after removal of MMF	Current is reduced to zero after removal of source of EMF
Reluctance stores energy.	Resistance dissipates energy.

Q. 12. How is BH curve of a ferromagnetic material different from that of non-magnetic material?

Or

What is hysteresis loop & what information is obtained from this loop? Draw hysteresis loop for

(i) Permanent magnet

(ii) Transformer core

(iii) Ferrite

Or

Draw and explain hysteresis loop. What is its significance?

[UPTU 2012, 16, 17]

Ans. Hysteresis loop is a four quadrant $B-H$ graph from where the hysteresis loss, coercive force and retentively of *s* magnetic material are obtained. To understand hysteresis loop, we suppose to take a magnetic material to use as a core around which insulated wire is wound. The coils is connected to the supply (DC) through variable resistor to vary the current *l*. We know that current *l* is directly proportional to the value of magnetizing force (H) as

$$H = \frac{NI}{l}$$

where, N = no. of turn of coil and *l* is the effective length of the coil. The magnetic flux density of this core is B which is directly proportional to magnetizing force H.

Step 1 : When supply current $l = 0$, so no existence of flux density (B) and magnetizing force (H). The corresponding point is '*O*' in the graph above.

Step 2 : When current is increased from zero value to a certain value, magnetizing force (H) and flux density (B) both are set up and increased following the path $0-a$.

Step 3 : For a certain value of current, flux density (B) becomes maximum $(B_{\max})$. The point indicates the magnetic saturation or maximum flux density of this core material. All element of core material get aligned perfectly. Hence $H_{\max}$ is marked on H axis. So no change of value of B with further increment of H occurs beyond point '*a*'.

Step 4 : When the value of current is decreased from its value of magnetic flux saturation, H is decreased along with decrement of B not following the previous path rather following the curve $a-b$.

Step 5 : The point '*b*' indicates $H = 0$ for $l = 0$ with a certain value of B. This lagging of B behind H is called hysteresis. The point '*b*' explains that after removing of magnetizing force (H), magnetism property with little value remains in this magnetic material and it is known as residual magnetism (B_r). Here $o-b$ is the value of residual flux density due to retenstivity of the material.

Step 6 : If the direction of the current *l* is reversed, the direction of H also gets reversed. The increment of H in reverse direction following path $p-c$ decreases the value of residual magnetism (B_r) that gets zero at point '*c*' with certain negative value of H. This negative value of H is called coercive force (H_c).

Step 7 : H is increased more in negative direction further; B gets reverse following path $c-d$. At point '*d*', again magnetic saturation takes place but in opposite direction with respect to previous case. At point '*d*', again magnetic saturation takes place but in opposite direction with respect to previous case. At point '*d*', B and H get maximum values in reverse direction, i.e., $(-B_m$ and $-H_m)$.

Step 8 : If we decrease the value of H in this direction, again B decreases following the path de. At point '*e*', H gets zero valued but B is with finite value. The point '*e*' stands for residual magnetism $(-B_r)$ of the magnetic core material in opposite direction with respect to previous case.

Step 9 : If the direction of H again reversed by reversing the current l, then residual magnetism or residual flux density $(-B_r)$ again decreases and gets zero at point 'f' following the path $e-f$. Again further increment of H, the value of B increases from zero to its maximum value or saturation level at point a following path $f-a$.

The path $a-b-c-d-e-f-a$ forms hysteresis loop.

Now, we should be bamiliar with some important terms related to hysteresis Loop.

Definition of Hysteresis

Hysteresis of a magnetic material is a property by virtue of which the flux density (B) of this material lags behind the magnetizing force (H).

Definition of Coercive Force

Coercive force is defined as the negative value of magnetizing force $(-H)$ that reduces residual flux density of a material to zero.

Residual Flux Density

Residual flux density is the certain value of magnetic flux per unit area that remains in the magnetic material without presence of magnetizing force (i.e., $H=0$).

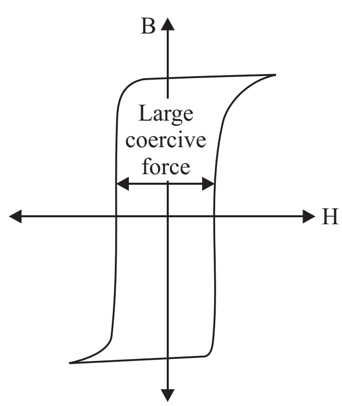
Definition of Retentivity

It is defined as the degree to which a magnetic material gains its magnetism after magnetizing force (H) is reduced to zero. Now, let us proceed step by step to make a clear idea about hysteresis loop.

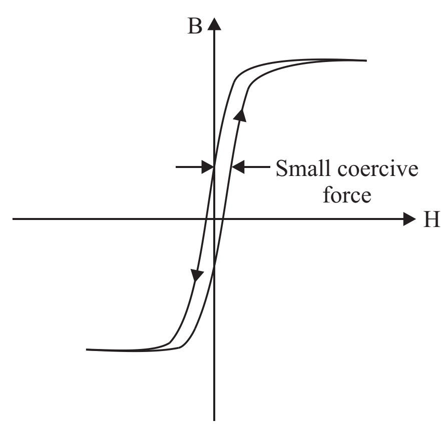
Importance of Hysteresis Loop

The main advantages of hysteresis loop are given below.

1. Smaller hysteresis loop area symbolizes less hysteresis loss.
2. Hysteresis loop provides the value of retentivity and coercivity of a material. Thus are way to choose perfect material to make permanent magnet, core of machines becomes easier.



Hysteresis curve of Hand magnetic material



Hysteresis curve of Soft magnetic material

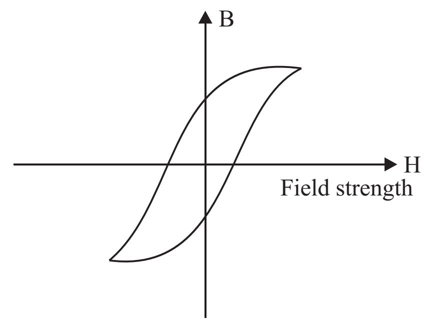
3. From $B - H$ graph, residual magnetism can be determined and thus choosing of material for electromagnets is easy.
4. Hysteresis curve of Hard magnetic material Hysteresis curve of Soft magnetic material

Q. 13. Prove that hysteresis loss is obtained from $B - H$ curve.

Or

How to calculate hysteresis loss from $B - H$ curve.

Ans. We know that flux density



$$B = \mu H$$
$$B = \mu \frac{NI}{l}$$
$$\therefore \quad I = \frac{Bl}{\mu N}$$

Voltage induced in coil

$$V = N\frac{d\phi}{dt} = N\frac{d}{dt}(BA)$$
$$= NA = \frac{dB}{dt}$$

Instantanous energy

$$dE = VI\ dt$$
$$= NA\frac{dB}{dt} \times \frac{Bl}{\mu N}\ dt \text{ Joules}$$
$$= \frac{NAlB\ dB}{\mu N}$$
$$dE = V\left(\frac{B}{\mu}\right) dB \qquad [V = Al \Rightarrow \text{Volume}]$$
$$dE = VH\ dB$$
$$\int dE = \int VH\ dB$$
$$E = V\int H\ dB$$

Energy per unit volume

$$E_h = \int H \cdot dB \Rightarrow \text{for one cycle}$$
$$\Downarrow$$
$$\text{Area under the } B - H \text{ curve}$$
$$E_h = \int H \cdot dB = \int \frac{B}{\mu}\ dB = \frac{1}{2}\frac{B^2}{\mu} = \frac{1}{2}BH$$

Corresponding Hysteresis Power Loss

$$P_h = \frac{E_h}{T} = \frac{1/2BH}{T}$$

$$P_h = \frac{1}{2} BHf$$

Q. 14. Explain hysteresis and eddy current loss. How are they minimize?

[UPTU 2014, 17]

Ans. Hysteresis loss During the complete cycle, the magnets within the magnetic material try to align first in one way and then in reverse way. The tendency to turn around of elementary magnets give rise to mechanical stresses in the magnetic material, which in turn produces heat which is a waste form of energy. The dissipitated heat energy during the cycle of magnetization is given by the area within the hysteresis loop and is called hysteresis loss.

Hysteresis power loss = $P_h = KfB_{\max}V$

where, K = Hysteresis coefficient

f = frequency of magnetization

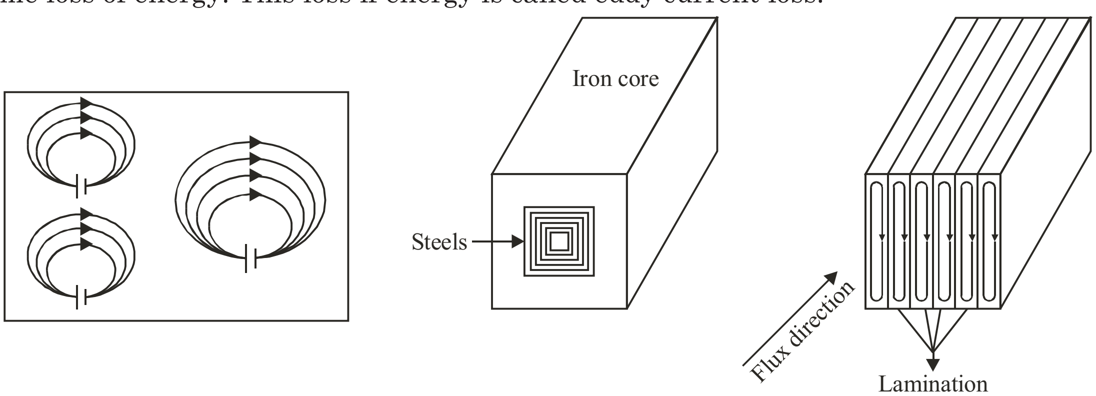
V = volume of the material (m^3)

$B_{\max}$ = Maximum flux density (wb/m^2)

$x = 1.5 - 2.5$

Eddy Current Loss

During the cycle of magnetization, the change in flux density induces an emf in the core of an electromagnet. The effect sets up small locally circulating currents called eddy currents. These currents are of no practical significance but produce heat which means some loss of energy. This loss if energy is called eddy current loss.



Eddy current loss

$$P_e = K_e t^2 f^2 B_{\max}^2 V$$

where, K_e = Eddy current constant

t = Thickness of the lamination of the pole core and armature

B = Flux density

F = Frequency

V = Volume of iron subject to change of flux

Q. 15. What do you mean by Core or Hysteresis loss? ***[UPTU 2014]***

Ans.

- Two Varying fluxes produce losses in form anegnetic materials, known as core losses or iron losses
- The core losses consist of
- Hysteresis loss
- Eddy current loss

$$P_{\max} = P_n + P_t$$

- These losses donot accur in forromagnetic cores that carry flux which does not vary with time.
- Both hysteresis K eddy current loss produce heat in magnetic ckt.
- Within an electric machine hysteresis μ eddy current losses occure simulation eausly.

Q. 16. What do mean by Leakage flux?

Ans.

- The part of the total magnetic flux which has its path wholly the magnetic ckt is called the useful magnetic flux.
- The magnetic flux having its path in air is called leakage magnetic flux.
- Total flux produced = useful flux + leakage flux.
- Leakage factor OR leakage coefficient

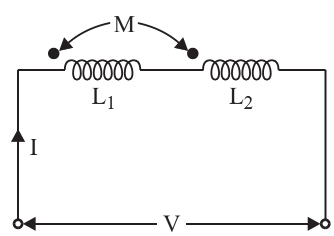
$$\lambda = \frac{\text{total flux produced}}{\text{useful flux}}$$

$$\lambda > 1 \text{ always}$$

Q. 17. Explain the calculation of series and parallel connected inductance with mutual inductance?

Ans.

Series Connection



$L_1 \rightarrow$ self inductance of coil-1

$L_2 \rightarrow$ self inductance of coil-2

$M \rightarrow$ mutual inductance between L_1 and L_2

- If current enters OR leaves in bath dot, the flux produced by one coil will be in same direction as other coil.
- If current enters in one dot while leaves to other doe OR vice-versa then flux produced by one coil will be in opposite direction as other coil.

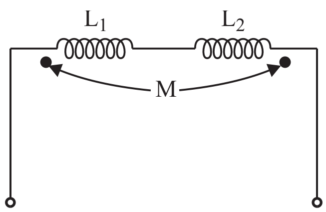
For Fig. 1

$$V - j\omega L_1 I - j\omega MI - j\omega L_2 I - j\omega MI = 0$$

$$\frac{V}{I} = j\omega[L_1 + L_2 + 2M]$$

$\therefore \quad L_{eq} = L_1 + L_2 + 2M$

For

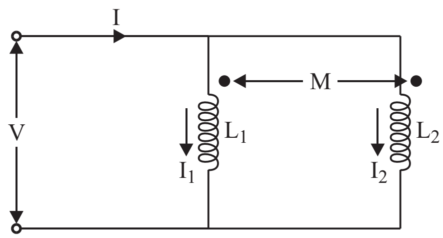


$$V - j\omega L_1 I + j\omega MI - j\omega L_2 I + j\omega MI = 0$$

$$\frac{V}{I} = j\omega[L_1 + l_2 - 2M]$$

$\therefore \quad L_{eq.} = L_1 + L_2 - 2M$

Parallel Connection



$$V = j\omega L_1 I_1 + j\omega MI_2$$

$$V = j\omega L_1 I_1 + j\omega M(I - I_1)$$

$$V = j\omega I_1(L_1 - M) + j\omega MI \quad \text{...(1)}$$

Also

$$V = j\omega L_2 I_2 + j\omega MI_1$$

$$V = j\omega L_2(I - I_1) + j\omega MI_1$$

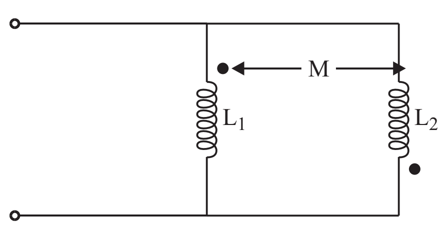
$$V = j\omega I_1(-L_2 + M) + j\omega L_2 I \quad \text{...(2)}$$

Using eqn. (1) and (2) eliminates I_1 and get

$$\frac{V}{I} = j\omega\left[\frac{L_1 L_2 - M^2}{L_1 + L_2 - 2M}\right]$$

$\therefore \quad L_{eq.} = \dfrac{L_1 L_2 - M^2}{L_1 + L_2 - 2M}$

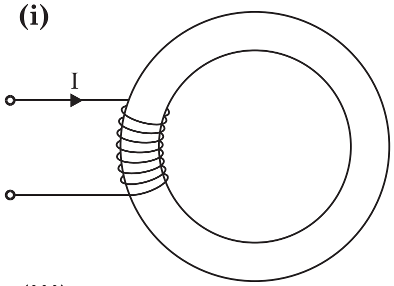
For



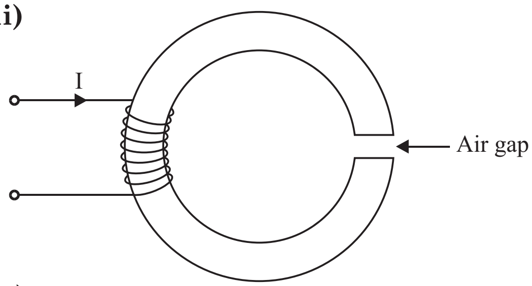
$$L_{eq.} = \frac{L_1 L_2 - M^2}{L_1 + L_2 - 2M}$$

Q. 18. Draw the equivalent electric ckt of following magnetic ckt using electric magnetic ckt analogy.

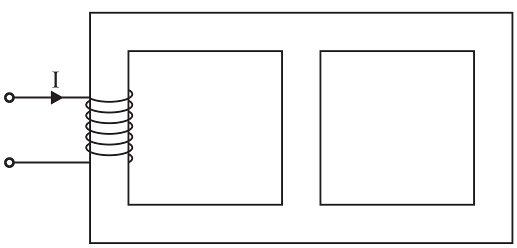
(i)



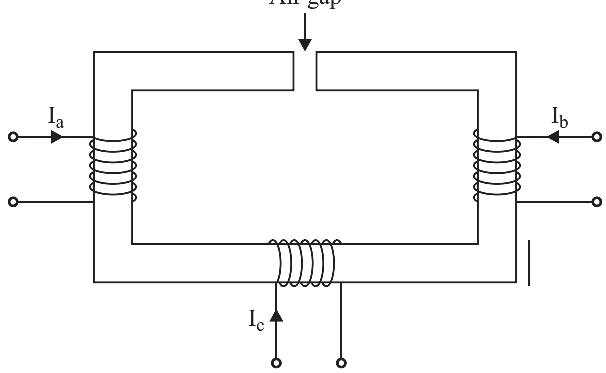
(ii)



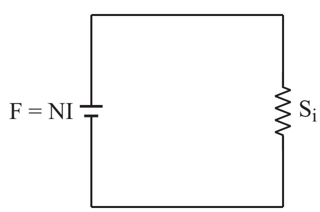
(iii)



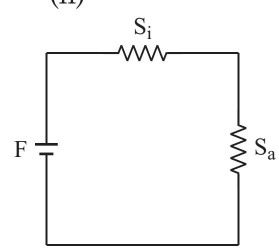
(iv)



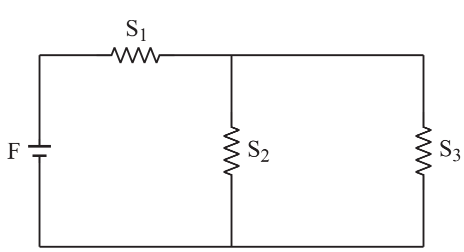
Ans. (i)



(ii)

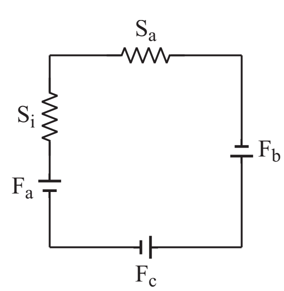


(iii)



$S_1 = S_3$

(iv)



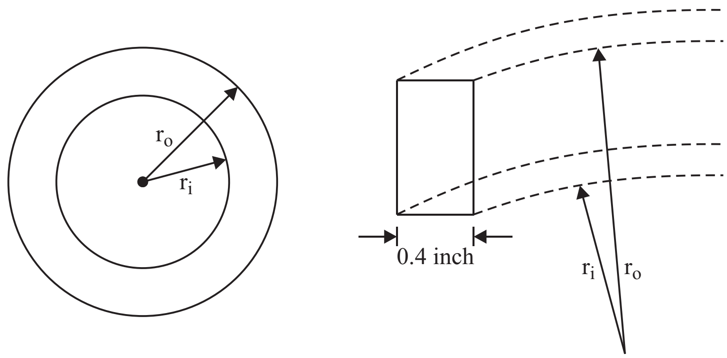
Q. 19. A ring of ferromagnetic material has cross-section. The inner diameter is 7.4 in the outer diameter is 9 inch and thickness is 0.8 inch. There is a coil of 600 turns worm on the ring. When coil carries a current 2.5 A, the flux produced in the ring is 1.2×10^3 find :

(1) Magnetic flux

(2) Reluctance

(3) Permeability *[UPTU 2013]*

Sol.



Given,

$$\text{Inner dia} = 7.4 \text{ inch}$$

$$\therefore \quad \text{Inner radius} = 3.7 \text{ inch}$$

$$r_i = 9.25 \times 10^{-2} \text{ m}$$

$$\text{Outer dia} = 9 \text{ inch}$$

$$\text{Inner radius} = 4.5 \text{ inch}$$

$$r_0 = 11.25 \times 10^{-2} \text{ m}$$

$$\therefore \quad \text{Mean length} = \frac{2\pi r_0 + 2\pi r_i}{2}$$

$$l = \frac{2\pi}{2}[11.25 + 9.25] \times 10^{-2}$$

$$= 64.37 \times 10^{-2} \text{ m}$$

Loss thickness = 0.8 inch = 2×10^{-2} m Cross section area = $(r_0 - r_i) \times 2 \times 10^{-2}$

$$a = (11.25 - 9.25) \times 10^{-2} \times 2 \times 10^{-2}$$

$$= 4 \times 10^{-4} \text{ m}^2$$

(i) $\therefore$ Magnetic flux density

$$B = \frac{\phi}{a} = \frac{1.2 \times 10^{-3}}{4 \times 10^{-4}}$$

$$= 3 \text{ Wb/m}^2$$

(ii) Reluctance

$$S = \frac{MMF}{\phi} = \frac{NI}{\phi}$$

$$= \frac{600 \times 2.5}{1.2 \times 10^{-3}}$$

$$= 1250 \times 10^{3} \text{ AT/Wb}$$

(iii) Permeability

$\because$
$$S = \frac{l}{\mu a}$$

$$\mu = \frac{l}{Sa}$$

$$= \frac{64.37 \times 10^{-2}}{1250 \times 10^{3} \times 4 \times 10^{-4}}$$

$$= 0.001287 \text{ H/m}$$

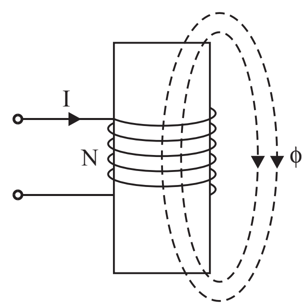
$\therefore$
$$\mu_r = \frac{\mu}{\mu_0} = \frac{0.001287}{4\pi \times 10^{-7}} = 1019$$

Q. 20. Derive the expression for inductance of a coil.

Ans. Let flux link with 1 turn = ϕ

$\therefore$ flux link with total turn i.e.,

Linkage flux



$$\psi = N\phi$$

$l \rightarrow$ Mean length of magnetic path

$A \rightarrow$ Area cross-section

We know that
$$\phi = \frac{MMF}{S}$$

$$= \frac{NI}{S} = \frac{NI}{\frac{l}{\mu A}}$$

$\therefore$
$$\phi = \frac{NI\mu A}{l}$$

$\therefore$
$$\psi = N \times \frac{NI\mu A}{l}$$

$$\psi = \frac{N^2 \mu A}{l} I$$

$$\psi = LI$$

L is constant
$$L = \frac{N^2 \mu A}{l}$$

$$\psi = LI \text{ and } \psi = N\phi$$

$$\therefore \quad N\phi = LI$$

by faraday's law

$$\text{Induced EMF} = |e| = \frac{d\psi}{dt} = \frac{d}{dt}(N\phi)$$

$$= \frac{d}{dt} LI = L\frac{dI}{dt}$$

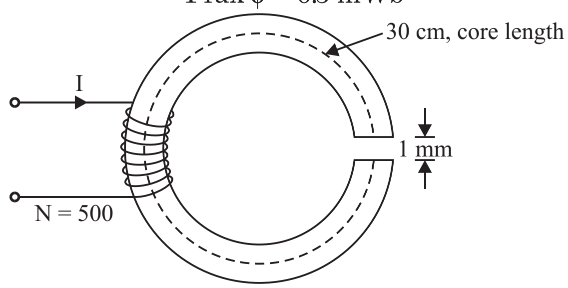
$$\therefore \quad e = L\frac{dI}{dt}$$

Q. 21. A wrough iron bar 30 cm long and 2 cm indiameter is bent in to a circular shape as shown in fig. It is then wound with 500 turns of wire. Calculate the current required to produce a flux of 0.5 mWb in magnetic ckt with an air gap of 1 mm (μ_{iron} = 4000).

Sol. **Relative permiability of Iron**

Given

Flux $\phi = 0.5$ mWb



$= 0.5 \times 10^{-3}$ Wb

dia of iron bar $= d = 2$ cm

Length of iron $\quad l_i = 30 \text{ cm} = 30 \times 10^{-2}$ m

Length of air gap $\quad l_a = 1 \text{ mm} = 1 \times 10^{-3}$ m

Area of cross section of iron bar and air gap

$$a = \pi r^2$$

$$= \pi \left(\frac{d}{2}\right)^2$$

$$= 3.14 \left(\frac{2 \times 10^{-2}}{2}\right)^2 = 3.14 \times 10^{-4} \text{ m}^2$$

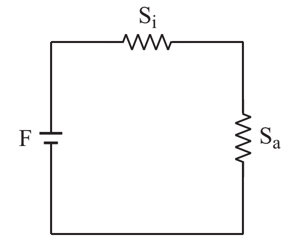
Equivalent electric ckt

Reluctance of iron bar

$$S_i = \frac{l_i}{\mu a}$$

$$= \frac{30 \times 10^{-2}}{\mu_r \mu_0 \times a} = \frac{30 \times 10^{-2}}{4000 \times \mu_0 a}$$

$$= \frac{7.5 \times 10^{-5}}{\mu_0 a}$$



Reluctance of air gap

$$S_a = \frac{l_a}{\mu_0 a} = \frac{1 \times 10^{-3}}{\mu_0 \times a}$$

$$\text{Total Reluctance } S = S_i + S_a = \frac{7.5 \times 10^{-5}}{\mu_0 a} + \frac{1 \times 10^{-3}}{\mu_0 a}$$

$$= \frac{7.5 \times 10^{-5} + 10^{-3}}{4\pi \times 10^{-7} \times 3.14 \times 10^{-4}}$$

$$= 2.72 \times 10^{6} \text{ AT/Wb}$$

$\because$

$$F = \phi S$$

$$NI = \phi S$$

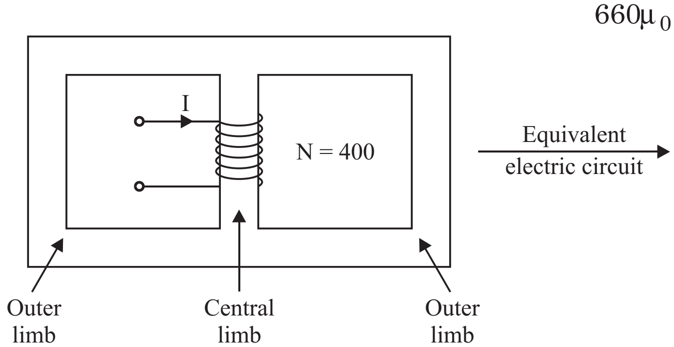
$$I = \frac{\phi S}{N} = \frac{0.5 \times 10^{-3} \times 2.72 \times 10^{6}}{500}$$

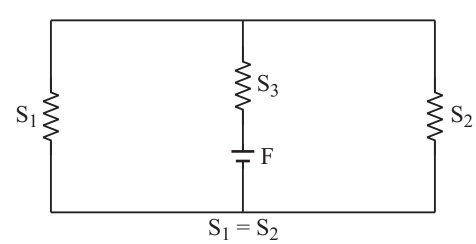
$$= 2.72 \text{ Amp}$$

Q. 22. A magnetic frame is made up of case steel. The winding having 400 turns is placed on central limb having cross sectional area of 10 cm^2. Area of outer limb is 8 cm^2 Calculate the current required in the central limb to set up a flux of 1.4 mWb in the central limb. The length of mean flux path is central core is 15 cm and each of outer frame is 35 cm. Permeability is 660. Neglect leakage and fringing.

Sol. Reluctance of outer limb $S_1 = S_2 = \dfrac{l}{\mu a}$

$$= \frac{35 \times 10^{-2}}{660\mu_0 \times 8 \times 10^{-2}}$$





$$= \frac{0.67}{\mu_0}$$

Reluctance of central limb $S_3 = \frac{l}{\mu a} = \frac{15 \times 10^{-2}}{660\mu_0 \times 10 \times 10^{-2}}$

$$= \frac{0.23}{\mu_0}$$

∴ Total Reluctance $S = \left(\frac{S_1 S_2}{S_1 + S_2}\right) + S_3$

$$= \left(\frac{S_1}{2}\right) = S_3 \qquad [\because S_1 = S_2\ S_1 \parallel S_2]$$

$$= \left(\frac{0.67/\mu_0}{2}\right) + \frac{0.23}{\mu_0}$$

$$= 450 \times 10^3 \qquad [\because \mu_0 = 4\pi \times 10^{-2}]$$

∵ $F = \phi S$

$$NI = \phi S$$

$$I = \frac{\phi S}{N} = \frac{1.4 \times 10^{-3} \times 450 \times 10^3}{400} = 1.575 \text{ amp}$$

Q. 23. A cast steel electromagnet has an air gap length of 3 mm and iron path of length 40 cm. Find the no. of ampere-turn necessary to produce a flux density of 0.7 Wb/m^2 in gap. Neglect leakage and fringing. Assume A-T required for air gap to be 70% of the total A-T. ***[UPTU 2001]***

Ans. A-T in air gap $F_a = \phi_a S_a$

$$= \phi_a \frac{l_a}{\mu_0 a}$$

$$= \left(\frac{\phi_a}{a}\right)\frac{l_a}{\mu_0}$$

$$= (B_a)\frac{l_a}{\mu_0}$$

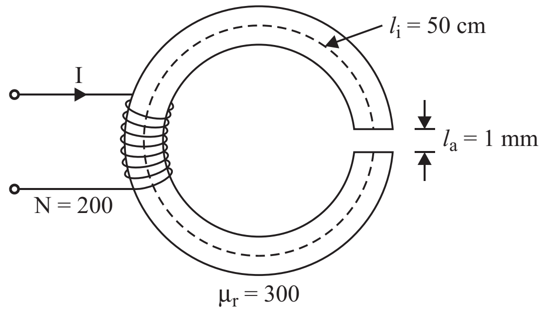
$$= 0.7 \times \frac{3 \times 10^{-3}}{4\pi \times 10^{-7}} \text{ A-T}$$

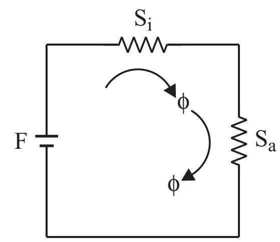
∵ 70% of total A-T = A-T in air gap

$$0.7 \times F_{\text{total}} = 0.7 \times \frac{3 \times 10^{-3}}{4\pi \times 10^{-7}}$$

$$F_{\text{Total}} = 2388 \text{ A-T}$$

Q. 24. An iron ring of mean length 50 cm and relative permeability 300 has an air gap of 1 mm. If the ring is provided with a wind of 200 turns and a current of 1 A is allow to flow through, find the flux density across the air gap. *[UPTU 2001]*





Sol.

$$F = \phi(S_1 + S_2)$$

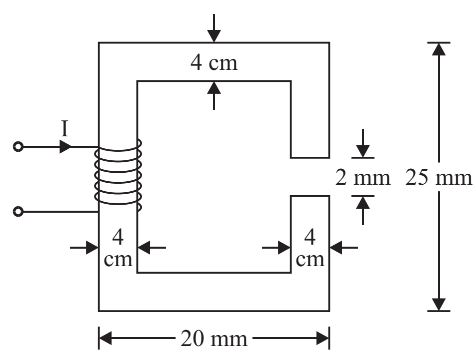
$$NI = \phi\left(\frac{l_i}{\mu_r \mu_0 a} + \frac{l_a}{\mu_0 a}\right)$$

$$200 \times 1 = \left(\frac{\phi}{a}\right)\left(\frac{l_i}{\mu_r} + l_a\right)\frac{1}{\mu_0}$$

$$200 = B\left(\frac{50 \times 10^{-2}}{300} + 1 \times 10^{-3}\right)\frac{1}{4\pi \times 10^{-7}}$$

$$B = 0.0942 \text{ Wb/m}^2$$

Q. 25. A rectangular magnetic core shown in fig has square cross-section are of 16 cm^2. An air gap of 2 mm is cut across one of its limbs. Find the exciting current needed in the coil having 1000 turns mand on the core to create an air gap flux of 4 mWb. The relative permeability of the core is 2000. *[UPTU 2002]*



Ans. Area of cross-section

$$a = 16 \text{ cm}^2$$

$\because$ Area of cross-section is square

$$\therefore \quad \text{Thickness of core} = \sqrt{16} = 4 \text{ cm}$$

Outer length of iron core = 20 cm

Inner length of iron core = 20 − 4 − 4 = 12 cm

$$\therefore \quad \text{Mean length} = \frac{20 + 12}{2} = 16 \text{ cm}$$

Outer width of iron core = 25 cm

$$\text{Inner midth of iron core} = 25 - 4 - 4 = 17\,\text{cm}$$

$$\text{Mean midth} = \frac{25+17}{2} = 21\text{ cm}$$

$\therefore$ Total mean length of magnetic path with air gap $= 2(l + b) = 2(16 + 21)$

$$= 74\text{ cm}$$

$\because$ Length of air gap $= 1\text{ mm} \times 10^{-3}\text{ m}$

$\therefore$ Mean length of rectangular iron core

$$l_i = 74 \times 10^{-2} - 1 \times 10^{-3}$$

$$= 73.8 \times 10^{-2}\text{ m}$$

Total Reluctance $S = S_i + S_a$

$$= \frac{l_i}{\mu_r \mu_0 a} + \frac{l_a}{\mu_0 a}$$

$$= \frac{1}{\mu_0 a}\left(\frac{l_i}{\mu_r} + l_a\right)$$

$$= \frac{1}{4\pi \times 10^{-7} \times 16 \times 10^{-4}}\left(\frac{73.8 \times 10^{-2}}{2000} + 2 \times 10\right)$$

$$= 1.18 \times 10^{6}\text{ AT/Wb}$$

$\because$

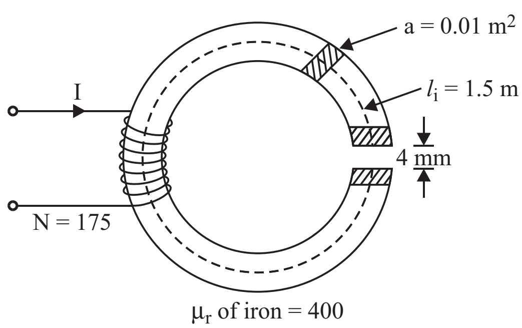
$$F = \phi S$$

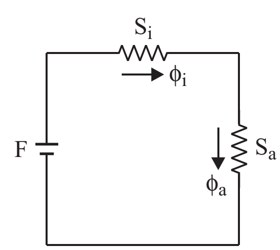
$$NI = \phi S$$

$$I = \frac{\phi S}{N}$$

$$= \frac{4 \times 10^{-3} \times 1.18 \times 10^{6}}{1000} = 4.72\text{ amp}$$

Q. 26. A circular iron ring has a mean circum forcence of 1.5 m and a cross-section area of 0.01 cm^2. A saw cut of 4 mm wite is made in the ring. Calculate the magnetising current required to produce a flux of 0.8 mWb in the air gap if the ring is wound with a coil of 175 turns. Assume realative permeability of iron as 400 and leakage factor 1.25.





Sol. Flux in air gap $\phi_a = 0.8$ mWb

$$\text{Leakage factor } \lambda = \frac{\phi_i}{\phi_a}$$

$$1.25 = \frac{\phi_i}{0.8} \Rightarrow \phi_i = 1 \text{ mWb}$$

$$F = \phi_i S_i + \phi_a S_a$$

$$= 1 \times \frac{1.5}{400\mu_0 a} + 0.8 \times \frac{4 \times 10^{-3}}{\mu_0 a}$$

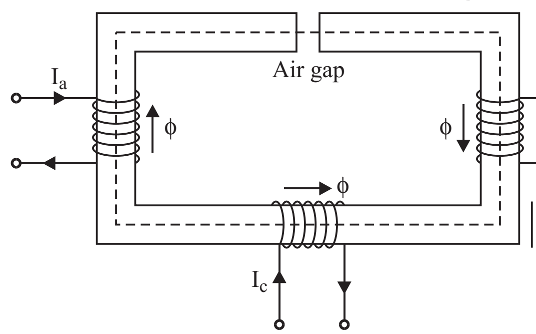
$$= \left(\frac{1.5}{400} + 0.8 \times 4 \times 10^{-3}\right)\frac{1}{\mu_0 a}$$

$$= (6.95 \times 10^{-3}) \frac{1}{4\pi \times 10^{-7} \times 0.01}$$

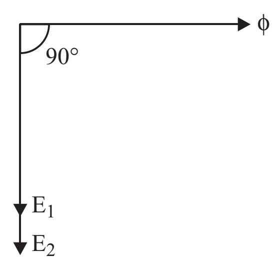
$$NI = 553.3$$

$$I = \frac{5533}{N} = \frac{5533}{175} = 3.16 \text{ amp}$$

Q. 27. A rectangular iron core is shown in fig. It has mean length of magnetic path of 100 cm, cross-section of 2 cm × 2 cm, relative permeability of 1400 and an air-gap of 5 mm cut in the core. The three coils carried by the core have no. of turns $N_a = 335$, $N_b = 600$ and $N_c = 600$ and the respective currents are 1.6 A, 4 A and 3 A. The direction of currents are as shown in fig. Find the flux in the air gap.



Ans. Equivalent electric ckt of above ckt.



$$(F_a + F_b - F_c) = \phi(S_i + S_a)$$

$$\therefore \quad \phi = \frac{F_a + F_b - F_c}{S_i + S_a}$$

$$= \frac{335 \times 1.6 + 600 \times 4}{1136 \times 10^4}$$

$$= 1 \times 10^{-4} \text{ Wb}$$

$$= 100\ \mu\text{Wb}$$

$$S_i = \frac{l}{\mu a}$$

$$= \frac{100 \times 10^{-2}}{1400\mu_0 a}$$

$$S_a = \frac{5 \times 10^{-3}}{\mu_0 a}$$

$$S_i + S_a = \frac{1}{\mu_0 a}\left(\frac{100 \times 10^{-2}}{1400} + 5 \times 10^{-3}\right)$$

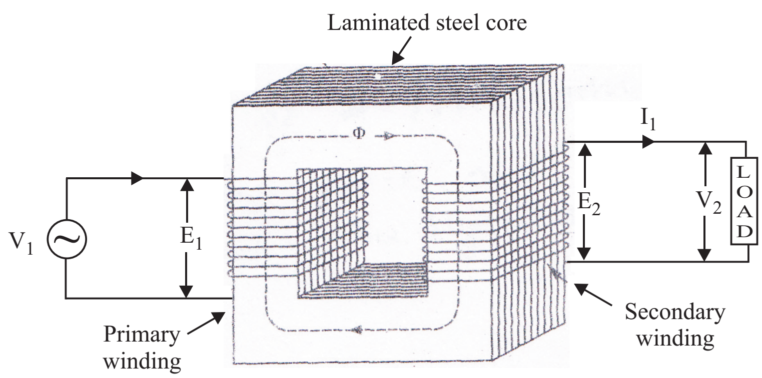
$$= \frac{1}{4\pi \times 10^{-7} \times 2 \times 2 \times 10^{-4}}(5.7 \times 10^{-3})$$

$$= 1136 \times 10^4$$

Q. 28. Write the short note on transformer.

Ans.

- Transformer is a static machine which transfer electrical energy from one ckt to another ckt at constant frequency.
- Transformer is a static machine used usually either for raising or lowering the voltage of an a.c. supply with a corresponding decrease OR increase in ckt.



- A transformer essentially consists of two windings, the primary and secondary. Wound on a common laminated magnetic core as shown in figure.
- The winding connected to the a.c. source is called primary minding and the one connected to load is called secondary winding.

$V_1 \rightarrow$ Primary terminal voltage

$V_2 \rightarrow$ Secondary terminal voltage

$N_1 \rightarrow$ No. of turn of primary winding

$N_2 \rightarrow$ No. of turn of secondary winding

$E_1 \rightarrow$ Induced E.M.F. in primary winding

$E_2 \rightarrow$ Induced E.M.F. in Secondary winding

Q. 29. What is the working principle of operation of 1-ϕ transformer.
[AKTU 2015-16]

Ans. Working principle of T/F is based on mutual inductance between two coils wound on the same core.

When an alternating voltage V_1 is applied to the primary, an atternating flux ϕ is set-up in the core. This alternating flux links both the windings is induced emfs E_1 and E_2 in them according to Faraday's law of electromagnetic inductin.

Magnitude of E_1 and E_2 depend up on no. of turns in primary and secondary winting respectively.

$$E_1 = -N_1 \frac{d\phi}{dt} \text{ and } E_2 = -N_2 \frac{d\phi}{dt}$$

Q. 30. What is condition for step-up and step down transformer?

Sol. If

$$N_2 > N_1$$
$$E_2 > E_1$$
$$\Downarrow \quad \text{We get a step-up transformer}$$
$$V_2 > V_1$$

if

$$N_2 < N_1$$
$$E_2 < E_1$$
$$\Downarrow \quad \text{We get a step-down transformer}$$
$$V_2 < V_1$$

Q. 31. Discuss about the interconnection of 2 windings of 1-ϕ transformer.

Ans.

- There is no connection between primary and secondary winding.
- The two windings of T/F are magnetically coupled OR interlinked.
- The a.c. power is transferred from primary to secondary through magnetic flux.
- There is no change in frequence i.e., o/P power has the same freq. as the i/P power.

Q. 32. Derive the EMF equation of 1-ϕ transformer.

Or

Derive EMF equation of 1-ϕ transformer and obtained relation for secondary to primary winding voltage. ***[UPTU 2009-10, 2014-15, 10-11]***

Ans. Consider that an alternating voltage V_1 of frequency f is applied to the primary of T/F, the sinusoidal flux ϕ produced by the primary can be represented as :

$$\phi = \phi_m \sin \omega t$$

Induced E.M.F.

$$\begin{aligned}\rho &= -N \frac{d\phi}{dt} \\ &= -N \frac{d}{dt}(\phi_m \sin \omega t) \\ &= -N\omega\phi_m \cos \omega t \\ &= N\omega\phi_m \sin(\omega t - 90^\circ)\end{aligned}$$

$$\rho = E_m \sin(\omega t - 90°) \quad ...(1)$$

where

$$E_m = N\omega\phi_m$$

$$E_{rms} = \frac{E_m}{\sqrt{2}} = \frac{N\omega\phi_m}{\sqrt{2}} = \frac{N2\pi f\phi_m}{\sqrt{2}}$$

$\therefore$
$$E = 4.44Nf\phi_m$$

For primary

$$E_1 = 4.44N_1 f\phi_m$$

For secondary

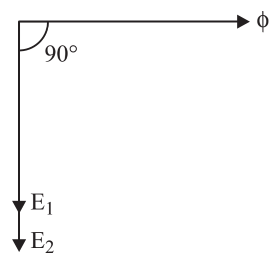
$$E_2 = 4.44N_2 f\phi_m$$

$\therefore$
$$\frac{E_1}{E_2} = \frac{N_1}{N_2}$$

In an ideal T/F $E_1 = V_1$ and $E_2 = V_2$

$\therefore$
$$\frac{E_1}{E_2} = \frac{V_1}{V_2} = \frac{N_1}{N_2}$$

It is clear from eqn. (1) that induced emfs in primary and secondary lag behind the flux ϕ by 90°.



Q. 33. What is transformer ratio?

Ans. From T/F equation

$$\frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{N_2}{N_1} = k$$

k is called T/F ratio

For iteal T/F, there is no loss

$\therefore$ Volt ampere in primary

= volt ampere in secondary

$$V_1 I_1 = V_2 I_2 \Rightarrow \frac{V_2}{V_1} = \frac{I_2}{I_2}$$

$\therefore$
$$\frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{I_2}{I_2} = \frac{N_2}{N_1} = k$$

Q. 34. Why can transformer not work on DC?

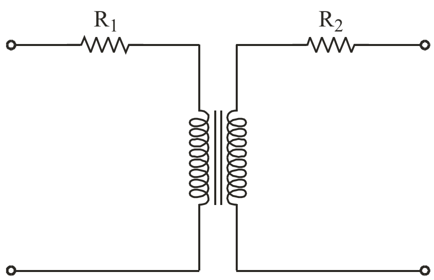
Ans.

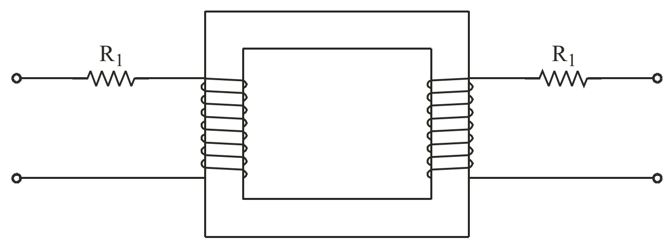
- A T/F can not operate on DC supply and never connect to DC source.
- When a dc voltage is applied to primary side, flux produced in care will not vary but remain constant.
- There is no induced EMF in primary and secondary windings.
- T/F is not capable raising OR lowering the dc voltage.

Q. 35. What is the winding resistance and leakage flux? ***[UPTU 2003-4]***

Ans. **Winding Resistance**

- Since the windings consist of copper conductors, therefore primary and secondary will have resistance are known as windings resistance.
- The effect of resistance is equivalent to an ideal T/F with resistance connected in series with each windings.





$R_1 \rightarrow$ winding resistance of primary

$R_2 \rightarrow$ winding resistance of secondary

Leakage flux

- In actual T/F, not all of the flux remains within the magnetic core, a portion of this flux is directed to the non-ferromagnetic material surrounding the windings (air).
- This is because the surrounding medium also has a finite permiability.
- These diverted flux are known as leakage fluxes.

Q. 36. What is properties of ideal transformer. ***[UPTU 2013-14]***

Ans. Primary and Secondary winding resistances are zero.

Core has ∞ permiability

Leakage fluxes are zero.

No losses in ideal T/F.

Q. 37. Explain the working of transformer on load. ***[UPTU 2005-06]***

Ans. Consider a practical T/F on no load i.e., secondary on open ckt

Secondary current $I_2 = 0$

$$\therefore \quad E_2 = V_2$$

The primary will draw a small current I_0 is known as no load current.

It is also known as exciting current.

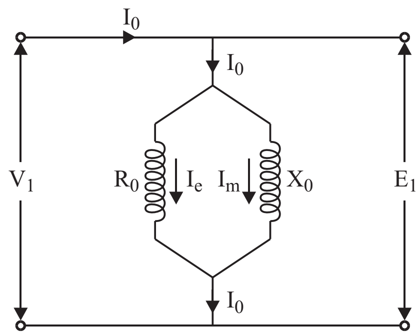
The no load primary current can be in to two component.

(i) I_m OR I_e In phase with the applied voltage V_1
This is known as active or working or iron loss component and supplies the iron loss and a very small primary copper loss.

(ii) I_m Lagging behind V_1 by 90° and is known as magnetising component. It produces the mutual flux ϕ in the core

$$\therefore \quad \vec{I}_0 = \vec{I}_e + \vec{I}_m$$

No. load equivalent ckt



$$R_0 = \frac{V_1}{I_e}$$

$$R_0 = \frac{V_1}{I_m}$$

Resistance $R_0 \rightarrow$ represents the core loss

Reactance $X_0 \rightarrow$ represents a loss-free coil which pass I_m.

- No load primary copper loss $I_0^2 R_1$ is very small is may be neglected.
- No load primary *i/f* power is practically equal to the iron loss [core loss] in the core of *T/F*

i/P power on no load

$$P_0 = V_1 I_0 \cos\phi_0 \rightarrow \text{iron OR core loss}$$

$\phi_0 \rightarrow$ Phase angle also known as hysteresis angle.

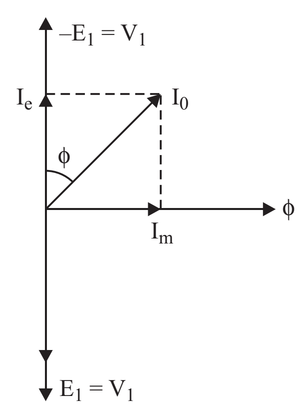
Q. 38. Draw the phasor diagram of transformer on load. ***[UPTU 2009-10, 13-14]***

Sol.

$$\phi = \phi_m \sin\omega t$$

$$e_1 = E_{m_1} \sin(\omega t - 90^\circ)$$

$$e_2 = E_{m_2} \sin(\omega t - 90^\circ)$$



On No-land

$$I_2 = 0$$

$$\therefore \quad E_2 = V_2$$

and due to I_0 is very small

$\therefore$ drop in primary winding is very small.

$\therefore \vec{V}_1 = -\vec{E}_1$ [voltage drop in winding can be neglected]

–ve sign represents induced emf E_1 is such a may so that it opposes V_1 [length law]

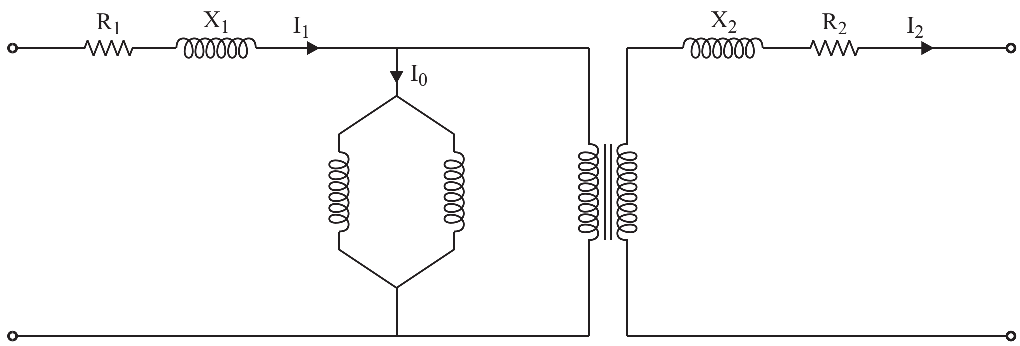
$$I_e = I_0 \cos\phi_0$$

$$I_m = I_0 \sin \phi_0$$
$$I_0 = \sqrt{I_e^2 + I_m^2}$$

Q. 39. Sketch the equivalent ckt diagram of practical transformer.

[UPTU 2013-14]

Ans.



Q. 40. What do you mean by shifting of impedances in transformer?

[UPTU 2013-14]

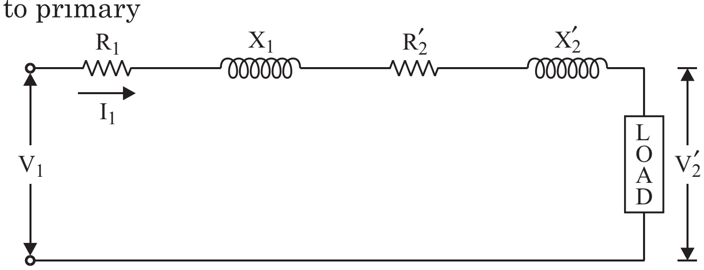
Or

Develop an equivalent ckt of 1-phase transformer as referred to primary and secondary side both.

Ans. **Shifting impedances in a *T/F***

Two independent ckts of *T/F* can be resolved in to an equivalent ckt to the calculation simple.

(i) Referred to primary



$$\text{Initial power} = \text{Final power}$$
$$I_2^2 R_2 = I_1^2 R_2^1$$
$$R_2^1 = \left(\frac{I_2}{I_1}\right)^2 R_2 = \frac{R_2}{k^2}$$

∴ Equivalent resistance referred to primary

$$R_{01} = R_1 + R_2^1$$

$$R_{01} = R_1 + \frac{R_2}{k^2}$$

Similarly $$X_{01} = X_1 + \frac{X_2}{k^2}$$

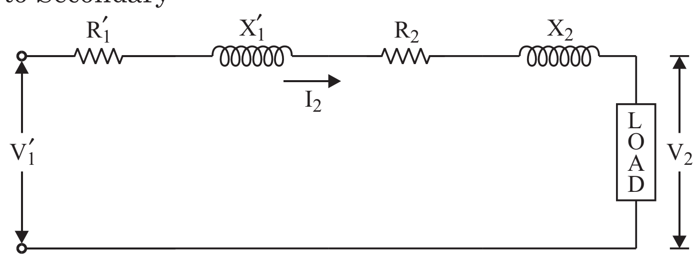
∴ $$Z_{01} = \sqrt{R_{01}^2 + X_{01}^2}$$

and $$V_2 I_2 = V_2^1 I_1$$

$$V_2^1 = \frac{I_2}{I_1} V_2$$

$$V_2^1 = \frac{V_2}{k}$$

(ii) Referred to Secondary



$$V_1 I_1 = V_1^1 I_2$$

$$V_1^1 = \frac{I_1}{I_2} V_1$$

$$V_1^1 = k V_1$$

$$I_1^2 R_1 = I_2^2 R_1^1$$

$$R_1^1 = \left(\frac{I_1}{I_2}\right)^2 R_1 = k^2 R_1$$

∴ Equivalent resistance referred to secondary

$$R_{02} = R_1^1 + R_2$$

$$R_{02} = R_2 + k^2 R_1$$

Similarly $$X_{02} = X_2 + k^2 X_1$$

and $$Z_{01} = \sqrt{R_{02}^2 + X_{02}^2}$$

Q. 41. Explain all losses in transformer in details. *[UPTU 2009-10, 13-14]*

Or

Decribe the power losses that take place in a transformer. On what factors and how do each of these losses depends?

Ans. **Transformer Losses**

T/F is a static machine and therefore, there are no friction or windage lasses.

The various lasses accuring in *T/F* are given below.

(i) Iron loss OR core lass (P_i)

It is caused by the alternating flux in the core.

It consists of two lasses

(a) Hysteresis loss (P_s)

(b) Eddy current loss (P_e)

(a) Hysteresis loss : The core of *T/F* is subjected to an alternating magnetising force and for each cycle of emf, a hysteresis loop is trace out hysteresis loss is

$$P_n = K_n B_{\max}^{1.6} f v \text{ watt}$$

$f \rightarrow$ Supply frequency

$K_n \rightarrow$ Hysteresis coefficient

$v \rightarrow$ Volume of core

$B_{\max} \rightarrow$ Maximum flux density in core.

(b) Eddy current loss : If the magnetic ckt is made up of bon as flux in the ckt is variable, current will induced by induction in the ckt it self.

All such current are known as eddy current, this current results in a loss of power is known as eddy current lass and is given by

$$P_e = K_e B_{\min}^2 f^2 t^2 v \text{ watt}$$

$t \rightarrow$ thickness of lamination

Eddy current loss can be reduced by using core of thin lamination.

$$\therefore \quad P_i = P_n + P_e$$

P_n and P_e are to be remain constant from No load to full load.

$\therefore P_i$ is constant loss.

(ii) Copper loss Or Ohmic loss : There lasses occur in both the primary and secondary winding due to their ohmic resistance.

Total Cu-loss

$$P_c = I_1^2 R_1 + I_2^2 R_2$$
$$= I_1^2 R_{01} \text{ OR } I_2^2 R_{02}$$

This lass varies as the square of the load current

$$P_c \propto I_2^2$$

$\because$ Load current varies according to the connected of load.

For full load if current is I_2 then the current for fraction of full load $= xI_2$

$x \rightarrow$ fraction of load it may be

$$x = \frac{1}{2} \rightarrow \text{half of full load}$$

$$x = \frac{1}{3} \rightarrow \text{one third of full load}$$

$\therefore$ if P_{ell} is the culoss for ful load then $x^2 P_{cf}$ will be cu-lass for x of full load.

$\therefore$ Cu-loss will not be constant.

Q. 42. What is the efficiency of transformer and Derive the condition for maximum efficiency of 1-ϕ transformer.

Or

Prove that

$$(\text{KVA}_{\text{max}}) = (\text{KVA}_{\text{rated}})\sqrt{\frac{P_{\text{core}}}{P_{\text{ohmicfL}}}} \text{ or } (\text{KVA}_{\text{max}}) = (\text{KVA}_{\text{rated}})\sqrt{\frac{P_1}{P_{\text{cuFL}}}}$$

[UPTU 2007, 08, 10, 11, 13, 14, 15, 16]

Ans.

Transformer Efficiency

It is defined as the ratio of usefull power i.e., o/P power to i/P power.

T/F efficiency

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

$\because$ $$i/P \text{ power} = o/P \text{ power} + \text{losses}$$

$\therefore$ $$\eta = \frac{o/P \text{ power}}{o/P \text{ power} + \text{losses}}$$

$$o/P \text{ power at full load} = V_2 I_{2fl} \cos\phi$$

$$P = V_2 I_{2fl} \cos\phi$$

It is also known as rated power

$V_2 \rightarrow$ Secondary terminal voltage

$I_{2fl} \rightarrow$ Secondary full load current

$\cos\phi \rightarrow$ power factor of load

$$\text{Losses} = P_i + P_c = P_1 + x^2 P_{cfl}$$

$$o/P \text{ power for } x \text{ of full load} = xV_2 I_{2fl} \cos\phi$$

$$= xP$$

$\therefore$ $$\eta = \frac{xP}{xP + P_i + x^2 P_{cfl}}$$

For maximum efficiency

$$\frac{d\eta}{dx} = 0$$

$$\frac{d}{dx}\left[\frac{xP}{xP + P_i + x^2 P_{cfl}}\right] = 0$$

$$\frac{(xP + P_i + x^2 P_{cfl})P - (P + 2xP_{cfl})xP}{(xP + P_i + x^2 P_{cfl})^2} = 0$$

$$(xP + P_i + x^2 P_{cfl})P = (P + 2xP_{cfl})xP$$

$$P_i = x^2 P_{cfl}$$

$$P_i = P_c$$

Iron loss = Cu-loss

$x = \sqrt{\frac{P_i}{P_{cfl}}}$ ⇒ Fraction of full food at which maximum efficiency occurs

We know that

$$I_2 = xI_{2fl}$$

multiplied by V_2

$$V_2 I_2 = xV_2 I_{2fl}$$
$$(kVA) = x(kVA)_{fl}$$

For maximum efficiency

$$x = \sqrt{\frac{P_i}{P_{efl}}}$$

∴ KVA corresponding to max eff = $\sqrt{\frac{P_i}{P_{cfl}}}$ × noted KVA

$$(\text{KVA})_{\text{max}} = (\text{KVA})_{\text{ruted}} \sqrt{\frac{P_i}{P_{cfl}}}$$

$$(\text{KVA})_{\text{max}} = (\text{KVA})_{\text{ratna}} \sqrt{\frac{P_{\text{core}}}{P_{\text{orminfl}}}}$$

Q. 43. Why is transformer rating in KVA?

Ans. Cu-loss of T/F depends on current iron loss of T/F depends on voltage.

∴ Total loss depends on volt-ampere (V-A) and not on phase angle between voltage and current.

It is independent of load power factor that is why rating of T/F is in KVA not in KW.

$$P_c = I_1^2 R_1 + I_2^2 R_2$$

$$P_i \propto B_{\text{max}}^2$$

From emf eqn.

$$E = 4.44 fNB_{\text{max}}$$

$$B_{max} \propto \frac{E}{f}$$

and $$E \propto V$$

$\therefore$ Iron loss depends on applied voltage.

Q. 44. A 10 kVA, 2000/400 V 1-ϕ *T/F* has $R_1 = 5\ \Omega$, $X_1 = 12\ \Omega$, $R_2 = 0.2\ \Omega$ and $X_2 = 0.48\ \Omega$ determine the equivalent impedance of the *T/F* referred to :

(i) Primary (ii) Secondary.

Sol.
$$K = \frac{V_2}{V_1} = \frac{400}{2000} = \frac{1}{5}$$

(i) Equivalent resistance referred to primary

$$R_{01} = R_1 + \frac{R_2}{k^2}$$

$$= 5 + \frac{0.2}{(1/5)^2} = 10\ \Omega$$

and equivalent reactance

$$X_{01} = X_1 + \frac{X_2}{k^2}$$

$$= 12 + \frac{0.48}{(1/5)^2} = 24\ \Omega$$

$\therefore$ Equivalent impedance referred to primary

$$Z_{01} = \sqrt{R_{01}^2 + X_{01}^2} = \sqrt{10^2 + 24^2}$$

$$= 26\ \Omega$$

(ii) Equivalent resistance referred to secondary

$$R_{02} = R_2 + k^2 R_1$$

$$= 0.2 + \left(\frac{1}{5}\right)^2 \times 5$$

$$= 0.4\ \Omega$$

Equivalent reactance

$$X_{02} = X_2 + k^2 X_1$$

$$= 0.48 + \left(\frac{1}{5}\right)^2 12$$

$$= 0.96\ \Omega$$

$\therefore$ Equivalent impedance referred to secondary

$$Z_{02} = \sqrt{R_{02}^2 + X_{02}^2}$$

$$= \sqrt{(0.4)^2 + (0.96)^2} = 1.04\ \Omega$$

Alternative

$$Z_{02} = k^2 Z_{01}$$

$$= \left(\frac{1}{5}\right)^2 \times 26 = 1.04\ \Omega$$

Q. 45. A 100 KVA, 2200/440 V *T/F* has $R_1 = 0.3\ \Omega$, $X_1 = 1.1\ \Omega$, $R_2 = 0.01\ \Omega$ and $X_2 = 0.035\ \Omega$ calculate (i) equivalent impedance of *T/F* reforred to the primary (ii) total cu-loss.

Sol.

$$T/F \text{ ratio} = \frac{440}{2200} = \frac{1}{5}$$

Assuming the efficiency of *T/F* to be 100%

$$\therefore \quad V_1 I_1 = V_2 I_2 = 100 \text{ KVA}$$

$$\therefore \quad I_1 = \frac{100 \times 1000}{2200} = 45.45 \text{ A}$$

$$I_2 = \frac{100 \times 1000}{440} = 227.25 \text{ A}$$

I_2 can be determined by $I_2 = \dfrac{I_1}{k}$

$$= \frac{45}{1/5} = 227.45 \text{ A}$$

$$\therefore \quad R_{01} = R_1 + \frac{R_2}{k^2} = 0.3 + \frac{0.01}{(1/5)^2} = 0.55\ \Omega$$

$$X_{02} = X_1 + \frac{X_2}{k^2} = 1.1 + \frac{0.01}{(1/5)^2} = 1.975\ \Omega$$

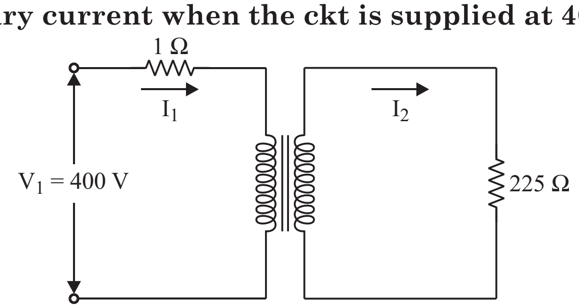
$$\therefore \quad Z_{01} = \sqrt{R_{01}^2 + X_{01}^2} = \sqrt{0.55^2 + 1.975^2} = 2.05\ \Omega$$

Cu-loss $= I_1^2 R_{01} = (45.45)^2 \times 0.55 = 1136.14$ W

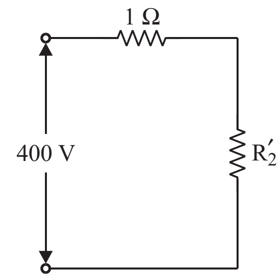
Cu-loss $= I_1^2 R_1 + I_2^2 R_2 = 45.45^2 \times 0.3 + 227.25^2 \times 0.01 = 113614$ m

Q. 46. A 1-ϕ *T/F* 400/2000 V has a resistance of 1 Ω connected in series with primary minding 225 Ω resistor connected across its secondary minding calculate the primary current when the ckt is supplied at 400 V.

Sol.



ckt is supplied at 400 V



∴ Referred to primary

$$R_2^1 = \frac{R_2}{k^2} = \frac{225}{5^2}$$

$$= 9\ \Omega$$

∴ $$R_{01} = R_1 + R_2^1 = 1 + 9 = 10\ \Omega$$

∴ $$\text{Primary current } I_1 = \frac{V_1}{R_{01}} = \frac{400}{10}$$

$$= 40\ \text{A}$$

Q. 47. A 40 KVA *T/F* has iron loss of 450 W and full load copper loss of 250 W. If the p.f. of the load is 0.8 lagging calculate (i) full load eff (ii) KVa load at which maximum eff. eccurns (iii) max^m eff^n. *[AKTU 2015-16, 17]*

Sol. (i)

$$V_2 I_2 = 40\ \text{KVA}$$

$$P_1 = 450\ \text{W} = 0.45\ \text{kW}$$

$$P_{\text{cufl}} = 850\ \text{W} = 0.85\ \text{kW}$$

Total loss at full-load = 0.45 + 0.85

$$= 1.3\ \text{kW}$$

$$o/P\ \text{power} = V_2 I_2 \cos\phi$$

$$\text{at fil.} = 40 \times 0.8 = 32\ \text{kW}$$

$$I/P\ \text{power at fil} = o/P + \text{losses}$$

$$= 32 + 1.3 = 33.3\ \text{kW}$$

∴ $$\text{f.l. eff} = \frac{o/P}{I/P} = \frac{32}{33.3} = 0.961$$

$$\%\ \eta = 96.1\ \%$$

(ii) Load at which max^m eff^n occurs

$$x = \sqrt{\frac{P_i}{P_{cufl}}}$$

$$= \sqrt{\frac{0.45}{0.85}} = 0.73$$

KVA corresponding to $x = xV_2 I_2$

$$= 0.73 \times 48$$

$$= 29.1\ \text{KVA}$$

∴ $$\text{Corresponding } o/P\ \text{power} = 29.1 \times pf$$

$$= 29.1 \times 0.8$$

$$= 23.28\ \text{kW}$$

$$\text{Iron loss} = P_i = 450\ \text{W}$$

$$\text{For max}^m \text{ eff}^n \text{ cu-loss} = P_i = 450 \text{ W}$$

$$\text{Total losses} = 450 + 450 = 900 \text{ W}$$

$$= 0.9 \text{ kW}$$

$$i/P \text{ power} = 23.28 + 0.9 = 24.18 \text{ kW}$$

$$\therefore \quad \eta = \frac{23.28}{24.18} = 0.9626$$

$$\% \ \eta = 96.26\%$$

Q. 48. The efficiency of a 400 KVA, 1-ϕ *T/F* is 08.77% when delivering full load at 0.8 pf lagging is 99.13% at half full load at unity p.f. calculate

(i) Iron loss

(ii) Full load cu-loss ***[UPTU 2013014, 07-08]***

Ans. At full load

$$\text{KVA} = 400$$

$$o/P \text{ power} = 400 \times pf$$

$$= 400 \times 0.8 = 320 \text{ kW}$$

$$i/P \text{ power} = \frac{o/P \text{ power}}{\text{efficiency}}$$

$$= \frac{320}{0.9877} = 324 \text{ kW}$$

$$\text{Total losses} = i/P - o/P$$

$$= 324 - 320$$

$$P_i + P_{cufl} = 4 \text{ kW} \quad \ldots(1)$$

at half full load,

$$\text{KVA} = \frac{1}{2} \times 400 = 200$$

$$o/P \text{ power} = 200 \times pf$$

$$200 \times 1 = 200 \text{ pf}$$

$$i/P \text{ power} = \frac{o/P}{\text{eff}^n} = \frac{200}{0.9913} = 201.8 \text{ kW}$$

$$\text{Total losses} = 201.8 - 200$$

$$P_i + \left(\frac{1}{2}\right)^2 P_{cufl} = 1.8 \text{ kW}$$

$$P_i + \frac{1}{4} P_{cufl} = 1.8 \text{ kW} \quad \ldots(2)$$

Solving eqn. (1) and (2)

$$P_i = 1.07 \text{ kW}$$

$$P_{cufl} = 2.93 \text{ kW}$$

Q. 49. A 20 KVA, 440/220 V, 1-ϕ 50 Hz *T/F* has iron loss of 324 W. The cu-loss is found to be 100 W when delivering half full load current. Determine

(i) the effn when delivering full-load

(ii) % of f.l. KVA when the effn will be maximum.

Sol. KVA = 20

$$P_i = 324 \text{ W} = 0.324 \text{ kW}$$

Cu-loss at half f.l. = 100 W

$$\left(\frac{1}{2}\right)^2 P_{cufl} = 100 \text{ W}$$

$$P_{cufl} = 400 \text{ W} = 0.4 \text{ kW}$$

$$\text{KVA at } \frac{1}{2} \text{ f.l.} = \frac{1}{2} \times 20 = 10$$

$$\text{Corresponding } o/P \text{ power} = 20 \times pf$$

$$= 20 \times 0.8 = 16 \text{ kW}$$

$$\text{Total losses at f.l.} = P_i + P_{cufl}$$

$$= 0.324 + 0.4$$

$$= 0.724 \text{ kW}$$

$$\therefore \quad i/P \text{ power} = o/P + \text{losses}$$

$$= 16 + 0.724$$

$$= 16.726 \text{ kW}$$

$$\eta = \frac{16}{16.726} = 0.9567$$

$$\% \, \eta = 95.67\%$$

% of f.l. when effn will be maximum

$$x = \sqrt{\frac{P_i}{P_{cufl}}}$$

$$= \sqrt{\frac{0.324}{0.4}} = 0.9$$

$$\% \quad x = 90\% \text{ of f.l. KVA}$$

Q. 50. A 600 KVA, 1-ϕ *T/F* when working at unity p.f. has an effn of 92% at f.l. and also at half f.l.. Determine the effn when it operates at unity p.f. and 60% of f.l.

Sol. KVA at f.l. = 600

$$\eta \text{ at f.l.} = 92\% = 0.92$$

$$\text{Corresponding } o/P \text{ power} = 600 \times pf$$

$$= 600 \times 1 = 600 \text{ kW}$$

$$i/P \text{ power} = o/P \text{ power}/\eta$$

$$= \frac{600}{0.92} = 6.52.17 \text{ kW}$$

$$\therefore \quad \text{losses} = i/P - o/P$$
$$= 652.17 - 600$$
$$P_i + P_{cufl} = 52.17 \text{ kW} \quad \ldots(1)$$

at half full load

$$\text{KVA} = \frac{1}{2} \times 600 = 300$$
$$\eta = 92\% = 0.92$$
$$\text{Corresponding } o/P \text{ power} = 300 \times pf$$
$$= 300 \times 1$$
$$= 300 \text{ kW}$$
$$i/P \text{ power} = \frac{o/P}{\eta}$$
$$= \frac{300}{0.92} = 326 \text{ kW}$$
$$\text{losses} = i/P \text{ power} - o/P \text{ power}$$
$$= 326 - 300$$
$$P_i + \left(\frac{1}{2}\right)^2 {}_{cufl} = 26 \text{ kW}$$
$$P_i + \frac{1}{4} P_{cufl} = 26 \quad \ldots(2)$$

Solving eqn. (1) and (2)

$$P_i = 17.4 \text{ kW}, P_{cufl} = 34.8 \text{ kW}$$

η at 60% of full load at unity pf

$$\text{KVA} = \frac{60}{100} \times 600 = 360$$
$$o/P \text{ power} = 360 \times 1 = 360 \text{ kW}$$
$$\text{Total losses} = P_i + \left(\frac{60}{100}\right)^2 P_{cufl}$$
$$= 17.4 + (0.6)^2 \times 34.8$$
$$= 29.93 \text{ kW}$$
$$i/P = o/P + \text{losses}$$
$$= 360 + 29.93 = 389.93 \text{ kW}$$
$$\eta = \frac{o/P}{i/P} = \frac{360}{389.93} = 0.9232$$
$$= 92.32\%$$

Q. 51. The primary and secondary mindings of a 50 KVA, 6600.220 V *T/F* has resistances of 7.8 Ω and 0.0085 Ω respectively. The *T/F* drawn no-load current of 0.328 A at *pf* of 0.3 lagging. Calculate the effn at f.l. if the p.f. of the load is 0.8 logging.

Sol.

$$k = \frac{220}{6600} = \frac{1}{30}$$

at no-load total losses = Iron loss

$$= V_1 I_0 \cos\phi_0$$
$$= 6600 \times 0.328 \times 0.3$$
$$= 650 \text{ W}$$

$$\therefore \quad P_i = 650 \text{ W} = 0.65 \text{ kW}$$

Resistance referened to primary

$$R_{01} = R_1 + \frac{R_2}{k^2}$$
$$= 7.8 + \frac{0.0085}{(1/30)^2} = 15.45\ \Omega$$

$$\therefore \quad P_{cufl} = I_1^2 R_{01}$$

$I_1 \rightarrow$ full load primary current

$$= \frac{\text{KVA}}{V_1} = \frac{50 \times 1000}{6600} \text{ amp}$$
$$= 7.57 \text{ amp}$$

$$\therefore \quad P_{cufl} = (7.57)^2 \times 15.45$$
$$= 885.36 \text{ W}$$

$$\text{Total losses at f.l.} = 650 + 88.5.36$$
$$= 1535.36 \text{ W}$$
$$= 1535.4 \text{ W}$$

$$\text{Full load } o/P \text{ power} = 50 \times 10^3 \times pf$$
$$= 50 \times 10^3 \times 0.8$$
$$= 40000 \text{ W}$$

$$i/P \text{ power} = o/P + \text{losses}$$
$$= 40000 + 1535.4$$
$$= 41535.4 \text{ W}$$

$$\text{F.L. } \eta = \frac{o/P}{i/P}$$
$$= \frac{40000}{41535.4} = 0.963$$

$$\%\ \eta = 96.3\%$$

Q. 52. A 440/110 V *T/F* has a primary resistance of 0.03 Ω and secondary resistance of 0.02 Ω. Its iron loss at normal *i/P* is 150 W. Determine the secondary current at which max eff will occur and the value of this max eff at a unity p.f. load.

Sol.

$$k = \frac{110}{440} = \frac{1}{4}$$

$$R_{02} = R_2 + k^2 R_1$$

$$= 0.02 + \left(\frac{1}{4}\right)^2 0.03 = 0.022\ \Omega$$

$$\text{Iron loss} = 150\text{ W}$$

For max eff

$$\text{Iron loss} = \text{Cu-loss} = 150\text{ W}$$

$$I_2^2 R_{02} = 150$$

$$I_2^2 \times 0.022 = 150$$

$$I_2 = 82.58\text{ A}$$

$$\text{KVA} = V_2 I_2 = 110 \times 82.58$$

$$= 9083.8$$

$$o/P\text{ power} = \text{KVA} \times pf = 9083.8 \times 1$$

$$= 9083.8\text{ W}$$

$$i/P\text{ power} = o/P + \text{losses}$$

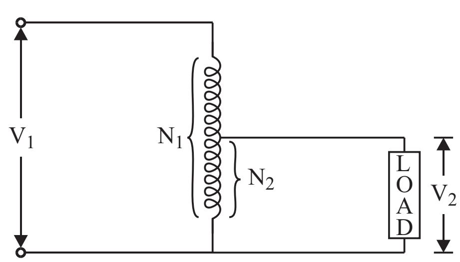
$$9083.8 + 150 + 150 = 9383.8\text{ W}$$

$$\therefore \quad \eta = \frac{9083.8}{9383.8} = 96.8\%$$

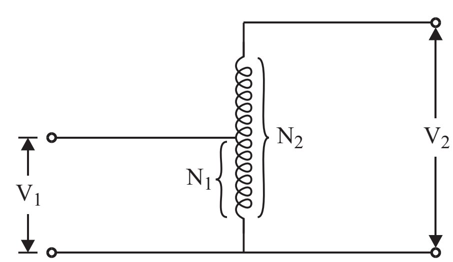
Q. 53. Write the short note on auto-transformer and how is it differ from ordinary transformer. ***[UPTU 2012, 15, 16]***

Ans.

- An auto *T/F* has a single winding on an iron core and a part of winding is common to both the primary and secondary ckts.
- The auto *T/F* differ from a conventional two-winding *T/F* in the may in which primary and secondary are interlinked directly.



Step down auto transformer



Step up auto transformer

- In conventional T/F, primary and secondary windings are insulated from each other but are magnetically linked by a common core.
- In auto T/F, the two mindings are connected electrically as well as magnetically.
- A single continuous minding is common to bath primary and secondary.
- Operating principle of an auto T/F is some as that of conventional two winting T/F.

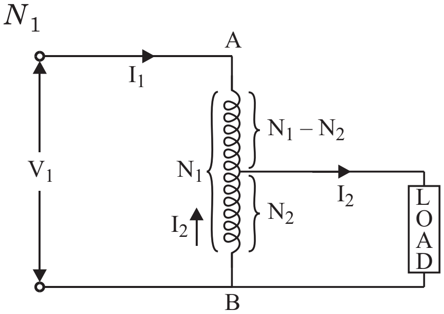
Q. 54. Derive the equation of voltage ratio or transformer ratio for auto transformer. ***[UPTU 2012]***

Ans. $AB \rightarrow$ Primary minding coveists whole term N_1

$V_1 \rightarrow$ applied voltage to AB

$BC \rightarrow$ secondary winding consists turns N_2

$V_2 \rightarrow$ secondary terminal voltage



$$\frac{V_2}{V_1 - V_2} = \frac{N_2}{N_1 - N_2}$$

$$V_2(N_1 - N_2) = (V_1 - V_2)N_2$$

$$V_1N_1 - V_2N_2 = V_1N_2 - V_2N_2$$

$$\frac{V_2}{V_1} = \frac{N_1}{N_1} = k$$

Also

$$(V_1 - V_2)I_1 = V_2(I_2 - I_1)$$

$$V_1I_1 - V_2I_1 = V_2I_2 - V_2I_1$$

$$V_1I_1 = V_2I_2$$

$$\frac{V_1}{V_1} = \frac{I_1}{I_2}$$

$$\therefore \quad \frac{V_1}{V_2} = \frac{I_2}{I_2} = \frac{N_2}{N_1} = k$$

Q. 55. Derive the expression for output power transferred by magnetically and conductively. ***[UPTU 2015-16]***

Ans. Since primary is secondary windings of an auto T/F are connected magnetically as well as electrically, the power from primary is transferred to secondary inductively (T/F action) as well as conductively (i.e., conducted directly from source to load)

$$o/P \text{ power} = \text{power delivered to load}$$

$$= V_2I_2$$

Power transferred inductively

$$= \text{Power in winding } BC$$

$$= V_2(I_2 - I_1)$$

$$= V_2I_2\left[1 - \frac{I_1}{I_2}\right]$$

$$= V_2I_2[1 - T_2] = V_1I_1[1 - k]$$

$= i/P \times (1 - k)$

Power transferred condictively = power delivered to load

– power transferred by T/F action

$= V_2 I_2 - V_2 I_2 [1 - k]$

$= V_2 I_2 \times k$

$= k \times V_2 I_2$

$= k \times o/P$ power

$= k \times i/P$ power

Suppose i/P power of an ideal auto T/F

$= 1000$ W

and T/F ratio $k = \frac{1}{4}$

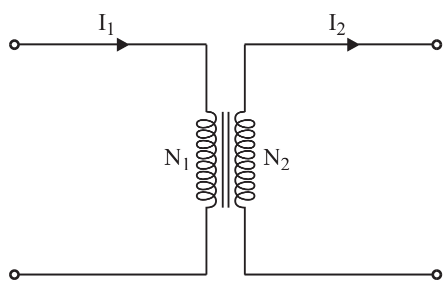
then power transferred inductively

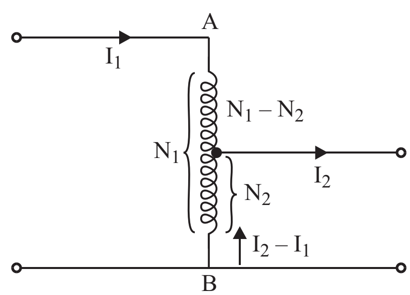
$$= 100\left(1 - \frac{1}{4}\right)$$

$= 750$ W

and power transferred conductively $= 250$ W

Q. 56. How much are materials saving in autotransformer w.r.t. ordinary transformer?





Sol. Weight of Cu required in a winding × current × turns

For 2-winding T/F

$$\text{Weight of Cu required} \times N_1 I_1 + N_2 I_2$$

N_1 and N_2 → No. of turns in primary and secondary windings

I_1 and I_2 → Current carried by primary and secondary of T/F

$\because \quad N_1 I_1 = N_2 I_2$

$\therefore \quad$ Weight of Cu required $\times 2 N_1 I_1$

In auto T/F

AC has $N_1 - N_2$ and carries I_1

BC has N_2 and carries $I_2 - I_1$

$\therefore \quad$ Weight of Cu required $\times (N_1 - N_2) I_1 + N_2 (I_2 - I_2)$

$$\times (N_1 - N_2)I_1 + N_2 I_2 - N_2 I_1$$
$$\times (N_1 - N_2)I_1 + N_1 I_1 - N_2 I_1$$
$$\times (N_1 - N_2)I_1 + (N_1 - I_2)I_1$$
$$\times 2(N_1 - N_2)I_1$$

$$\therefore \quad \frac{\text{Weight of Cu in auto } T/F}{\text{Weight of Cu in ordinary } T/F} = \frac{2(N_1 - N_2)I_1}{2N_1 I_1}$$
$$= 1 - \frac{N_2}{N_1}$$
$$= 1 - k$$

$$\text{Weight of Cu in auto } T/F = (1 - k) \times \text{weight of Cu in ordinary } T/F$$
$$W_a = (1 - k)W_0$$

$$\therefore \quad \text{Saving of Cu} = \text{Weight of Cu in oridary } T/F - \text{Weight of Cu in auto } T/F$$
$$= W_0 - W_a$$
$$= W_0 - (1 - k)W_0$$
$$= kW_0$$
$$= k \times \text{weight of Cu in ordinary } T/F$$

if $k = 0.1$

Saving = 10% only

but $k = 0.9$

Saving = 90%

Therefore the nearer the value of k of auto T/F is to 1, the greater is the saving of Cu.

Q. 55. What is the advantages and disadvantages of autotransormer over 2-winding transformer? ***[UPTU 2012]***

Ans.

Advantages

- Less conducting materials are required for windings
- Less Cu-loss
- More efficient
- Required smaller exciting current

Disadvantages

- o/P is no longer dic. isolated from i/P
- for small value of k (very high volt to very low)
- little saving in conductor then it is preferrable to use an ordinary T/F.

❑

Unit 5

Electrical Installation

Switchgear:

The apparatus used for switching, controlling and protecting the electrical circuits and equipment is known as switchgear. The term 'switchgear' is a generic term encompassing a wide range of products like circuit breakers, switches, switch fuse units, off-load isolators, HRC fuses, contactors, earth leakage circuit breaker, etc.

Classification of Switchgear:

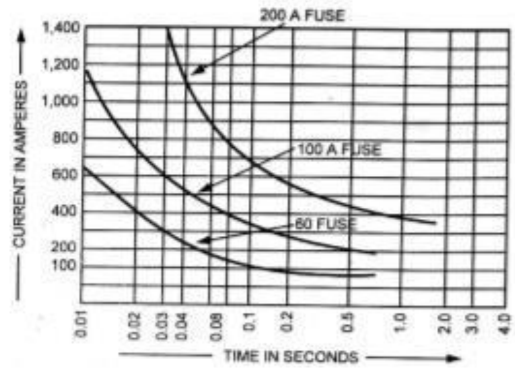
Switchgear can be classified on the basis of voltage level into the following:

1. Low voltage (LV) Switchgear: up to 1KV
2. Medium voltage (MV) Switchgear: 3 KV to 33 KV
3. High voltage (HV) Switchgear: Above 33 KV

Components of LT Switchgear: The term LT Switchgear includes low voltage Circuit Breakers, Switches, off load electrical isolators, HRC fuses, Earth Leakage Circuit Breaker, Miniature Circuit Breakers (MCB) and Molded Case Circuit Breakers (MCCB) etc i.e. all the accessories required to protect the LV system. The most common use of LV switchgear is in LV distribution board.

FUSE:

Fuse is perhaps the simplest and cheapest device used for interrupting an electrical circuit under short circuit, or excessive overload, current magnitudes. The action of a fuse is based upon the heating effect of the electric circuit. The fuse has inverse time-current characteristics as shown in fig.The part which actually melts and opens the circuit is known as the fuse element.



Time-Current Characteristic

Fuses have following advantages and disadvantages:

Advantages:

1. It is cheapest form of protection available.
2. It needs no maintenance.
3. Its operation is inherently completely automatic unlike a circuit breaker which requires elaborate equipment for automatic action.
4. It interrupts enormous short circuit currents without noise, flame, gas or smoke.

Disadvantages:

1. Considerable time is lost in rewiring or replacing a fuse after operation.
2. On heavy short circuits, discrimination between fuses in series cannot be obtained unless there are considerable differences in the relative sizes of the fuse concerned.

3. The current-time characteristics of a fuse cannot always be correlated with that of the protected device.

FUSE UNITS:

The various types of fuse units, most commonly available are:

1. Round type fuse unit.
2. Kit-kat type fuse unit.
3. Cartridge type fuse unit.
4. HRC (High Rupturing Capacity) fuse units
5. Semiconductors fuse units.

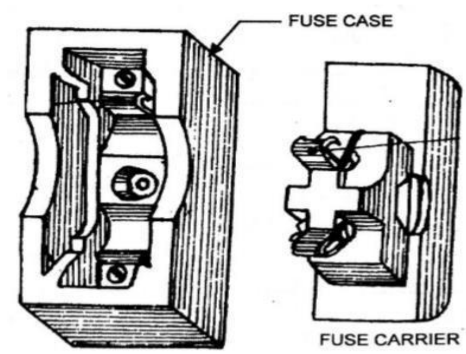
1. Round type fuse unit:

This type of fuse unit consists of a porcelain or Bakelite box and two separated wire terminals for holding the fuse wire between them. This type of fuse is not common use on account of its Following disadvantages:

1. One of the terminals remains always energized and, therefore, for replacement of fuse either the worker will have to touch the live mains or open the main switch.
2. Appreciable arching takes place at the instant of blowing off fuse and thus damage the terminals. After two or three arcing the fuse unit becomes unusable.

2. Rewirable or Kit-kat Type Fuses:

The most commonly used fuse in "house wiring' and small current circuits is the semi-enclosed or rewirable fuse (also sometimes known as kit-kat type fuse). It consists of a porcelain base carrying the fixed contacts to which the incoming and outgoing live or phase wires are connected and a porcelain fuse carrier holding the fuse element, consisting of one or more strands of fuse wire, stretched between its terminals.



The fuse wire may be of lead, tinned copper, aluminum or an alloy of tin-lead. A fuse wire of any rating not exceeding the rating of the fuse may be used in it i.e. a 80A fuse wire can be used in a 100A fuse, but not in the 63A fuse.

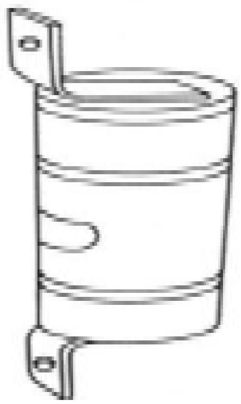
Disadvantages of Rewirable or Kit-kat Type Fuses:

- Unreliable operation.
- Lack of discrimination.
- Small time lag.
- Low rupturing capacity.
- No current limiting feature.
- Slow speed of operation.

3. Cartridge Type Fuses:

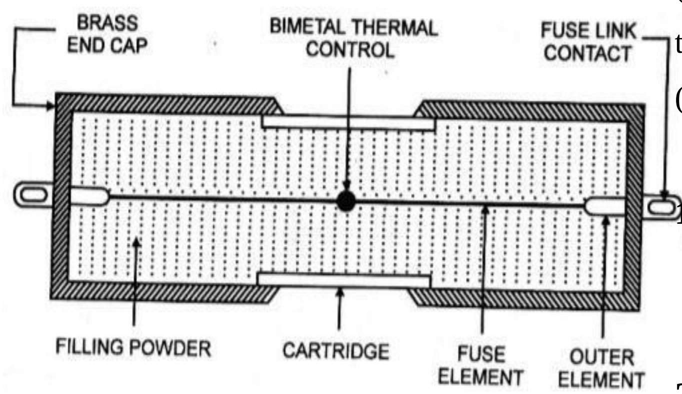
This is a totally enclosed type fuse unit. It essentially consists of an insulating container of bulb or tube shape and sealed at its ends with metallic cap known as cartridge enclosing the fuse element and filled with powder or granular material known as filler.

There are various types of materials used as filler like sand, calcium carbonate, quartz etc. This type of fuse is available up to 660V and the current rating up to 800 A.



4. High Rupturing Capacity (HRC) Fuses:

With a very heavy generating capacity of the modern power stations, extremely heavy currents would flow into the fault and fuse clearing the fault would be required to withstand extremely high stresses in this process.



HRC fuses developed and designed after intensive research for use in medium and high voltage installations. Their rupturing capacity is as high as 500MVA up to 66 KV and above.

There are basically two types of HRC fuses are used.

1. Cartridge Type HRC Fuse.
2. Tetra Chloride Type HRC Fuse.

5. Semiconductor Fuses:

These are very fast acting fuses for protection of thyristor and other electronic circuits.

Switch Fuse Unit (SFU):

Switch fuse is a combined unit and is known as an iron clad switch, being made of iron. It may be double pole for controlling single phase two-wire circuits or triple pole for controlling three-phase, 3-wire circuits or triple pole with neutral link for controlling 3-phase, 4-wire circuits. The respective switches are known as double pole iron clad (DPIC), triple pole iron clad (TPIC), and triple pole with neutral link iron clad (TPNIC) switches.

1. For two-wire dc circuits or single phase ac circuits:

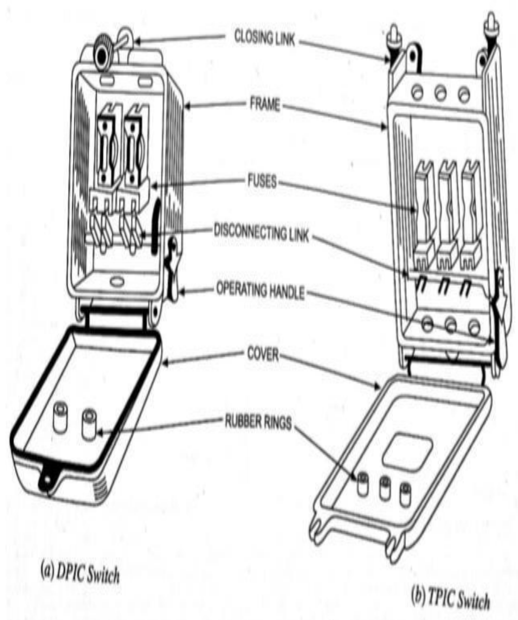
240V, 16A, DPIC switch fuse

2. For Three-Wire DC Circuits:

500V, 32A (63/100/150 or higher amperes), IS approved TPIC switch fuse.

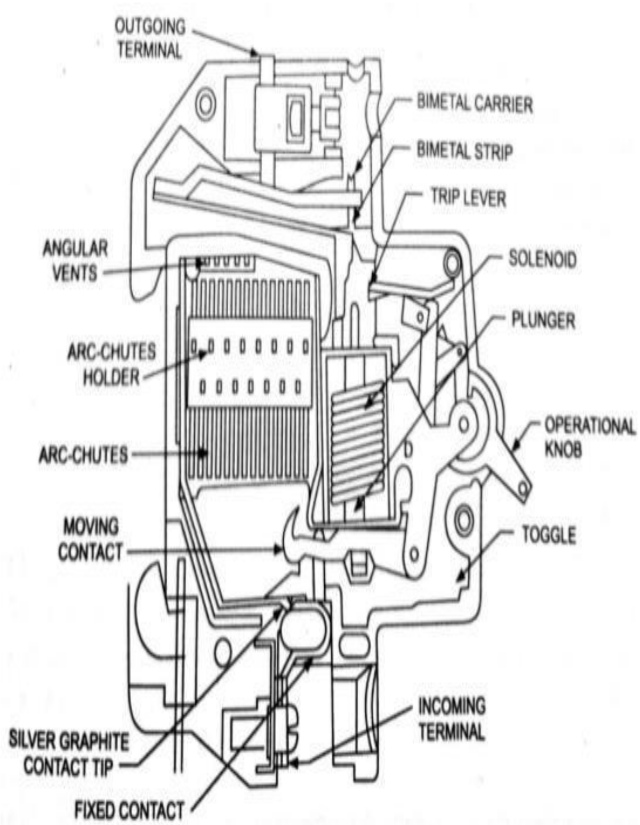
3. For Three-Phase Balanced Load Circuits:

415V, 32A (63/100/150 or higher amperes), IS approved TPIC switch fuse.



Miniature Circuit Breaker (MCB):

A device which provides definite protection to the wiring installations and sophisticated equipment against over-currents and short-circuit faults.



On occurrence of short circuit, the rising current energizes the solenoid, operating the plunger to strike the trip lever causing immediate release of the latch mechanism. Rapidity of the magnetic solenoid operation causes instantaneous opening of contacts.

They are suitable for the protection of important and sophisticated equipment, such as air-conditioners, refrigerators, computers etc.

Earth Leakage Circuit Breaker (ELCB):

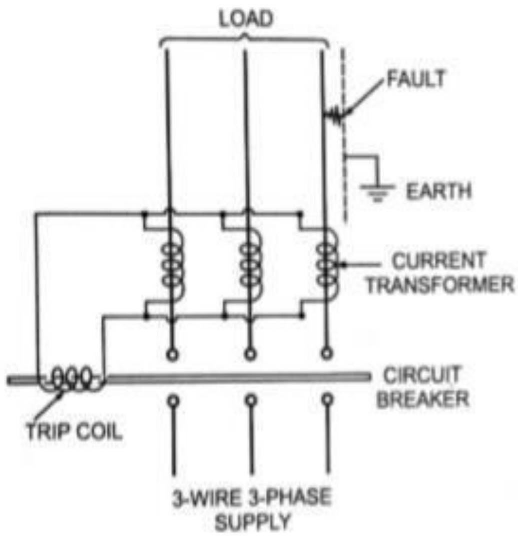
It is a device that provides protection against earth leakage. These are of two types.

1. **Current operated earth leakage circuit breaker**
2. **Voltage operated earth leakage circuit breaker**
3. **Current operated earth leakage circuit breaker**

It is used when the product of the operating current in amperes and the earth-loop impedance in ohms does not exceed 40. Such circuit breakers are used where consumer's earthing terminal is connected to a suitable earth electrode.

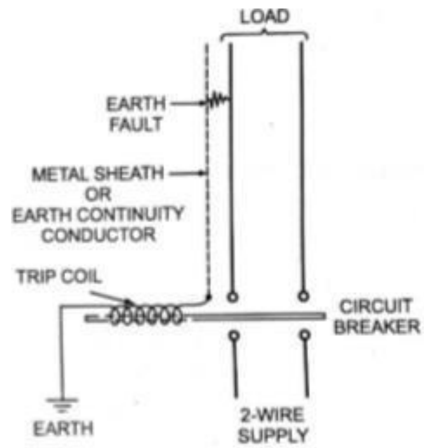
1. **Current operated earth leakage circuit breaker:**

A current-operated earth leakage circuit breaker is applied to a 3-phase, 3-wire circuit. In normal condition when there is no earth leakage, the algebraic sum of the currents in the three coils of the current transformers is zero, and no current flows through the trip coil. In case of any earth leakage, the currents are unbalanced and the trip coil is energized and thus the circuit breaker is tripped.



2. **Voltage operated earth leakage circuit breaker:**

It is suitable for use when the earth –loop impedance exceeds the values applicable to fuses or excess-current circuit breaker or to current operated earth leakage circuit breaker. When the voltage between the earth continuity conductor (ECC) and earth electrode rises to sufficient value, the trip coil will carry the required current to trip the circuit breaker. With such a circuit breaker the earthing lead between the trip coil and the earth electrode must be insulated; in addition, the earth electrode must be placed outside the resistance area of any other parallel earths which may exist.



Molded Case Circuit Breaker (MCCB)

It is a type of electrical protection device that can be used for a wide range of voltages, and frequencies of both 50 Hz and 60 Hz, the main distinctions between molded case and miniature circuit breaker are that MCCB can have current rating up to 2500 amperes, and its trip setting are normally adjustable. MCCBs are much larger than MCBs. An MCCB has three main functions:

- **Protection against overload.**
- **Protection against electrical faults.**
- **Switching a circuit ON and OFF.**

The wide range of current ratings available from molded-case circuit breakers allows them to be used in a wide variety of applications. MCCBs are available with current ratings that range from low values such as 15 amperes, to industrial ratings such as 2500 amperes. This allows them to be used in both low power and high power applications.

Different Types of Batteries and Their Applications

Battery- A Battery is a chemical device that stores electrical energy in the form of chemicals and by means of electrochemical reaction, it converts the stored chemical energy into direct current (DC) electric energy.

Types of Batteries

Batteries are basically classified into 2 types:

- Non-rechargeable batteries (primary batteries)
- Rechargeable batteries (secondary batteries)

Non-rechargeable Batteries

These are basically considered as **primary batteries** because they can be used only once. These batteries cannot be recharged and used again.

I.-Alkaline batteries: It is basically constructed with the chemical composition of Zinc (Zn) and Manganese dioxide (MnO_2), as the electrolyte used in it is potassium hydroxide which is purely an alkaline substance the battery is named as alkaline battery having he power density of 100 Wh/Kg.

Advantages:

1. Cycle life is more
2. More compatible and efficient for powering up portable devices.

3. Shelf life is more.
4. Small in size.
5. Highly efficient.
6. Low internal resistance so that discharge state in idle state is less.
7. Leakage is low.

Disadvantages:

1. Cost is a bit high. Except it everything is an advantage.

Applications:

It can used in torches, remotes, wall clocks, small portable gadgets etc.

ii.-Coin cell batteries: The chemical composition of coil cell batteries is also alkaline in nature.

Apart from alkaline composition, lithium and silver oxide chemicals will be used to manufacture these batteries which are more efficient in providing steady and stable voltage in such a small sizes. It has Power density of 270 Wh/Kg.

Advantages:

1. Light in weight
2. Small in size
3. High density
4. Low cost
5. High nominal voltage (up to 3V)
6. Easy to get high voltages by arranging serially
7. Long shelf life

Disadvantages:

1. Needs a holder
2. Low current draw capability

Applications:

Used in watches, wall clocks, miniature electronic products etc.

Rechargeable Batteries

These are generally called as **secondary batteries** which can be recharged and can be reused. Though the cost is high, but they can be recharged and reused and can have a huge life span when properly used and safely charged.

i.-Lead-acid batteries-It consists of lead-acid which is very cheap and seen mostly in cars and vehicles to power the lighting systems in it. These are more preferable in the products where the size/space and weight doesn't matter. These comes with the nominal voltage starting 2V to24V and most commonly seen as 2V, 6V, 12V and 24V batteries. It has Power density of 7 Wh/Kg.

Advantages:

1. Cheap in cost
2. Easily rechargeable
3. High power output capability

Disadvantages:

1. Very heavy
2. Occupies much space
3. Power density is very low

Applications: Used in cars, UPS (uninterrupted Power Supply), robotics, heavy machinery etc..

ii.-Ni-Cd batteries- These batteries are made of Nickel and Cadmium chemical composition. Though these are very rarely used, these are very cheap and their discharge rate is very low when compared to NiMH batteries. These are available in all standard sizes like AA, AAA, C and rectangular shapes. The nominal voltage is 1.2V, often connected together in a set of 3 which gives 3.6V. It has Power density of 60 Wh/Kg.

Advantages:

1. Cheap in cost
2. Easy to recharge
3. Can be used in all environments
4. Comes in all standard sizes

Disadvantages:

1. Lower power density

2. Contains toxic metal
3. Needs to be charged very frequently in order to avoid growth of crystals on the battery plate.

Applications:

Used in RC toys, cordless phones, solar lights and mostly in the applications where price is important.

iii.-Ni-MH batteries- The Nickel – Metal Hydride batteries are much preferable than Ni-Cad batteries because of their lower environmental impact. Its nominal voltage is 1.25 V which is greater than Ni-Cad batteries. It has less nominal voltage than alkaline batteries and they are good replacement due to its availability and less environmental impact. The power density of Ni-MH batteries is 100 Wh/Kg.

Advantages:

1. Available in all standard sizes.
2. High power density.
3. Easy to recharge.
4. A good alternative to alkaline which has almost all similarities and also it is rechargeable.

Disadvantages:

1. Self-discharge is very high.
2. Expensive than Ni-Cad batteries.

Applications:

Used in all applications similar to the alkaline and Ni-Cad batteries.

iv.-Li-ion batteries- These are made up of Lithium metal and are latest in rechargeable technology. As these are compact in size they can be used in most of the portable applications which need high power specifications. These are the best rechargeable batteries available. These have a nominal voltage of 3.7V (most commonly we have 3.6V and 7.2V) and have various ranges of power capacity (starting from 100s of mAh to 1000s of mAh). Even the C-rating ranges from 1C to 10C and Power density of Li-ion batteries is 126 Wh/Kg.

Advantages:

1. Very light in weight.
2. High C-rating.
3. Power density is very high.
4. Cell voltage is high.

Disadvantages:

1. These are a bit expensive.
2. If the terminals are short circuited the battery might explode.
3. Battery protection circuit is needed.

v.-Li-Po batteries- These are also called as Lithium Ion polymer rechargeable batteries because it uses high conductivity polymer gel/polymers electrolyte instead of liquid electrolyte. These come under the Li-ion technology. These are a bit costly. But the battery is very highly protected when compared to the Li-ion batteries. It has Power density of 185 Wh/Kg.

Advantages:

1. These are highly protective compared to Li-ion batteries.
2. Very light in weight
3. Thin in structure when compared to Li-ion batteries.
4. Power density, nominal voltages are comparatively very high compared to Ni-Cad and Ni-MH batteries.

Disadvantages:

1. Expensive.
2. Might explode if wrongly connected.
3. Should not be bent or exposed to high temperature which may cause to explosion.

Applications: Can be used in all the portable devices which need rechargeable advantage like drones, robotics, RC toys etc.

Types of Electrical Wire- There are mainly 5 types of wire:

- **Triplex Wires:** Triplex wires are usually used in single-phase service drop conductors, between the power pole and weather heads. They are composed of two insulated aluminum wires wrapped with a third bare wire which is used as a common neutral. The neutral is usually of a smaller gauge and grounded at both the electric meter and the transformer.

- **Main Feeder Wires:** Main power feeder wires are the wires that connect the service weather head to the house. They're made with stranded or solid THHN wire and the cable installed is 25% more than the load required.

- **Panel Feed Wires:** Panel feed cables are generally black insulated THHN wire. These are used to power the main junction box and the circuit breaker panels. Just like main power feeder wires, the cables should be rated for 25% more than the actual load.

- **Non-Metallic Sheathed Wires:** Non-metallic sheath wire, or Romex, is used in most homes and has 2-3 conductors, each with plastic insulation, and a bare ground wire. The individual wires are covered with another layer of non-metallic sheathing. Since it's relatively cheaper and available in ratings for 15, 20 and 20 amps, this type is preferred for in-house wiring.

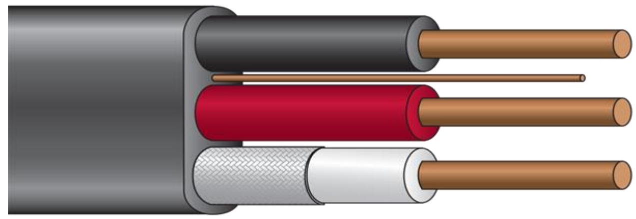
- **Single Strand Wires:** Single strand wire also uses THHN wire, though there are other variants. Each wire is separate and multiple wires can be drawn together through a pipe easily. Single strand wires are the most popular choice for layouts that use pipes to contain wires.

Types of Electrical Cables – There are more than 20 different types of cables available today, designed for applications ranging from transmission to heavy industrial use.

Some of the most commonly-used ones include:**.**

- **Non-Metallic Sheathed Cable:** These cables are also known as non-metallic building wire or NM cables. They feature a flexible plastic jacket with two to four wires (TECK cables are covered with thermoplastic insulation) and a bare wire for grounding. Special varieties of this cable are used for underground or outdoor use, but NM-B and NM-C non-metallic sheathed cables are the most common form of indoor residential cabling.

- **Underground Feeder Cable:** These cables are quite similar to NM cables, but instead of each wire being individually wrapped in thermoplastic, wires are grouped together and embedded in the flexible material. Available in a variety of gauge sizes, UF cables are often used for outdoor lighting and in-ground applications. Their high water-resistance makes them ideal for damp areas like gardens as well as open-to-air lamps, pumps, etc.



- **Metallic Sheathed Cable:** Also known as armored or BX cables, metal-sheathed cables are often used to supply mains electricity or for large appliances. They feature three plain stranded copper wires (one wire for the current, one grounding wire and one neutral wire) that are insulated with cross-linked polyethylene, PVC bedding and a black PVC sheathing. BX cables with steel wire sheathing are often used for outdoor applications and high-stress installations.

- **Multi-Conductor Cable:** This is a cable type that is commonly used in homes, since it is simple to use and well-insulated. Multi-conductor or multi-core

(MC) cables feature more than one conductor, each of which is insulated individually. In addition, an outer insulation layer is added for extra security. Different varieties are used in industries, like the audio multicore ‘snake cable’ used in the music industry.

- **Coaxial Cable :** A coaxial (sometimes heliax) cable features a tubular insulating layer that protects an inner conductor which is further surrounded by a tubular conducting shield, and might also feature an outer sheath for extra insulation. Called ‘coaxial’ since the two inner shields share the same geometric axis, these cables are normally used for carrying television signals and connecting video equipment.

- **Unshielded Twisted Pair Cable:** Like the name suggests, this type consists of two wires that are twisted together. The individual wires are not insulated, which makes this cable perfect for signal transmission and video applications. Since they are more affordable than coaxial or optical fiber cables, UTP cables are often used in telephones, security cameras and data networks. For indoor use, UTP cables with copper wires or solid copper cores are a popular choice, since they are flexible and can be easily bent for in-wall installation.

- **Ribbon Cable:** Ribbon cables are often used in computers and peripherals, with various conducting wires that run parallel to each other on a flat plane, leading to a visual resemblance to flat ribbons. These cables are quite flexible and can only handle low voltage applications.

- **Direct-Buried Cable:** Also known as DBCs, these cables are specially-designed coaxial or bundled fiber-optic cables, which do not require any added sheathing, insulation or piping before being buried underground. They feature a heavy metal core with many layers of banded metal sheathing, heavy rubber coverings, shock-absorbing gel and waterproof wrapped thread-fortified tape. High tolerance to temperature changes, moisture and other environmental factors makes them a popular choice for transmission or communication requirements.

- **Twin-Lead Cable:** These are flat two-wire cables that are used for transmission between an antenna and receiver, like TV and radio.

- **Twin-axial Cable:** This is a variant of coaxial cables, which features two inner conductors instead of one and is used for very-short-range high-speed signals.

- **Paired Cable:** With two individually insulated conductors, this cable is normally used in DC or low-frequency AC applications.

- **Twisted Pair:** This cable is similar to paired cables, but the inner insulated wires are twisted or intertwined.

IMPORTANCE OF EARTHING (Most Important)

Why Earthing is necessary?

Earthing is the process of the excessive amount of fault current flow of the electrical energy directly into the ground with the help of the low resistance wire. The electrical earthing is done by connecting the non-current carrying part of the equipment or neutral of the supply system to the ground. It helps in the diversion of the excessive amount of fault current directly into the ground and ensures safety. Let us discuss the necessity of earthing.

The necessity of earthing: The reasons

The prime reasons why earthing is necessary are as follows:

1. **Minimizes risk of electric shock**: The main purpose of earthing is to avoid or minimize the chance of electrocution. Any leakage or faulty current in the circuit causes the presence of electric charge on exposed conductive surfaces. Earthing provides a low resistive conductive path directly to the earth, which carries any such fault or leakage current.
2. **Dissipation of static charge**: In a perfectly earthed system its potential remains approximately equal to zero. So it can remove most of the static charge build-up in the conductors.
3. **Eliminate stray voltage**: Similar to static charge it also prevents stray voltage in the line. That is no potential difference to build in the conductor.
4. **Voltage Stabilization**: In a network which has multiple feeders or sources there must be a common point which acts as a universal reference point. The Earthing acts like as a balance point.
5. **Protection from power surges**: Earthing can protect from sudden excessive surges, it also provides protection from lightning strikes. Any lighting strikes on the exposed

metal or received through another path which is connected to earth line get discharged directly to earth.

6. **For proper functioning of equipment's**: Proper earthing is very important for the functioning of the devices connected to the system. Mainly protective devices like ELCB, earth fault relays, etc. needs proper earthing for its functioning.

The necessity of earthing allows it to be used in different platforms as given below as- Dg Set, Transformer ,Lightening system, Solar system, Datacenter, Railways, Highways, Refinery, Power plant, Cement plant, Steel plant, For every electrical installation.

Types of Earthing:

These are some main types of the earthing system given below:

1- Plate Earthing: Plate earthing requires a plate electrode made of copper or galvanized iron buried in pits vertically more than 10 feet inside the ground. The pit gets filled with salt and charcoal. The dimensions of the ideal copper plate earthing are 60cm x 60cm x 3.18mm. The dimension for ideal galvanized iron is 60cm x 60cm x 6.35 mm.

2- Pipe Earthing: A pipe earthing system is a pipe made of galvanized steel or iron is buried vertically into the ground. The pipe earthing size depends on the magnitude of current and type of soil which includes moisture soil, sandy soil and rocky soil. Pipe earthing helps in the dissipation of faulty currents in the electrical system.

3- Rod Earthing: These rods are specially designed rods made of metal and alloys to conduct fault current. Similar to the Pipe earthing. A copper rod replaces the pipe electrode for burying a rod made of copper or galvanized iron.

4- Wire Earthing: In wire earthing, strip electrodes are buried inside these several dug trenches. These strip electrodes are a combination of copper or galvanized iron. The ground wire provides a path back to the source of the electrical current in the fault current.

5- Waterman method: The process of earthing in which waterman or galvanized Gi pipes are used is known as the Waterman method. The rod is buried inside the ground to reduce resistance in this process.

There are mainly two types of electrical earthing:

1-Neutral Earthing:

The neutral of the system is inserted into the earth with the help of the GI wire. This process is also known as earthing. These neutral earthing are used in the generator transformer etc.

2-Equipment Earthing:

The equipment earthing connects to the earth with the help of the conducting wire. If any fault occurs in the apparatus, the short-circuit current flows to the Earth through a wire. It protects the system from damage.

(Most important) The Formula for Energy Consumption

The equation for energy consumption is expressed as,

$$E= (P \times t) / 1000$$

Where, E represents energy in kilowatt-hours (kWh),

P stands for power in Watts, and t is the time in hours. **{Note- Convert time into second}**

Examples of Energy Consumption Calculations

Let's consider some practical examples to understand Energy Consumption better:

Example 1: Calculate the energy consumption of a system that uses 150 Watts of power and operates for 4 hours a day.

Solution : Given: Power P = 150 W, total time = 4 hrs

$$E= (P \times t) / 1000$$

E = (150*4*60*60)/1000

E = 2160 kWh {Note- Convert time into second}

Hence, the energy consumption is 2160 kWh

Example 2: A drone uses 600 Watts of power and operates for 1 hour a day. What is its daily energy consumption?

Solution: Given: Power P = 600 W, total time= 1 hr

$$E = P \times t/1000$$

E = (600*1*60*60)/1000

E =2160 kWh

Therefore, the drone's daily energy consumption is 2160 kWh.

Sample Questions

Ques. In a house, there are 5 lamps 25 Watt used 14 hours per day, a 200 Watt refrigerator used 24 hours per day, and a 125 Watt water pump used 8 hours per day. How much electrical energy is used for a month (30 days)?

Ques. If a 40-watt lamp is turned on for one hour, how many joules of electrical energy has been converted by the lamp?

Ques. Calculate the heat produced by an electric iron, which has a resistance of 30 ohms and takes a current of 3 amperes when it is switched on for 15 seconds.

Ques. Compute the heat generated while transferring 96000 coulomb of charge in one hour through a potential difference of 50 V.

Ques. An electric iron of resistance 20Ω takes a current of 5 A. Calculate the heat developed in 30 s.

Ques. An electric motor takes 5 A from a 220 V line. Determine the power of the motor and the energy consumed in 2h.

Ques. The electric heater is rated at 2-kilowatt electrical energy and costs 4 rupees per kilowatt-hour. What is the cost of using the heater for 3 hours?

Ques. An electric bulb draws a current of 8A and works on 250 volts on an average of 8 hours a day to find the power consumed by the bulb and find the cost of an electric distribution company if one unit is Rs 4.