BASIC ELECTRICAL ENGINEERING

DC CIRCUITS 1

PREVIOUS YEARS QUESTIONS

PART A

Q.1 *Explain the concept of voltage and current source transformation with an example.* *[R.T.U. 2019]*

Ans. Source Conversion : A non–ideal i.e. practical voltage source can be converted into its equivalent non–ideal i.e. practical current source and vice–versa. These source transformation can be used for simplifying the complexity of the circuit.

It is important to note that the source conversion can only be applied to practical sources,the ideal source can not be converted into other type of sources.

The source conversion says that "*A voltage source in series with a resistance can be converted into an equivalent current source in parallel with a resistance and vice–versa*".

For converting voltage source of V volt and having internal resistance r in series, the value of current source will be $\frac{V}{r}$ and the parallel resistance will be r.

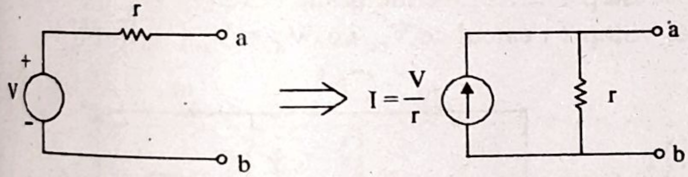


Fig. 1 : Conversion of voltage source into current source

The polarity of the current source i.e. direction will be selected in such a way that the direction of current will be from negative (–) to positive (+) terminal of the voltage source. This is due to the fact that the current direction across the terminals should not be changed.

For converting current source I A and having internal resistance r in parallel. The value of voltage source would be V = I. r and the resistance in series must be r. The polarity of the voltage source should be such that the current direction will be from (–) to (+) in the source.

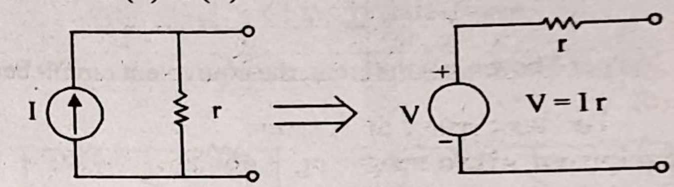
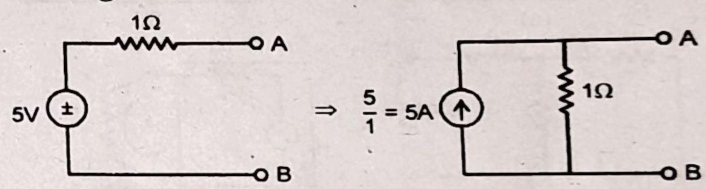
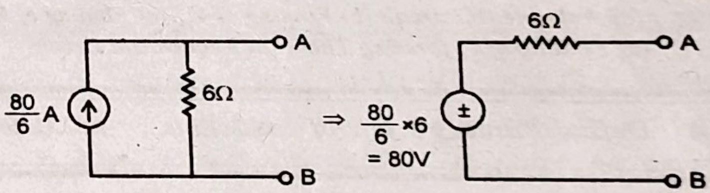


Fig. 2 : Conversion of current source into voltage sources

Voltage Source Transformation



Current Source Transformation



Q.2 *Explain the average power delivered to the circuit.* *[R.T.U. 2019]*

Ans. The average power absorbed by a circuit is the sum of the power stored and power returned over one complete cycle. So a circuits average power consumption will be the average of the instantaneous power over one full cycle with the instantaneous power (p) defined as the multiplication of the instantaneous voltage (V) by the instantaneous current (I).

Note that as the sine function is periodic and continuous, the average power given over all time will be exactly the same as the average power given over a single cycle.

Over a fixed number of cycles, the average value of the instantaneous power of the sinusoid is given simply as :

$$p = V \times I \cos \theta$$

Where V and I are the sinusoidal rms values and θ is the phase angle between the voltage and the current.

Q.3 *How do you find Thevenin's resistance?* [R.T.U. 2018]

Ans. To find the internal resistance of the network (Thevenin's resistance or equivalent resistance) in series with V_{oc}, the voltage source is removed (deactivated) by a short circuit (as the source does not have any internal resistance) as shown in Fig.(a).

$$R_{Th} = r_2 + \frac{r_1 r_3}{r_1 + r_3}$$

As per Thevenin's theorem, the equivalent circuit being Fig.(c).

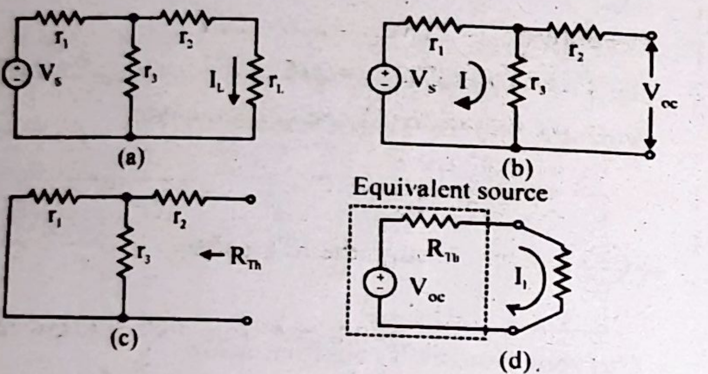


Fig. : (a) A simple DC circuit (b) Finding of V_{oc} (c) Finding of R_{Th} (d) Finding of I_L forming Thevenin's equivalent circuit

Q.4 *Define Faraday's law of Induction.* [R.T.U. 2018]

Ans. Faraday's Law of Electromagnetic Induction: Michael Faraday formulated two laws. These laws are called Faraday's laws of electromagnetic induction. The first law is related to emf induced in the conductor whereas the second law is related to magnitude of induced emf.

(i) Faraday's First Law: This law states that whenever an electrical conductor is linked with the changing flux or whenever the magnetic flux is cut by an electrical conductor there will be an induced emf in the conductor. In other words whenever relative motion exists between a conductor/coil and a magnetic field, a voltage is induced in the circuit.

(ii) Faraday's Second Law: This law states that the magnitude of the induced emf is directly proportional to the rate of change flux linkage with the conductor or is proportional to the rate of flux cutting by the conductor.

Q.5 *Describe Ohm's Law.*

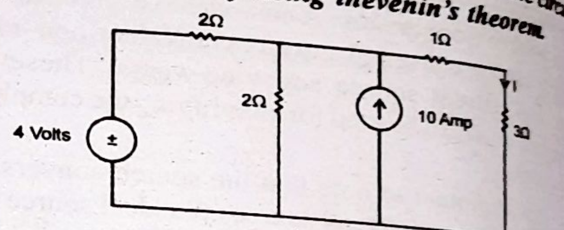
Ans. Ohm's law is defined as "the ratio of potential difference (V) between any two points on a conductor to the current flowing through them, is constant, provided the temperature of the conductor does not change." In other words,

$$\frac{V}{I} = \text{Constant (R)}$$

where, R = Resistance of the conductor between the two points considered.

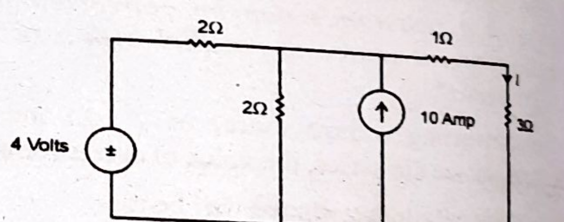
PART B

Q.6 *Find the current through 3Ω Resistor in the circuit shown in figure by using thevenin's theorem.*



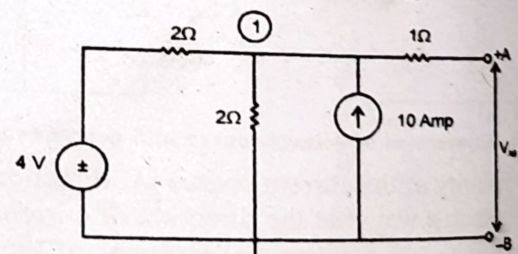
[R.T.U. ...]

Ans.



Step 1 : Remove the branch of 3Ω

Step 2 : calculate V_{oc} i.e. $V_{th} = V_{AB}$



Let us assume that the nodal voltage of node (1) is V

⇒ At node 1, we have (according to KCL)

$$\frac{4-V_1}{2}+10=\frac{V_1}{2}$$

$$2+10=\frac{V_1}{2}+\frac{V_1}{2}$$

$V_1 = 12$ volts

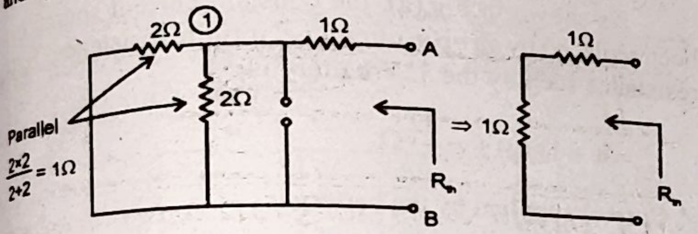
$\Rightarrow$ Drop across $1\Omega = 0V$ (since open circuited) ... (1)

$\Rightarrow$ Hence, $V_{th} = V_{AB}$ can be shown as

$V_{AB} = 1\,(0) + V_1$

$V_{th} = V_{AB} = 12$ volts ... (2)

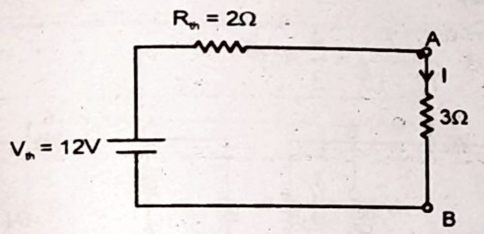
Step 3 : For calculating R_{th}, short the voltage source and open the current source



Henec, $R_{th} = 2\Omega$

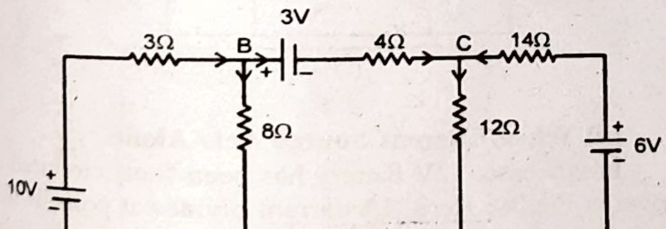
Step 4 :

Thevenin's Equivalent across A-B

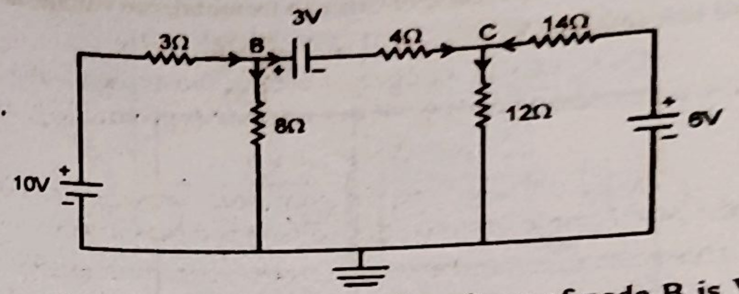


$$I=\frac{V_{th}}{R_{th}+3}=\frac{12}{2+3}=\frac{12}{5}=2.4\text{A from node A to B.}$$

Q.7 ***For the circuit shown in Figure. determine the voltages at nodes B and C and calculate the current through the 8Ω resistor.*** ***[R.T.U. 2019]***



Ans.



Let us assume that the node voltage of node B is V_B and node C is V_C respectively.

$\Rightarrow$ At node B, we have (according to KCL)

$$\frac{10-V_B}{3}=\frac{V_B}{8}+\frac{V_B-3-V_C}{4}$$

$\Rightarrow 36V_B - 24V_C - 72 = 320 - 32V_B$

$\Rightarrow 68V_B - 24V_C = 392$ ... (1)

$\Rightarrow$ At node C, we have (according to KCL)

$$\frac{V_B-3-V_C}{4}+\frac{6-V_C}{14}=\frac{V_C}{12}$$

$\Rightarrow 168V_B - 216V_C - 216 = 56V_C$

$\Rightarrow 168V_B - 272V_C = 216$ ... (2)

$\Rightarrow$ By Equation (1) and (2), we have

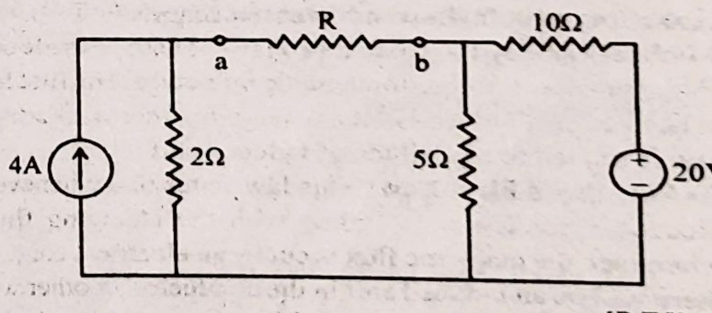
$V_B = 7.013$ volts

$V_C = 3.537$ volts

$\Rightarrow$ current through the 8Ω resistor,

$$=\frac{V_B}{8}=\frac{7.013}{8}=0.876\text{ A from node B to ground.}$$

Q.8 ***What should be the value of R such that Maximum power transfer can take place from the Rest of the Network to R. Obtain the amount of this power?***



[R.T.U. 2019]

Ans. Let us first convert the current source to voltage source and remove the resistance R from ab terminal, the voltage at these terminals is V_{oc}

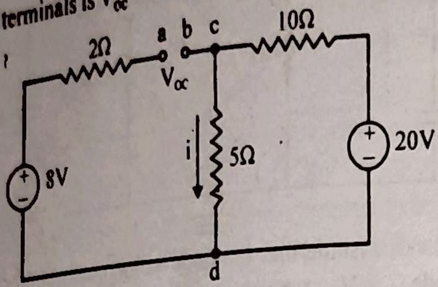


Fig. 1

From fig.1 $i = \frac{20}{15} = 1.33\text{ A}$

Voltage drop across cd,

$$V_{cd} = 1.33 \times 5$$
$$= 6.65 \text{ Volt}$$

Applying KVL in left loop

$$-10 + V_{oc} + 6.65 = 0$$
$$V_{oc} = 3.35 \text{ Volt}$$

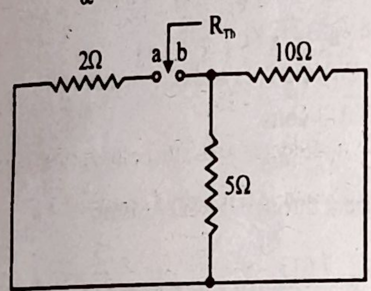


Fig. 2

From fig.2, thevenin's equivalent resistance across ab terminals

$$R_{Th} = 2 + \frac{5 \times 10}{5 + 10} = 5.33\ \Omega$$

As per maximum power transfer theorem

$$R = R_{Th} = 5.33\ \Omega$$

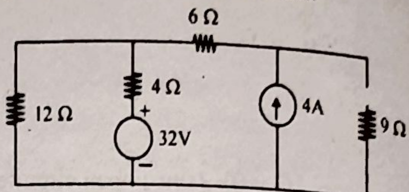
Now amount of power

$$P_{max} = \frac{V_{Th}^2}{4 R_{Th}}$$

$$= \frac{(3.35)^2}{4 \times 5.33}$$

$$= 526.38 \text{ mW}$$

Q.9 ***Compute the power dissipated in 9Ω resistor by applying superposition theorem.***



[R.T.U. 2018]

Ans. It should be kept in mind that an ideal voltage source has zero internal resistance whereas an ideal current source has an infinite internal resistance.

(i) When Voltage Source Acts Alone

As shown in Fig.(a), the constant current source has been replaced by an open circuit *i.e.* infinite resistance. Total resistance seen by the 32V battery is

$$= 4 + 12 \parallel 15 = \frac{32}{3}\Omega$$

$\therefore$ Current supplied by the battery is

$$= \frac{32}{32/3} = 3A$$

At point A, this current divides into two parts. The current going to 9Ω resistance is

$$I_1 = 3 \times \frac{12}{12 + 15} = \frac{4}{3}A$$

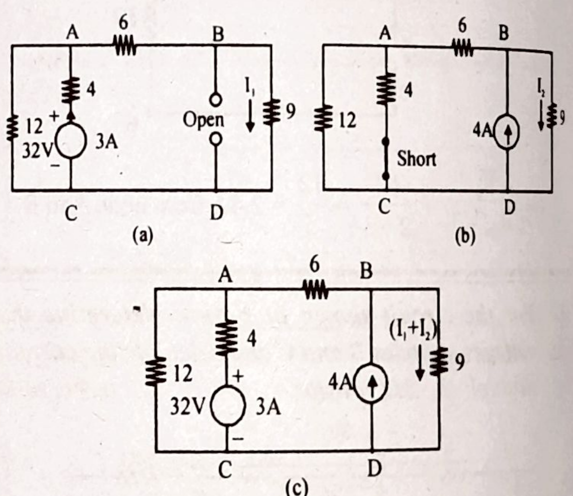


Fig.

(ii) When Current Source Acts Alone

In this case, 32V battery has been short circuited as shown in Fig.(b). Here, 4A current divides at point B into two parts. Current I_2 goes to 9Ω resistor and the rest $(4 - I_2)$ goes from B towards A.

The resistance of the series-parallel circuit to the left of the line BD is

$$= 6 + (4 \| 12) = 9\Omega$$

Hence, at point B the current divides into two equal parts.

$$I_2 = \frac{4}{2} = 2A$$

Total current through 9Ω resistor is

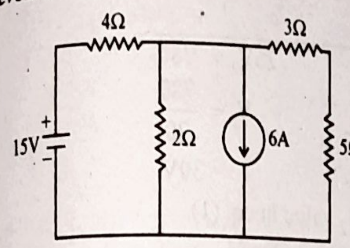
$$= I_1 + I_2 = \frac{4}{3} + 2 = \frac{10}{3} A$$

Power dissipated through 9Ω resistor is

$$= I^2 R$$

$$= \left(\frac{10}{3}\right)^2 \times 9 = 100W$$

Q.10 *Determine the current in 5Ω resistor using the Thevenin's Theorem.*



[R.T.U. 2018]

Ans.

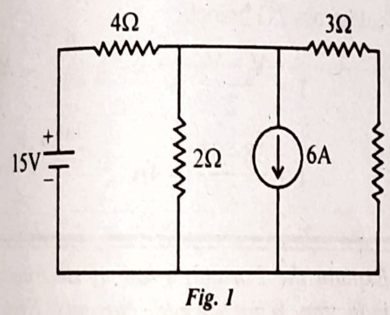


Fig. 1

Converting 6A current source in parallel with 2Ω resistor into an equivalent voltage source with a resistance in series

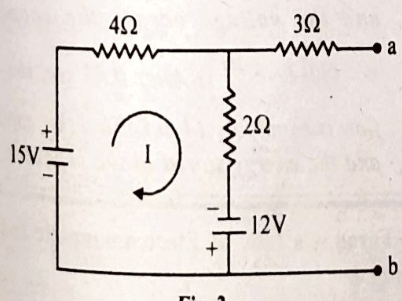


Fig. 2

Thevenin's Resistance

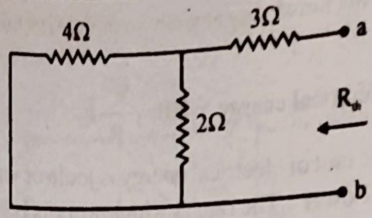


Fig. 3

$$R_{th} = 3 + 4 \| 2 = 3 + \frac{4 \times 2}{6}$$

$$= 4.33\ \Omega$$

Thevenin's Voltage

Since no current flows through 3Ω resistor apply KVL to the fig. (2)

$$4I + 2I - 12 - 15 = 0$$

$$6I = 27$$

$$I = \frac{27}{6} A$$

$$= 4.5 A$$

$$V_{th} = V_{ab} = 2I - 12$$

$$= 2 \times 4.5 - 12$$

$$= -3V$$

–ve sign indicates opposite polority of voltage.

Current flowing through 5Ω resistance.

$$I = \frac{V_{th}}{R_{th} + R_L} = \frac{3}{4.33 + 5}$$

$$\boxed{I = 0.321\text{ A}}$$

The direction of current is from terminal b to a through 5Ω resistor.

Q.11 *Define electrical power and energy.*

Ans. Electrical Energy : When a potential difference (V) is applied across a resistance, a current (I) flows through if for a particular time period (t sec.). A work is said to be done for moving electrons and this work done is called electrical energy.

$$V = \frac{\text{Work done}}{Q}$$

i.e. work done or electrical energy = V.Q as $I = \frac{Q}{t}$

so electrical energy $= VIt = \frac{V^2}{R}t$

Basic unit of electrical energy is joule or watt-second.

Electrical Power : The rate at which work is being done in an electric circuit is called "electrical power".

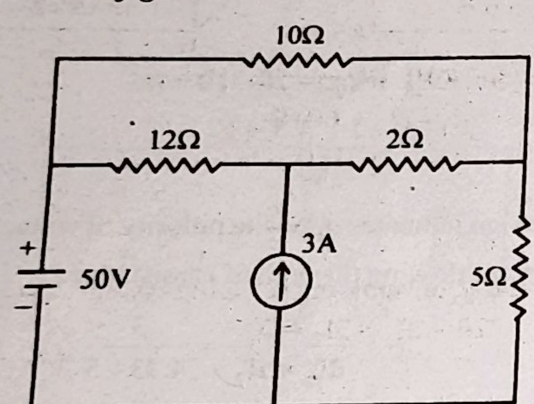
$$\text{Electrical Power} = \frac{\text{Work done in an electric circuit}}{\text{time}}$$

$$P = \frac{V.I.t}{t} = VI$$

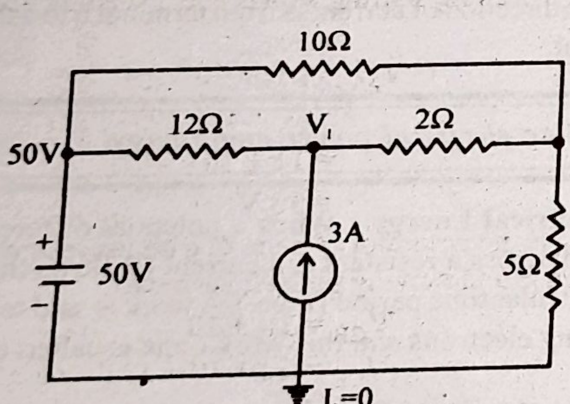
$$P = VI = I^2R = \frac{V^2}{R}$$

The unit of electrical power is watt.

Q.12 ***Calculate current in 2-ohm resistor in the network shown in figure.***



Ans.



Here we solved this circuit by Nodal analysis

ply KCL at node V_1:

$$\frac{V_1-50}{12} - 3 + \frac{V_1-V_2}{2} = 0$$

$$\frac{V_1 - 50 - 36 + 6V_1 - 6V_2}{12} = 0$$

$$7V_1 - 6V_2 = 86 \quad ...(1)$$

Now Apply KCL at node V_2

$$\frac{V_2-50}{10} + \frac{V_2}{5} + \frac{V_2 - V_1}{2} = 0$$

$$\frac{V_2 - 50 + 2V_2 + 5V_2 - 5V_1}{10} = 0$$

$$-5V_1 + 8V_2 = 50$$

$$5V_1 - 8V_2 = -50 \quad ...(2)$$

Now to find the value of V_1 and V_2, eq. (1) is multiply by '5' and eq (2) by '7' and solve-

$$35V_1 - 30V_2 = 430$$
$$35V_1 - 56V_2 = -350$$
$$- \quad + \quad +$$
$$26V_2 = 780$$
$$V_2 = \frac{780}{20}$$
$$= 30V$$

Put V_2 value in eq. (1)

$$7V_1 - (30 \times 6) = 86$$
$$7V_1 = 266$$
$$V_1 = 38\text{ V}$$

current across 2Ω branch

$$I = \frac{V_1 - V_2}{2}$$

$$I = \frac{38-30}{2} = 4A$$

Q.13 (a) ***Explain the Faraday's law of electromagnetic induction. What are eddy currents? Explain the process of generation of eddy currents on the basis of Faraday's law of EMI.***

(b) ***A direct voltage is applied to a capacitor and the voltage across the capacitor is $v = 150\left(1 - e^{-20t}\right)$. After 0.05 sec, the current flow is equal to 1.14 mA. Find the capacitance and the energy stored in the capacitor.***

Ans.(a) Faraday's Law of Electromagnetic Induction: *Refer to Q.4.*

...urrents: When a conductor is kept in a constantly ...g magnetic field, induced currents are produced in ...y of the conductor. These are known as eddy currents. ...urrent were discovered by Focault in 1985, hence ...e also called Focault's currents. Thus, eddy currents ... induced currents setup in the body of a conductor ...he amount of magnetic flux linked with the conductor ...es.

The direction of eddy currents is given by Lenz's law ...ing's right hand rule.

...rocess of Generation of Eddy Currents on the ...of Faraday's Law of EMI: According to Faraday's ...w, whenever the magnetic flux is cut by an electrical ...ctor there will be an induced emf in the conductor. If ...nductor circuit is closed, then the current will also ...te through the circuit and this current is called eddy ...t.

...) Given:

$$v = 150\left(1 - e^{-20t}\right)$$

$$t = 0.05 \text{ sec}$$

$$i = 1.14 \text{ mA}$$

Now $i = v\dfrac{dv}{dt}$

$$\therefore \frac{dv}{dt} = \frac{d}{dt}\left[150\left(1 - e^{-20t}\right)\right]$$

$$= 3000\, e^{-20t}$$

$$= 3000\, e^{-20 \times 0.05}$$

$\therefore$ Capacitance

$$C = \frac{i}{dv/dt}$$

$$= \frac{1.14 \times 10^{-3}}{3000\, e^{-20 \times 0.05}}$$

$$= \frac{0.00114}{1103.64}$$

$$\boxed{C = 1.03\ \mu F}$$

Energy stored in capacitor $= \dfrac{1}{2} Cv^2$

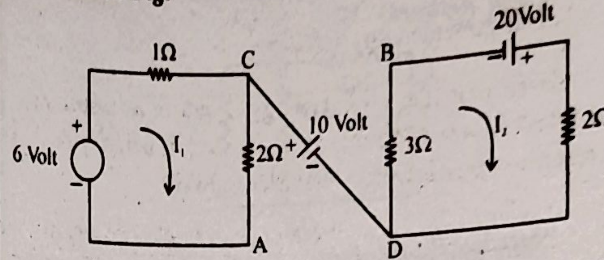
$$= \frac{1}{2} \times 1.03 \times 10^{-6}\left[150\left(1 - e^{-20 \times 0.05}\right)\right]^2$$

$$= \frac{1}{2} \times 1.03 \times 10^{-6} \times [94.82]^2$$

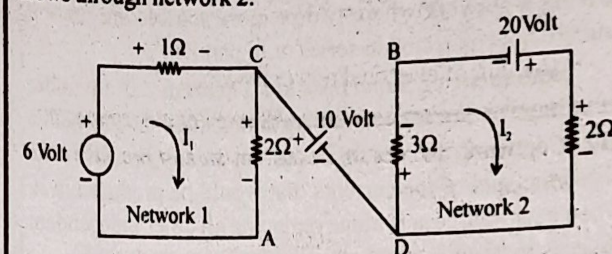
$$= 4.63 \times 10^{-3}\ J$$

$$= 4.63\ mJ$$

Q.14 ***Find the voltage drop between terminal AB, CB and AD in Fig.***



Ans. No current is flowing through CD since the two circuits are connected by only one path and no return path is available. Therefore, I_1 current flows through network 1 and I_2 current flows through network 2.



Applying KVL in network 1, we get

$$-I_1 - 2I_1 + 6 = 0$$

$$-3I_1 = -6$$

$$I_1 = \frac{6}{3} = 2\text{ A}$$

Similarly, on applying KVL in network 2, we get

$$20 - 2I_2 - 3I_2 = 0$$

$$20 = 5I_2$$

$$I_2 = 4\text{ A}$$

Now, voltage V_{AB} is the potential of node A with respect to B, therefore, starting with B and travelling upto A, we have

$$V_{AB} = 3\,I_2 + 10 - 2\,I_1$$

$$= (3 \times 4) + 10 - 2\,(2)$$

$$= 12 + 10 - 4$$

$$= 18\text{ V}$$

V_{CB} is the potential of node C with respect to B. So starting from B and moving upto C, we have

$$V_{CB} = 3I_2 + 10$$

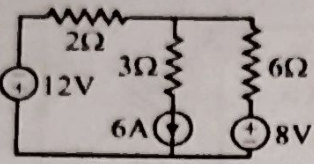
$$V_{CB} = 12 + 10 = 22\text{V}$$

V_{AD} is the potential of node A with respect to D. So starting with D and moving upto A, we have

$$V_{AD} = 10 - 2I = 10 - 2(2) = 10 - 4$$

$$= 6\text{ V}$$

Q.15 ***State and explain superposition theorem. Using Superposition theorem determine the current I in given network.***



OR

State and explain superposition theorem. Illustrate the application of this theorem with reference to an appropriate electric circuit.

Ans. Superposition Theorem : This theorem finds use in solving a network where two or more sources are present and are not connected in series or in parallel.

Statement of Superposition Theorem : If a number of voltage or current sources are acting simultaneously in a linear network, the resultant current in any branch is the algebraic sum of the currents that would be produced in it, when each source acts alone replacing all other independent sources by their internal resistances.

Explanation : In Fig. (a) to apply superposition theorem, let us first take, the source V_1 alone at first replacing V_2 by short circuit [Fig. (b)].

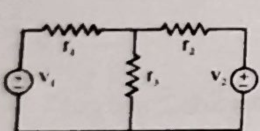


Fig. (a)

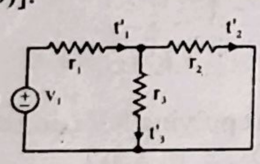


Fig. (b)

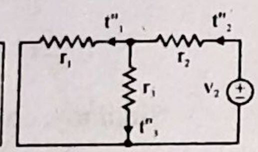


Fig. (c)

Here, $$i'_1 = \frac{V_1}{\frac{r_2 r_3}{r_2 + r_3} + r_1}\ ; \quad i'_2 = i'_1 \frac{r_3}{r_2 + r_3}$$

and $$i'_3 = i'_1 - i'_2$$

Next, removing V_1 by short circuit, let the circuit be energized by V_2 only Fig.(c).

Here, $$i''_2 = \frac{V_2}{\frac{r_1 r_3}{r_1 + r_3} + r_2}$$

and $$i''_1 = i''_2 \frac{r_3}{r_1 + r_3}$$

Also, $$i''_3 = i''_2 - i''_1$$

As per superposition theorem,

$$i_3 = i'_3 + i''_3\ ;\ i_2 = i'_2 + i''_2;\ i_1 = i'_1 + i''_1$$

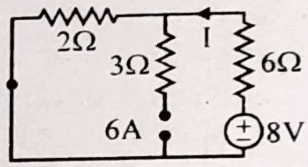
Steps for Solving a Network Using the Principle of Superposition

Step 1 : Take only one independent source of voltage/current and deactivate the other independent voltage/current sources. (For voltage sources, remove the source and short circuit the respective circuit terminals and for current sources, just delete the source keeping the respective circuit terminals open). Obtain branch currents .

Step 2 : Repeat the above step for each of the independent sources.

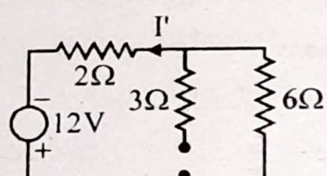
Step 3 : To determine the net branch current utilizing superposition theorem, just add the currents obtained in step-I and step-2 each branch. If the currents obtained in step-I and step-2 are in same direction, just add them; on the other hand, if the respective currents are directed opposite in each step, assume the direction of the clockwise current to be +ve and subtract the current obtained in the next step using the original current. The net current in each branch is then obtained.

Application of Superposition Theorem : According to superposition theorem remove all energy sources except 8V source.



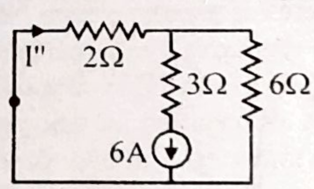
$$I = \frac{8}{8} = 1A$$

Remove all energy sources except 12V voltage source.



$$I' = \frac{12}{8} = \frac{3}{2}$$

Remove all energy sources except 6A.



$$I'' = 6 \times \frac{6}{6+2} = 6 \times \frac{6}{8} = \frac{36}{8} = \frac{9}{2}$$

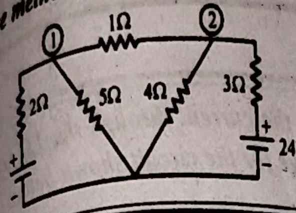
Current through 2Ω = $I + I' - I''$

$$= 1 + \frac{3}{2} - \frac{9}{2}$$

$$= -\frac{4}{2} = -2\text{ A}$$

Now current flowing through the 2Ω (resistance) is −2 A.

...d the current through the 1Ω resistor using node ...ltage method for the circuit shown below.



...et us assume that nodal voltages for nodes 1 and 2 be ...V_2, respectively.

...t node 1, we have (acc. to KCL)

$$\frac{V_1-12}{2}+\frac{V_1}{5}+\frac{V_1-V_2}{1}=0$$

$$\Rightarrow 5(V_1-12)+2V_1+10V_1-10V_2=0$$

$$\Rightarrow 17V_1-10V_2=60 \quad \text{...(i)}$$

At node 2, we have (according to KCL law)

$$\frac{V_2-V_1}{1}+\frac{V_2}{4}+\frac{V_2-24}{3}=0$$

$$\Rightarrow 12V_2-12V_1+3V_2+4V_2-96=0$$

$$\Rightarrow -12V_1+19V_2=96 \quad \text{...(ii)}$$

By eq.(i) and (ii), we have

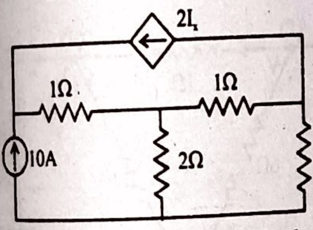
$$V_1=10.35\text{V}$$

$$V_2=11.6\text{V}$$

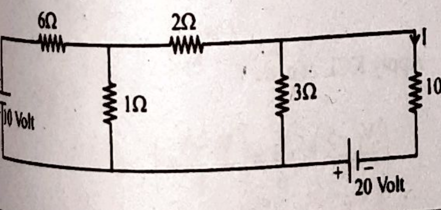
$\therefore$ Current through 1Ω resistor is $=\dfrac{V_2-V_1}{1}$

$= 1.25$ A from node 2 to 1

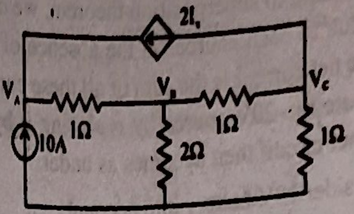
...7(a) *Find I_x in Fig. using Nodal Analysis.*



(b) *Solve for the current I of Fig. by applying the superposition theorem.*



Ans.(a)



Nodal eq. at A

$$\frac{V_A-V_B}{1}-2I_x-10=0 \quad \text{...(1)}$$

$$\frac{V_B-V_A}{1}+\frac{V_B-V_C}{1}+\frac{V_B}{2}=0 \quad \text{...(2)}$$

$$\frac{V_C-V_B}{1}+2I_x+\frac{V_C}{1}=0 \quad \text{...(3)}$$

$$\frac{V_C-V_B}{1}=I_x \quad \text{...(4)}$$

Put eq.(4) in (1) & (3) we get

$$V_A+V_B-2V_C=10$$

$$-2V_A+5V_B-2V_C=0$$

$$0V_A-3V_B+4V_C=0$$

With these equations, V_A, V_B and V_C are to be find out by applying matrix method –

$$\begin{bmatrix}1 & 1 & -2\\ -2 & 5 & -2\\ 0 & -3 & 4\end{bmatrix}\begin{bmatrix}V_A\\ V_B\\ V_C\end{bmatrix}=\begin{bmatrix}10\\ 0\\ 0\end{bmatrix}$$

$$V_B=\frac{\Delta_2}{\Delta}=\frac{\begin{bmatrix}1 & 10 & -2\\ -2 & 0 & -2\\ 0 & 0 & 4\end{bmatrix}}{\begin{bmatrix}1 & 1 & -2\\ -2 & 5 & -2\\ 0 & -3 & 4\end{bmatrix}}=\frac{80}{10}=8\text{V}$$

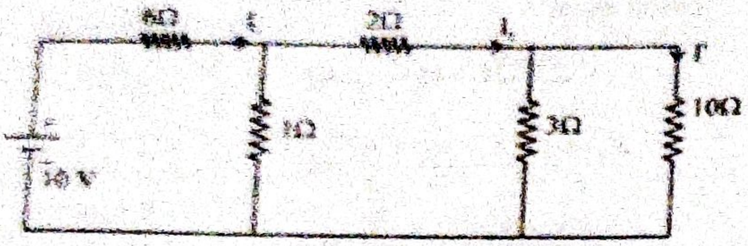
$$V_C=\frac{\Delta_3}{\Delta}=\frac{\begin{bmatrix}1 & 1 & 10\\ -2 & 5 & 0\\ 0 & -3 & 0\end{bmatrix}}{\begin{bmatrix}1 & 1 & -2\\ -2 & 5 & -2\\ 0 & -3 & 4\end{bmatrix}}=\frac{60}{10}=6\text{V}$$

$$I_x=\frac{V_C-V_B}{1}\Rightarrow\frac{6-8}{1}=-2\text{A}$$

It implies current flows in opposite direction given as questions.

Ans.(b) According to superposition theorem, we determine the current due to each source (in the absence of all other sources). The net current is the sum of all these currents. So let us eliminate the 20V source by replacing it by a short circuit. The net circuit then becomes as under.

First consider 10V battery into account.



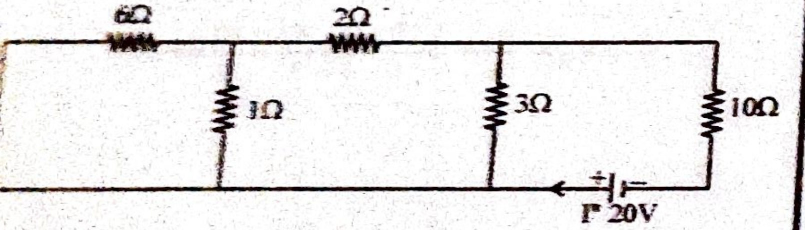
$$I_1 = \frac{10}{\dfrac{\left(\dfrac{10\times3}{10+3}+2\right)\times1}{\left(\dfrac{10\times3}{10+3}+2\right)+1}+6} = \frac{690}{470} = \frac{69}{47}$$

$$\Rightarrow \quad I_2 = \frac{69}{47}\cdot\frac{1}{\dfrac{56}{13}+1} = \frac{13}{47}$$

$$\Rightarrow \quad I' = \frac{13}{47}\cdot\frac{3}{3+10} = \frac{3}{47} = 0.0636\text{A}$$

$$I' = 0.0636\text{ A}$$

Next, we eliminate the 10V source to obtain the circuit shown below :



$$I'' = \frac{20}{\dfrac{\left(\dfrac{6\times1}{6+1}+2\right)\times3}{\left(\dfrac{6\times1}{6+1}+2\right)+3}+10} = -1.744\text{ A}$$

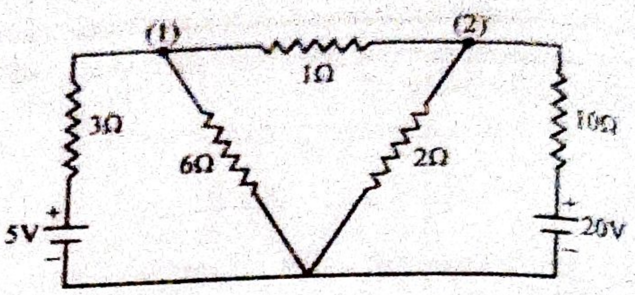
$$I'' = -1.744\text{ A}$$

$$I = I' + I''$$

$$I = 0.064 - 1.74 = -1.68\text{ A}$$

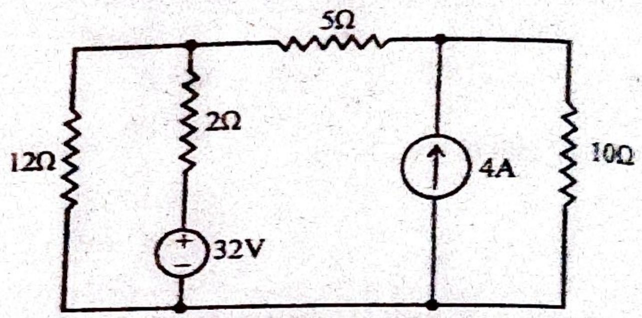
PART C

Q.18 *(a) Find the current through the 1Ω resistor node voltage for the circuit shown below.*



[R.T.U. 2019]

(b) Compute the power dissipated in 9Ω Resistor by applying superposition in circuit of fig.



[Note : Read '10Ω' as '9Ω' Resistor] *[R.T.U. 2019]*

Ans.(a) Let us assume that nodal voltages for nodes 1 and 2 be V_1 and V_2 respectively,

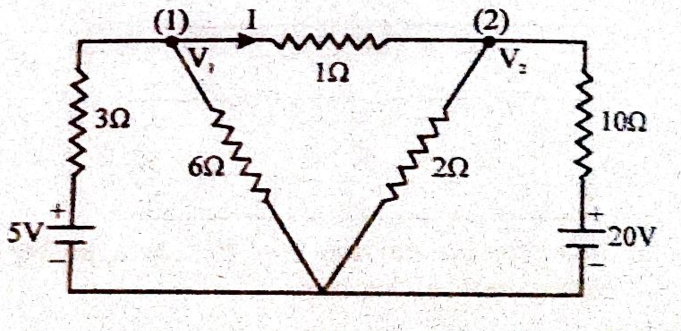


Fig.

Apply KCL at node 1

$$\left(\frac{V_1-5}{3}\right)+\frac{V_1}{6}+\left(\frac{V_1-V_2}{1}\right)=0$$

$$\Rightarrow 2V_1 - 10 + V_1 + 6V_1 - 6V_2 = 0$$

$$\Rightarrow 9V_1 - 6V_2 = 10 \quad \text{... (i)}$$

Apply KCL at node 2

$$\left(\frac{V_2 - 20}{10}\right) + \frac{V_2}{2} + \left(\frac{V_2 - V_1}{1}\right) = 0$$

$$\Rightarrow V_2 - 20 + 5\,V_2 + 10\,V_2 - 10\,V_1 = 0$$

$$\Rightarrow -10\,V_1 + 16\,V_2 = 20 \quad \text{... (ii)}$$

Solving the equation (i) and (ii), we have

$$V_1 = 3.33\text{ V}$$

$$V_2 = 3.33\text{ V}$$

$$\therefore \quad V_1 = V_2 = 3.33\text{ V}$$

Then node (i) and node (ii) at same potential,

Hence, the current doesn't flow in 1 Ω resistor.

$$\therefore \quad \boxed{I = 0}$$

Ans.(b) It should be kept in mind that an ideal voltage source has zero internal resistance whereas an ideal current source has an infinite internal resistance.

(i) **When Voltage Source Acts :** In this condition, current source acts as open circuit.

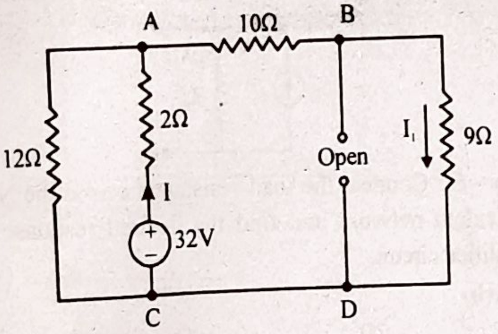


Fig. 1

Now total resistance is given by

$$R_{Total} = 2 + (5 + 9) \parallel 12$$

$$= 2 + \frac{14 \times 12}{14 + 12} = \frac{110}{13}\,\Omega$$

$\therefore$ Current supplied by the battery is

$$I = \frac{32}{110} \times 13 = 3.78\text{ A}$$

At point A, this current divided into two parts

$$I_1 = 3.78 \times \frac{12}{14} = 3.24\text{ A}$$

(ii) **When Current Source Acts :** In this condition, voltage source acts as short circuit.

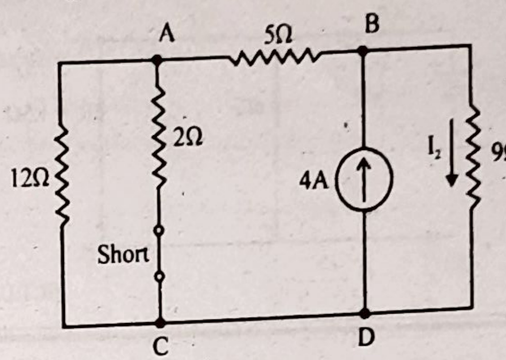


Fig. 2

The resistance of the series-parallel circuit to the left of the line BD is

$$= 5 + (2 \parallel 12) = \frac{47}{7}\,\Omega = 6.71\,\Omega$$

Hence, at point B the current divides

$$I_2 = 4 \times \frac{6.71}{(6.71 + 9)}$$

$$I_2 = 1.71\text{ A}$$

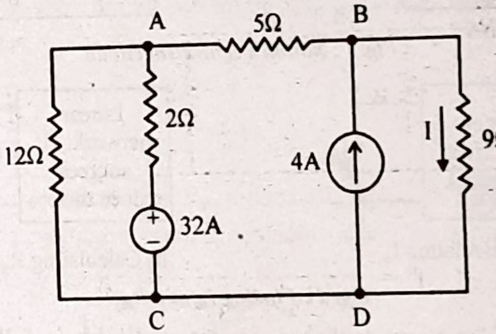


Fig. 3

Hence, total current through 9 Ω resistor is,

$$I = I_1 + I_2$$

$$= 3.24 + 1.71$$

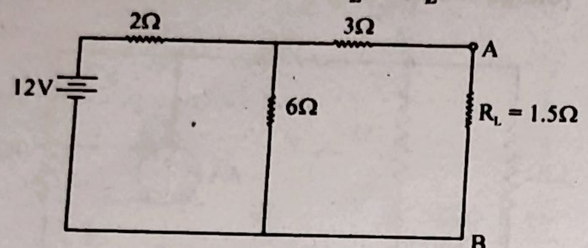
$$\therefore I = 4.95\text{ A}$$

Power dissipated through 9 Ω resistor is,

$$P = I^2R$$
$$= (4.92)^2 \times 9$$
$$= 220.52\ \Omega$$

Q.19 ***(a) State and Explain Norton's theorem.***

(b) Find the load current I_L in R_L.



[R.T.U. 2018]

Ans.(a) The complete statement of Norton's Theorem is "Any linear active bilateral two terminal network can be replaced across its terminals by a independent current source I_{th} in parallel with the single resistance R_{th}", where I_{th} is the short circuit current through the short circuited terminals ab and R_{th} is the equivalent resistance as viewed from the terminals when all the independent sources are reduced to zero *i.e.* leaving their internal resistances.

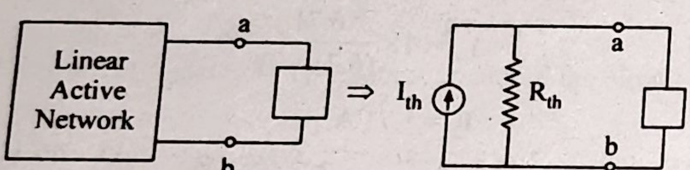
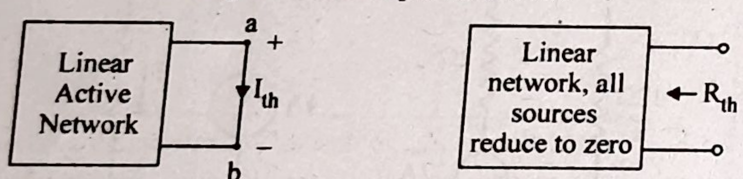


Fig. 1 : Norton's equivalent circuit



(a) Calculating I_{th} (b) Calculating R_{th}

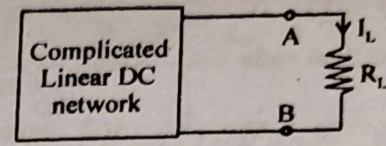
Fig. 2 : Finding I_{th} and R_{th}

The Norton's theorem is not applicable in following conditions :

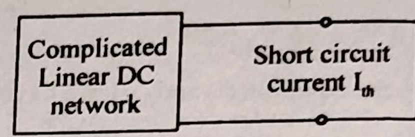
1. The circuit contains any non-linear element.
2. The circuit does not have any source.
3. There is mutual coupling between source and load network.

If the circuit resistance is infinity.

Steps to apply Norton's Theorem

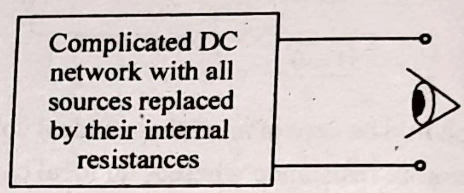


Step – 1 : Remove the load resistance *i.e.* the resistance across which the response is to be found. The terminals will be short circuited.



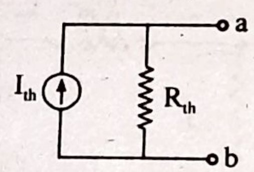
Step – 2 : Using any method like, nodal or loop analysis, find the current flowing through the short circuited terminals.

Step – 3 : Reduce all sources connected in circuit to zero. The voltage sources are replaced with short circuit and current sources are replaced with open circuit. Find the equivalent resistance R_{th} across the open circuited terminals.



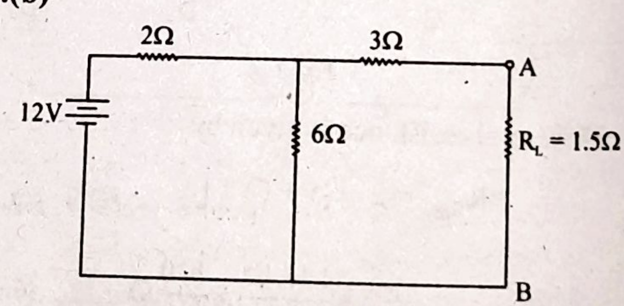
Looking "backward" into the network to find resistance between the load terminals equal, R_{th}.

Step – 4 : Connect the short circuit current I_{th} and resistance R_{th} in parallel to obtain Norton's equivalent network.

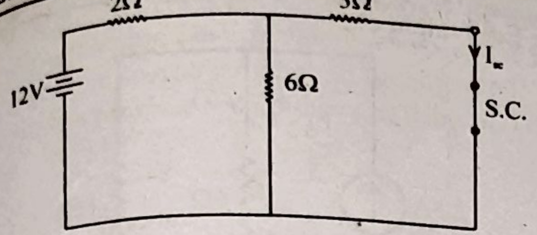


Step – 5 : Connect the load resistance across the Norton's equivalent network and find the desired response in the simplified circuit.

Ans.(b)

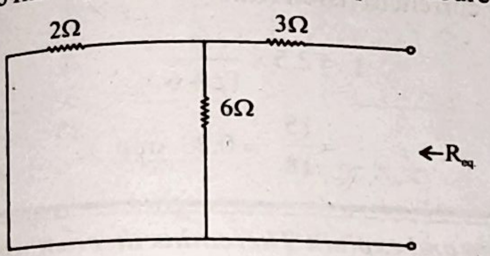


Step-1 : Replace $R_L = 1.5\Omega$ by short circuit and find short ckt current.



$$I_{sc}=\frac{12}{(3\|6)+2}=\frac{12}{4}=3\text{Amp.}\left[\because\frac{3\times6}{3+6}=\frac{18}{9}=2\right]$$

...ep-2 : To find equivalent resistence replace source voltage.

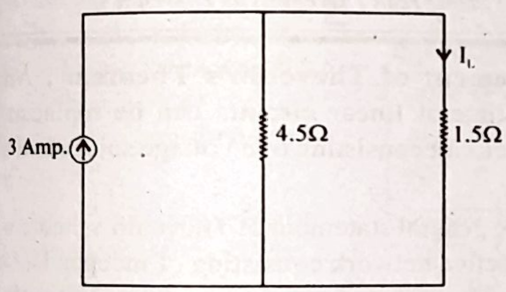


$$R_{eq}=(2\|6)+3$$

$$=\left(\frac{6\times2}{6+2}\right)+3$$

$$=\left(\frac{12}{8}\right)+3=4.5\Omega$$

...ep-3 : Equivalent ckt



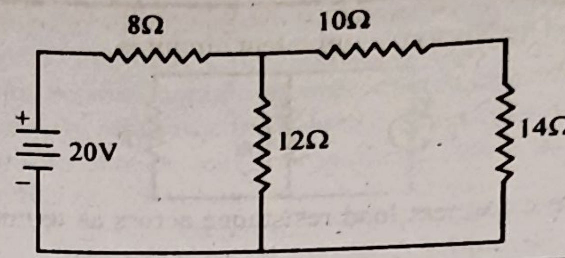
By current division rule-

$$I_L=3\times\frac{4.5}{4.5+1.5}=\frac{3\times4.5}{6}$$

$\boxed{I=2.25\text{ Amp.}}$

...20 ***(a)** State and explain Norton's theorem. Illustrate the application of this theorem with reference to an appropriate electric circuit.*

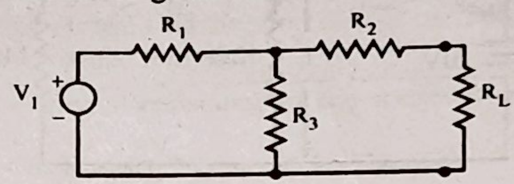
***(b)** Using Norton's theorem determine the current in 12-ohm resistor in the network shown in figure.*



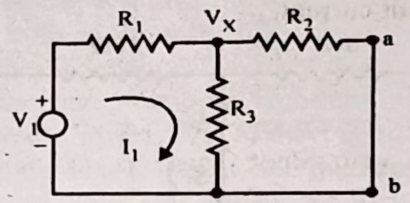
Ans.(a) *Refer to 19(a).*

Explanation

Let the circuit is given, the current in load resistance R_L is to be found using Norton's theorem.



Step 1 – Disconnect the load resistance.



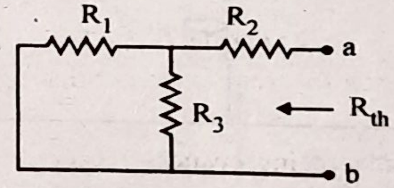
Step 2 – Calculating the short circuit curmet by applying KCL, the current is calculated as

$$\frac{V_x-V_1}{R_1}+\frac{V_x}{R_3}+\frac{V_x}{R_2}=0$$

The short circuit current through the terminals a and b is found as

$$I_{th}=\frac{V_x}{R_2}$$

Step 3 – For calculating R_{th}, reduce all sources to zero. The circuit has voltage source, so replacing it with short circuit.

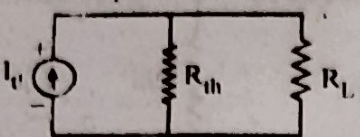


The resistance R_{th} is

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

$$=R_2+\frac{R_1R_3}{R_1+R_3}=\frac{R_1R_2+R_2R_3+R_1R_3}{R_1+R_3}$$

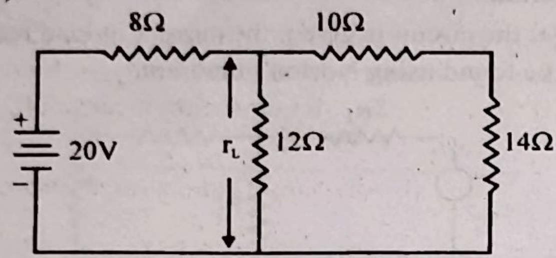
Step 4 – The Norton's equivalent circuit is



Now connect load resistance across ab terminal and find the current I

$$I = I_{th} \times \frac{R_{th}}{R_{th} + R_L}$$

Ans.(b)



Step 1 : Replace 12 Ω resistance by short circuit and find the short circuit current.

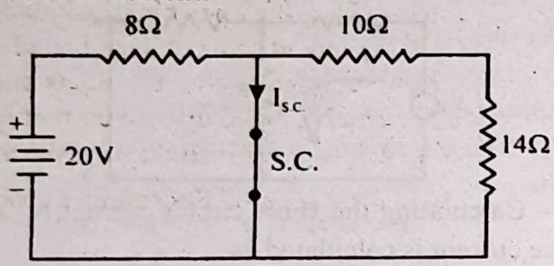
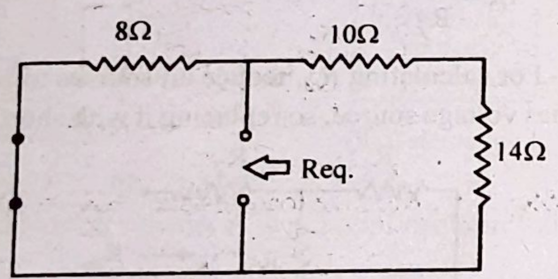


Fig.

Here we seen that whole current will flow in short circuit branch and resistance 10 Ω and 14Ω are negligible.

$$I_{s.c.} = \frac{20}{8} = 2.5\text{Amp}$$

Step 2 : To find equivalent resistance replace source voltage source.

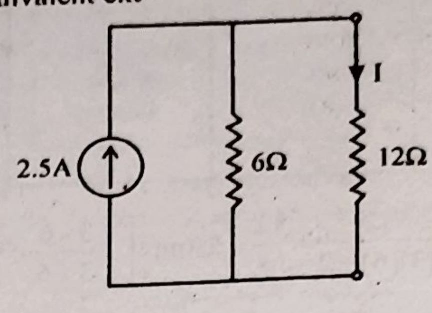


$$R_{eq} = 10 + 14 \parallel 8$$

$$= \frac{24 \times 8}{24 + 8}$$

$$\boxed{R_{eq} = 6\Omega}$$

Step 3 : Equivalent ckt –



By current division Rule –

$$I = 2.5 \times \frac{6}{12 + 6}$$

$$= \frac{15}{18} = 0.83\text{Amp}$$

Q.21 ***State and explain Theremins theorem with suitable example.***

OR

State and explain Thevenin's theorem with suitable example.

OR

State and explain Thevenin's theorem. Illustrate the application of this theorem with reference to an appropriate electric circuit.

[Note : Please read Theremins as Thevenin's]

Ans. Statement of Thevenin's Theorem : Any two terminal bilateral linear circuits can be replaced by an equivalent circuit consisting of a voltage source and a series resistor.

A more general statement of Thevenin's theorem is that any linear active network consisting of independent and/ or dependent voltage and current source (s) and linear bilateral network elements can be replaced by an equivalent circuit consisting of a voltage source in series with a resistance, the voltage source being the open circuited voltage across the open circuited load terminals and the resistance being the internal resistance of the source network looking through the open circuited load terminals.

Explanation : Let us consider a simple DC circuit as shown in Fig. 1(a). We have to find I_L by Thevenin's theorem. In order to find the equivalent voltage source, r_L is removed in Fig. 1(b) and V_{oc} is calculated.

$$V_{oc} = Ir_3 = \frac{V_S}{r_1 + r_3} r_3$$

Next, to find the internal resistance of the network (Thevenin's resistance or equivalent resistance) in series with V_{oc} the voltage source is removed (deactivated) by a short circuit (as the source does not have any internal resistance) as shown in Fig.1(a).

$$R_{Th} = r_2 + \frac{r_1 r_3}{r_1 + r_3}$$

As per Thevenin's theorem, the equivalent circuit being Fig.1(c).

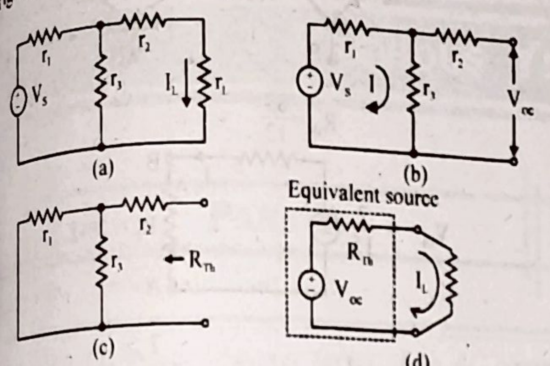


Fig. 1 : (a) A simple DC circuit, (b) Finding of V_{oc} (c) Finding of R_{Th} (d) Finding of I_L forming Thevenin's equivalent circuit

$$I_1 = \frac{V_{oc}}{R_{Th} + r_L} \text{ A}$$

Steps for Solving a Network Utilizing Thevenin's Theorem

Step – 1 : Remove the load resistor (R_L) and find the open circuit voltage (V_{oc}) across the open circuited load terminals.

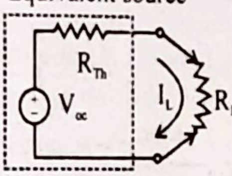


Fig. 2

Step – 2 : Deactivate the constant sources (for voltage source, remove it by internal resistance and for current source delete the source by open circuit) and find the internal resistance (Thevenin's resistance) of the source side looking through the open circuited load terminals. Let this resistance be R_{Th}.

Step – 3 : Obtain Thevenin's equivalent circuit (Fig.2) by placing R_{Th} in series with V_{oc}.

Step – 4 : Reconnect R_L across the load terminals as shown in Fig.2.

$$\text{Obviously I (the load current)} = \frac{V_{oc}}{R_{Th} + R_L}$$

Different Methods of Finding R_{Th} : (Thevenin's equivalent resistance or internal impedance)

(a) For Independent Sources : The most common method of finding R_{Th}, the internal resistance of any linear, bilateral network containing independent current or voltage sources is to deactivate the source by internal resistance *i.e.*, for independent current source, deactivate it by removing the source and for voltage source, deactivate it by shorting it (assuming the internal resistance of the voltage source being zero). Then find the internal resistance of the network looking through the load terminals kept open circuited.

(b) For the circuits containing dependent sources in addition of or in absence of independent sources.

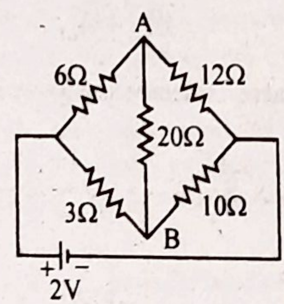
1st Method : Find V_{oc} across the open circuited load terminals by conventional network analysis. Next, short the load terminals and find the short circuit current (I_{sc}) through the short circuited terminals.

The internal resistance of the source network is then obtained as $R_{Th} = \dfrac{V_{oc}}{I_{sc}}$

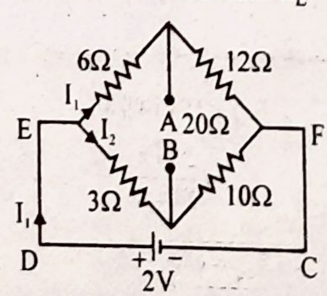
2nd Method: Remove the load resistance and apply a DC driving voltage V_{dc} at the open circuited load terminals. Keep the other independent sources deactivated during this time (*i.e.*, short the voltage source terminals and open the current source terminals). A DC driving current i_{dc} will flow in the circuit from the load terminals due to application of V_{dc}.

The internal resistance of the source network is then obtained as $R_{Th} = \dfrac{V_{dc}}{i_{dc}}$

Application of Thevenin's Theorem



Step – 1 : Remove load resistance $R_L = 20\Omega$.



Applying Kirchoff's Voltage Law (KVL) for path DEAFC

$$I_1 = \frac{2}{6+12} = \frac{2}{18} = \frac{1}{9}\,A$$

Step – 2 : Applying Kirchoff's Voltage Law (KVL) for path DEBFC

$$I_2 = \frac{2}{3+10} = \frac{2}{30} = \frac{1}{15}\,A$$

For path AEB using KVL

$$V_A + 6I_1 - 3I_2 = V_B$$

$$V_A - V_B = -6I_1 + 3I_2 = -6\times\frac{1}{9} + 3\times\frac{1}{15};$$

$$V_{th} - \frac{2}{3} + \frac{1}{5} = \frac{-10+3}{15} = -\frac{7}{15}\ \text{Volt.}$$

B is at higher potential.

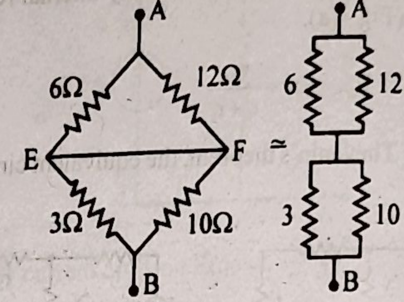
Step – 3 : Short circuit voltage sources

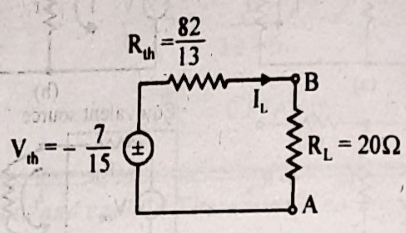
$$R_{Th} = 6\,||\,12 + 3\,||\,10 = \frac{6\times12}{6+12} + \frac{3\times10}{3+10}$$

$$= \frac{72}{18} + \frac{30}{13} = \frac{1476}{18\times13}$$

The Thevenin's Resistance

$$R_{Th} = \frac{82}{13}\,\Omega$$





$$\text{Load current } I_L = \frac{V_{th}}{R_{th} + R_L} = \frac{-\frac{7}{15}}{\frac{82}{13} + 20},$$

$$I_L = 0.0177\,A$$

□□□

AC Circuits 2

Previous Years Questions

Part A

Q.1 *What is meant by power factor of an AC circuit? What is its minimum value and its maximum value?* *[R.T.U. 2019]*

Ans. Power Factor of an AC Circuit : The power factor is very important term, used mainly in AC circuits. The power factor is basically known as the cosine of angle between voltage and current. But the power factor can be defined in the following ways :

(i) Power factor = $\cos \phi$

(ii) Power factor = $\frac{\text{Resistance}}{\text{Impedance}} = \frac{R}{Z}$

(iii) Power factor = $\frac{\text{Average power}}{\text{RMS voltage} \times \text{RMS current}}$

$$= \frac{P}{V_{rms} \cdot I_{rms}}$$

Power Factor is given as $\cos \phi$

∴ Minimum value of power factor = 0 (For purely inductive and capacitive circuit)

and

Maximum value of power factor = 1 (for purely resistive circuit)

Q.2 *The current in a 2H inductor varies at a rate of 2 A/s. Find the voltage across the inductor and the energy stored in the magnetic field after 2s.* *[R.T.U. 2019]*

Ans. From the given data

$$L = 2H ; \frac{di}{dt} = 2 \text{ A/s}$$

$$\therefore \quad v = L\frac{di}{dt}$$

$$= 2 \times 2 = 4 \text{ Volt}$$

The energy stored is given as

$$W = \frac{1}{2}Li^2$$

$$W = \frac{1}{2} \times 2 \times 2^2 = 4 \text{ joules}$$

Q.3 *Explain the concept of RMS value.* *[R.T.U. 2018]*

Ans. RMS Value (Root Mean Square Value) : As the effective value of a sine wave is zero for the entire cycle hence in order to get the effective value, we compute the capability of the sine wave in terms of its heating power. This is represented by the root mean square value (also known as effective value) and can be represented by

$x_{rms} = \sqrt{\frac{1}{T}\int_0^T x(t) \cdot dt}$ for a periodic function, T being the time period.

Hence for sinusoidal voltage waves,

$$V_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} (V_m \sin \omega t)^2 d(\omega t)}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{2\pi} V_m^2 \left[\frac{1 - \cos 2\omega t}{2}\right] d(\omega t)}$$

$$= \sqrt{\frac{V_m^2}{2}} = \frac{V_m}{\sqrt{2}} = 0.707\,V_m$$

It should be noted that the average heating effect produced during one cycle is

$$I^2R = \left(\frac{I_m}{\sqrt{2}}\right)^2 R = \frac{1}{2} I_m^2 R$$

Q.4 *Write the advantages of AC over DC.*

Ans. Advantages of AC Over DC : There are many advantages of using AC over DC, some of them are :

1. The generation of AC is efficient and economical due to high transmission efficiency.
2. AC can be increased or decreased efficiently with the help of transformer. Due to this, the efficient transmission and distribution is possible with AC.
3. AC motors are cheaper and efficient as compared to DC motors.
4. The control circuit for AC system (switch, gear, etc.) are simpler than DC system because the AC have natural zero.
5. The communication is done through AC only.

Q.5 *Draw the phasor diagram of pure inductor and pure capacitor.*

Ans.

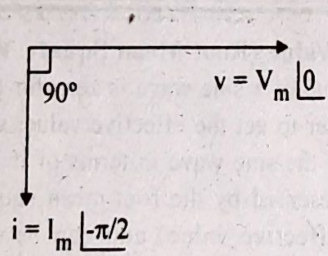


Fig. 1 : Phasor Diagram of Pure Inductor

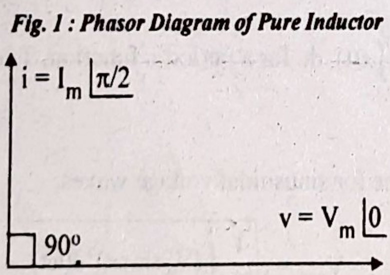


Fig. 2 : Phasor Diagram of Pure Capacitor

Q.6 *Differentiate between AC and DC.*

Ans. Difference between AC and DC

S.No.	DC	AC
1.	Current do not change with respect to time.	Current changes periodically with respect to time.
2.	The frequency of DC is zero.	The general frequency of AC in India is 50 Hz.
3.	It cannot be changed.	It can easily be changed with help of transformer.
4.	Energy loss in transmission is more..	Energy loss in transmission is less.
5.	DC has a single parameter *i.e.* resistance (R).	AC has three basic parameters *viz.* resistance (R), inductance (L), capacitance (C).

Q.7 *What is peak factor?*

Ans. Peak Factor : The peak factor of an AC wave is the ratio of maximum value of wave to its RMS value

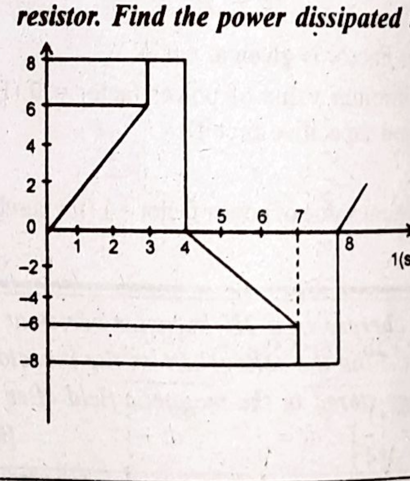
$$K_p = \frac{\text{Maximum Value}}{\text{RMS value}}$$

PART B

Q.8 *A voltage wave has the variation as shown in figure. Determine-*

(a) The average and RMS value of voltage. *[R.T.U. 2019]*

(b) If the voltage of part (1) is applied to a 50 Ω resistor. Find the power dissipated in watts.



[R.T.U. 2019]

...s. (a) The Average and RMS Value of Voltage : The waveform is a symmetrical wave because positive and negative half are same, so considering only half part. The wave has X axis in sec, so the time in sec will be considered so the integration will be with respect to t.

The wave has period time of T = 8 sec., after 8 sec. wave starts repeating itself.

$T = 8$ sec.

For symmetrical wave, only half cycle *i.e.*

$$\frac{T}{2} = 4 \text{ sec.}$$

The wave has two section between 0 to 4 sec. First section 0 to 3 sec. (OA) and second section 3 to 4 sec. (BC).

The equation for first section OA is

$$v = mt + c$$

$$\text{slope } m = \frac{y_2 - y_1}{x_2 - x_1}$$

Two points on the line are (0, 0) and (3, 6)

$$\therefore m = \frac{6-0}{3-0} = \frac{6}{3} = 2$$

So $v = 2t + c$

Putting (0, 0) in the line c = 0, so final equation

$$v = 2t \qquad 0 \le t \le 3$$

The equation for second section BC is

$v = 8$ (Because horizontal line, slope 0) $3 \le t \le 4$

The equation of wave is

$$v = \begin{cases} 2t & 0 \le t \le 3 \\ 8 & 3 \le t \le 4 \end{cases}$$

Average Value

$$V_{av} = \frac{2}{T}\int_0^{T/2} v\,dt = \frac{2}{8}\int_0^4 v\,dt = \frac{1}{4}\left[\int_0^3 v\,dt + \int_3^4 v\,dt\right]$$

$$= \frac{1}{4}\left[\int_0^3 2t\,dt + \int_3^4 8\,dt\right]$$

$$= \frac{1}{4}\left[\left\{2.\frac{t^2}{2}\right\}_0^3 + 8(t)_3^4\right] = \frac{1}{4}[9+8]$$

$$= \frac{17}{4} = 4.25\,V$$

RMS Value or Effective Value

$$V_{rms} = \sqrt{\frac{1}{4}\int_0^4 v^2\,dt} = \sqrt{\frac{1}{4}\left[\int_0^3 v^2\,dt + \int_3^4 v^2\,dt\right]}$$

$$= \sqrt{\frac{1}{4}\left[4\left\{\frac{t^3}{3}\right\}_0^3 + 64(t)_3^4\right]} = \sqrt{\frac{1}{4}(4 \times 9 + 64)}$$

$$= \sqrt{\frac{1}{4}[36+64]}$$

$$= \sqrt{\frac{1}{4}(100)} = \sqrt{25} = 5\,V$$

Ans. (b) The power dissipated in 50Ω resistor is :

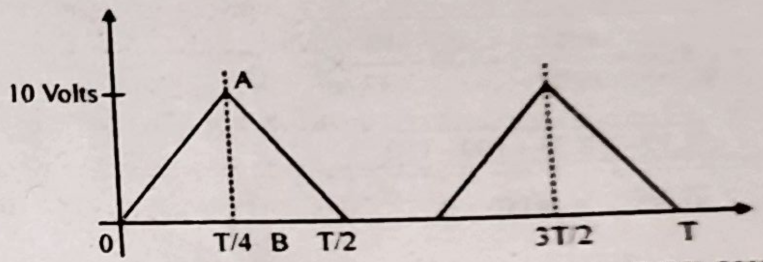
$$P = I_{rms}^2 R$$

$$= \frac{V_{rms}^2}{R} \qquad (\because V_{rms} = I_{rms} R)$$

$$P = \frac{5^2}{50} = \frac{25}{50}$$

$$P = 0.5 \text{ watt}$$

Q.9 ***Find the average and RMS values of the given wave shape over one cycle.***



[Note : See exact figure in Solution] **[R.T.U. 2018]**

Ans.

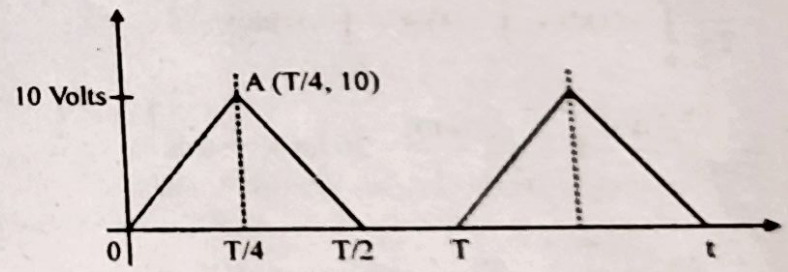


Fig.

$$v(t) = \begin{cases} \dfrac{40t}{T} & 0 < t < T/4 \\ \dfrac{-40t}{T} + 20 & T/4 < t < T/2 \\ 0 & T/2 < t < T \end{cases}$$

$$V_{rms} = \sqrt{\frac{1}{T}\left[\int_0^{T/4} v^2 dt + \int_{T/4}^{T/2} v^2 dt + \int_{T/2}^{T} v^2 dt\right]}$$

$$= \sqrt{\frac{1}{T}\left[\int_0^{T/4}\left(\frac{40t}{T}\right)^2 dt + \int_{T/4}^{T/2}\left(\frac{-40t}{T}+20\right)^2 dt + 0\right]}$$

$$= \sqrt{\frac{1}{T}\left[\frac{(40)^2}{T^2}\int_0^{T/4} t^2 dt + \int_{T/4}^{T/2}\left\{\left(\frac{-40}{T}\right)^2 t^2 + 400 + \left(2\times\frac{-40t}{T}\times 20\right)\right\}dt\right]}$$

$$= \sqrt{\frac{1}{T}\left[\frac{(40)^2}{T^2}\left(\frac{t^3}{3}\right)_0^{T/4} + \frac{(40)^2}{T^2}\left[\frac{t^3}{3}\right]_{T/4}^{T/2} + 400[t]_{T/4}^{T/2} - \frac{(40)^2}{T}\left[\frac{t^2}{2}\right]_{T/4}^{T/2}\right]}$$

$$= \sqrt{\frac{1}{T}\left[\frac{40^2}{T^2}\times\frac{T^3}{192} + \frac{40^2}{T^2}\left[\frac{T^3}{24}-\frac{T^3}{192}\right] + 400[T/4] - \frac{40^2}{2T}\left[\frac{T^2}{4}-\frac{T^2}{16}\right]\right]}$$

$$= \sqrt{\frac{1}{T}\left[\frac{40^2}{T^2}\times\frac{T^3}{192} + \frac{40^2}{T^2}\frac{(8T^3-T^3)}{192} + 400\times\frac{T}{4} - \frac{40^2}{2T}\times\frac{3T^2}{16}\right]}$$

$$= \sqrt{8.33 + \frac{40^2}{192}\times 7 + 100 - \frac{40^2}{32}\times 3}$$

$$= \sqrt{8.33+58.33+100-150}$$

$$= \sqrt{16.66} = 4.081\text{V}$$

$$V_{avg} = \frac{1}{T}\int_0^T v(t)dt$$

$$= \frac{1}{T}\left[\int_0^{T/4} v(t)dt + \int_{T/4}^{T/2} v(t)dt + \int_{T/2}^{T} v(t)dt\right]$$

$$= \frac{1}{T}\left[\int_0^{T/4}\frac{40t}{T}dt + \int_{T/4}^{T/2}\left(\frac{-40t}{T}+20\right)dt + \int_{T/2}^{T} 0\,dt\right]$$

$$= \frac{1}{T}\left[\frac{40}{T}\cdot\left[\frac{t^2}{2}\right]_0^{T/4} - \frac{40}{T}\cdot\left[\frac{t^2}{2}\right]_{T/4}^{T/2} + 20[t]_{T/4}^{T/2} + 0\right]$$

$$= \frac{1}{T}\left[\frac{40}{2T}\cdot\frac{T^2}{16} - \frac{40}{2T}\left[\frac{T^2}{4}-\frac{T^2}{16}\right] + 20[T/4]\right]$$

$$= \frac{1}{T}\left[\frac{40T}{32} - \frac{40}{2T}\times\frac{3T^2}{16} + \frac{20T}{4}\right]$$

$$= \frac{40}{32} - \frac{120}{32} + \frac{20}{4}$$

$$= \frac{40-120+160}{32}$$

$$= \frac{80}{32} = 2.5\text{ V}$$

Q.10 (a) ***Find the average value of Periodic sine wave for complete cycle which is clamped to half its Positive Maximum Value.***

(b) ***Establish relation of Power Consumed in balanced 3-Phase Load.*** **[R.T.U. 2019]**

Ans.(a) Average Value : The average value of an alternating quantity is the sum of all its values divided by the total number of values. A waveform has continuous variable values with repeat to time, t or angle θ where $\theta = \omega t$. The pattern of wave repeats after every cycle. The sum of all the values in a cycle is determined by the integration of its values over a period of time. A full cycle is formed in 2π radians or in T seconds where T is the time period. A symmetrical wave is one where the positive half cycle is exactly the same as the negative half cycle. If we integrate the values for a complete cycle and take its average over one cycle, the quantity becomes equal to zero. The average value if calculated over a complete cycle would become zero.

$$V_{av} = \frac{1}{2\pi}\int_0^{2\pi} v\,d\theta = 0$$

or, $$V_{av} = \frac{1}{2\pi}\int_0^{T} v\,dt = 0$$

Average value of a sinewave or any other symmetrical wave over a complete cycle is zero

For a half-wave or full-wave rectified waves we need to calculate the average value. When we intend to calculate the average value of such waves, we calculate the average value for one half-cycle.

The average value is calculated as

$$V_{av} = \frac{1}{\pi}\int_0^{\pi} v\,d\theta$$

or, $$V_{av} = \frac{2}{T}\int_0^{\frac{T}{2}} v\,dt$$

Ans.(b) Three Phase Power and Current : The power taken by a circuit (single or three phase) is measured in watts

W (or kW). The product of the voltage and current is the apparent power and measured in VA (or kVA). The relationship between kVA and kW is the power factor (pf) :

$$kW = kVA \times pf$$

This can also be express as,

$$kVA = \frac{kW}{pf}$$

Q.11 *Define cycle, frequency and time period with reference to AC quantity.*

Ans. Cycle, Frequency and Time Period

The cycle is the duration in which the AC quantity completes its one rotation and after which the wave starts repeating its values. AC quantities are periodic in nature *i.e.* they repeat after a definite time interval.

Set of complete positive and negative values of an alternating quantity is known as cycle.

Time period is the time interval in seconds, after which a waveform starts repeating itself, *i.e.* one complete cycle. The time period is denoted by 'T'. In other words, the time taken in completing one cycle is known as "Time period". The frequency is the reciprocal of the time period *i.e.* it indicates the number of cycles per second.

$$f = \frac{1}{T}\ Hz \text{ or cycles per second}$$

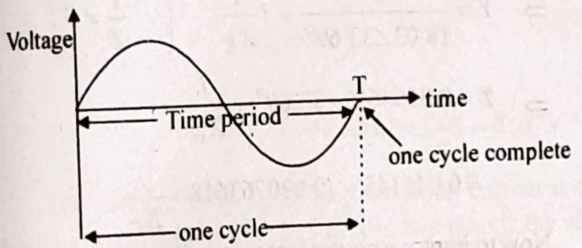


Fig. : Periodic Wave

Q.12 *How to convert polar form to Rectangular form? Explain with example.*

Ans. Let the phasor is given into polar form as $P = |P| \underline{\pm\phi}$

To find rectangular form simply convert this as

$$P = |P| \left[e^{\pm j\phi}\right] = |P| \left[\cos\phi \pm j\sin\phi\right]$$

$$= |P|\cos\phi \pm j|P|\sin\phi = A \pm jB$$

where $A = |P|\cos\phi$

$B = |P|\sin\phi$

Example

$$I = 10\,\underline{|-60^o} \quad \text{(Polar form)}$$

$$= 10\left[\cos(-60) + j\sin(-60)\right]$$

$$= 10\left[0.5 - j(0.866)\right]$$

$$= 5 - j8.66 \quad \text{(Rectangular form)}$$

Q.13 (a) *State and explain form factor and peak factor with required formulas.*

(b) *A supply voltage of 230V, 50Hz is fed to a residential building. Write down its equation for instantaneous value.*

Ans.(a) Form Factor (K_f)

The form factor of an alternating quantities defined as the ratio of r.m.s. value to the average value,

$$\text{Form factor, } \boxed{K_f = \frac{\text{r.m.s value}}{\text{Average value}}}$$

The form factor for sinusoidal alternating currents or voltages can be obtained as,

$$K_f = \frac{0.707\, I_m}{0.637\, I_m}$$

$K_f = 1.11$ for sinusoidal varying quantity

Crest or Peak Factor (K_p)

The peak factor for an alternating quantity is defined as the ratio of maximum value to the r.m.s. value.

$$\text{Peak factor, } \boxed{K_P = \frac{\text{Maximum value}}{\text{r.m.s. value}}}$$

The peak factor for sinusoidal varying alternating currents and voltages can be obtained as,

$$K_P = \frac{I_m}{0.707\, I_m} = 1.414$$

for sinusoidal waveform

Ans.(b) $E = E_0 \sin(2\pi f t)$

$$E = \left(\sqrt{2} \times 230\right)\sin\left(2\pi \times 50 \times t\right)$$

$$E = 325.26 \text{ Sin } 100\,\pi\, t$$

Above equation is the required equation

Q.14 *Three sinusoidal voltages acting in series are given by :*

$V_1 = 10 \sin 440t$

$V_2 = 10\sqrt{2}\sin(440t - 45^\circ)$

$V_3 = 20 \cos 440t$

find :

(a) The expression for resultant voltage

(b) Frequency and RMS value of resultant voltage

Ans. Here, $v_1 = 10 \sin 440t$

$v_2 = 10\sqrt{2}\sin(440t - 45^\circ)$;

$v_3 = 20 \cos 440t$

$$= 20\sin\left(440t + \frac{\pi}{2}\right)$$

All the three voltages are shown vectorially in fig.

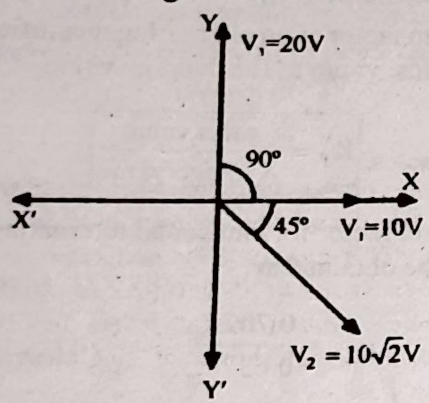


Fig. : Phasor diagram

Resolving voltage along X-axis and Y-axis, we get,

$V_{xx} = 10\cos 0^\circ + 10\sqrt{2}\cos(-45^\circ) + 20\cos 90^\circ$

$$= 10 + 10\sqrt{2} \times \frac{1}{\sqrt{2}} + 0 = 20$$

$V_{yy} = 10\sin 0^\circ + 10\sqrt{2}\sin(-45^\circ) + 20\sin 90^\circ$

$$= 0 - 10\sqrt{2} \times \frac{1}{\sqrt{2}} + 20 = 10$$

Maximum value of resultant voltage,

$$V_{max} = \sqrt{(V_{xx})^2 + (V_{yy})^2}$$

$$= \sqrt{20^2 + 10^2} = 22.36\text{V}$$

Phase angle,

$$\phi_r = \tan^{-1}\frac{V_{yy}}{V_{xx}} = \tan^{-1}\frac{10}{20}$$

$$= 26.56^\circ \text{ or } 0.1476\,\pi \text{ radian}$$

(a) Expression for resultant voltage,

$$v_r = 22.36\sin(440t + 0.1476\,\pi)$$

(b) Frequency, $f = \dfrac{440}{2\pi} = 70\text{Hz}$

RMS value of resultant voltage,

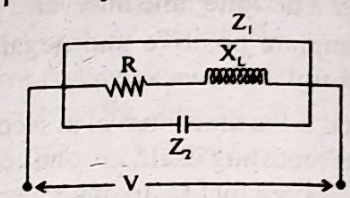
$$V_{rms(r)} = \frac{V_m}{\sqrt{2}} = \frac{22.36}{\sqrt{2}} = 15.81\text{V}$$

Q.15 *A series RL circuit has resistance and reactance of 15 ohm and 10 ohm respectively. Calculate the value of capacitor which when connected across the series combination in parallel, the system attain unity power factor.*

Ans. Given : $R = 15\Omega$

$X_L = 10\Omega$

So $Z_1 = 15 + j10 = 18.03\angle 33.69^\circ\,\Omega$



$$Z_2 = -jX_C = X_C\angle -90^\circ\,\Omega$$

Total impedance of circuit is :

$$\frac{1}{Z} = \frac{1}{Z_1} + \frac{1}{Z_2}$$

$$\Rightarrow \quad Y = \frac{1}{18.03\angle 33.69^\circ} + j\frac{1}{X_C} \qquad \left[\because \frac{1}{Z} = Y\right]$$

$$\Rightarrow \quad Y = 0.05546\angle -33.69^\circ + \frac{j}{X_C}$$

$$= 0.046145 - j0.030763618 + \frac{j}{X_C}$$

Now to improve power factor to unity means the circuit must be purely resistive *i.e.* imaginary term should be zero.

$$\therefore \quad -0.030763618 + \frac{1}{X_C} = 0$$

$$\Rightarrow \quad \frac{1}{X_C} = 0.030763618$$

$$\Rightarrow \quad X_C = 32.506$$

$$\Rightarrow \quad \frac{1}{\omega C} = 32.506$$

$$\Rightarrow \quad C = \frac{1}{2\pi f \times 32.506} \qquad \{\because f = 50\text{Hz}\}$$

$\Rightarrow\ C = \dfrac{1}{2\pi \times 50 \times 32.506}$

$\Rightarrow\ C = 9.79 \times 10^{-5} = 97.9\ \mu F$

Q.16 For a single phase sinusoidal waveform find the Average and RMS values in terms of maximum value. Determine the form factor of sine wave.

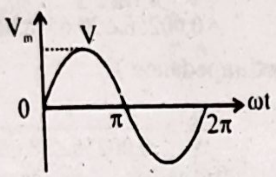
Ans. Average Value : In general, the average value of a periodic function x(t) can be represented as

$$x_{av} = \frac{1}{T}\int_0^T x(t)dt$$

[Where T is period of the function]

In case of a sinusoidal wave as shown in Fig. the average value will be represented as

$$V_{av} = \frac{1}{\pi}\int_0^{\pi} V_m \sin\omega t\, d(\omega t)$$



It may be noted that the average value of the sinusoidal voltage wave is computed for $\frac{1}{2}$ cycle as the average value of the sine wave would be zero for a complete cycle.

i.e. $$V_{av} = \frac{1}{\pi}[-V_m \cos\omega t]_0^{\pi}$$

$$= \frac{V_m}{\pi}[-\cos\pi + \cos 0] = \frac{2V_m}{\pi} = 0.637V_m$$

The average value I_{av} of an alternating current is that steady current which transfers across any circuit the same charge as is transferred by that alternating current.

RMS Value (Root Mean Square Value) : As the effective value of a sine wave is zero for the entire cycle hence in order to get the effective value, we compute the capability of the sine wave in terms of its heating power. This is represented by the root mean square value (also known as effective value) and can be represented by

$x_{rms} = \sqrt{\frac{1}{T}\int_0^T x(t)\cdot dt}$ for a periodic function, T being the time period.

Hence for sinusoidal voltage waves,

$$V_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi}(V_m \sin\omega t)^2 d(\omega t)}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{2\pi} V_m^2\left[\frac{1-\cos 2\omega t}{2}\right]d(\omega t)}$$

$$= \sqrt{\frac{V_m^2}{2}} = \frac{V_m}{\sqrt{2}} = 0.707\,V_m$$

It should be noted that the average heating effect produced during one cycle is

$$I^2R = \left(\frac{I_m}{\sqrt{2}}\right)^2 R = \frac{1}{2}I_m^2 R$$

Form Factor : Two alternating waves of same peak values and same frequency may look different *i.e.*, their configurations are different. Form factor represents this change in configuration of periodic waves where the frequencies and amplitudes are same. Form factor is defined as the ratio of R.M.S. and average values.

The form factor (FF) of a sinusoidal voltage wave is then,

$$= \frac{V_{rms}}{V_{av}} = \frac{0.707\,V_m}{0.637\,V_m} = 1.11$$

Q.17 Two coils A and B are connected in series across a 240 V, 50Hz supply. The resistance of A is 5Ω and the inductance of B is 0.015 H. If the input from the supply is 3kW and 2kVAR, find the inductance of A and the resistance of B. Calculate the voltage across such coil.

Ans. The kVA triangle is shown in Fig.(b) and the circuit in Fig.(a). The circuit kVA is given by $S = \sqrt{P^2 + Q^2}$

$$kVA = \sqrt{3^2 + 2^2} = 3.606$$

In $\quad VA = 3606$ Volt-Ampere

$$\text{Circuit current} = \frac{3606}{240} = 15.03\,A$$

Resistance of B

$\because\quad I^2 R_{net} = P$

$\therefore\quad (15.032)^2 (R_A + R_B) = 3000$

$\Rightarrow\quad R_A + R_B = 13.3\ \Omega$

$\therefore\quad R_B = 13.3 - 5 = 8.3\ \Omega$

Now, impedance of the whole circuit is given by

$$Z = \frac{240}{15.03} = 15.97\Omega$$

$\therefore\quad X_A + X_B = \sqrt{Z^2 - (R_A + R_B)^2}$

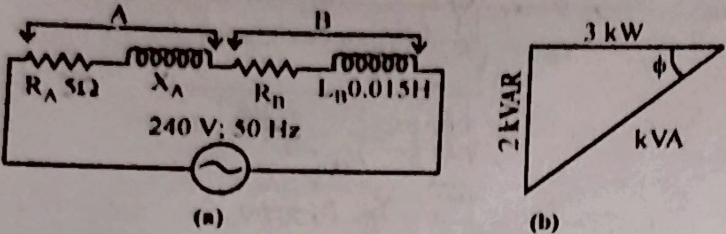


Fig.

$$X_A + X_B = \sqrt{15.97^2 - 13.3^2} = 8.843\Omega$$

Now, $X_B = 2\pi \times 50 \times 0.015 = 4.713\Omega$

$\therefore$ $X_A = 8.843 - 4.713 = 4.13\Omega$

$\therefore$ $2\pi \times 50 L_A = 4.13$

Inductance of A

$\therefore$ $L_A = 0.0132$ H (approx.)

Now, $Z_A = \sqrt{R_A^2 + X_A^2} = \sqrt{5^2 + 4.13^2} = 6.485\Omega$

Potential drop across coil

$$A = IZ_A = 15.03 \times 6.485 = 97.5\text{ V}$$

$$Z_B = \sqrt{8.3^2 + 4.713^2} = 9.545\Omega$$

Potential drop across coil

$$B = IZ_B = 15.03 \times 9.545 = 143.5\text{V}$$

Q.18 (a) ***A circuit consists of the following in parallel :***

(i) A resistor of 500 Ω

(ii) An inductance of 2H

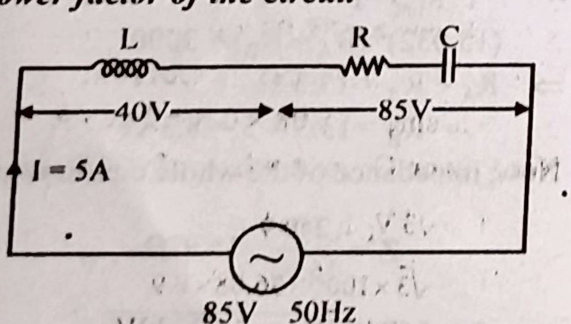
(iii) A capacitor of 10 μF

A source voltage of 200V, 50Hz is applied, determine the total current drawn from the supply complex power, active power, reactive power and power factors of the circuit.

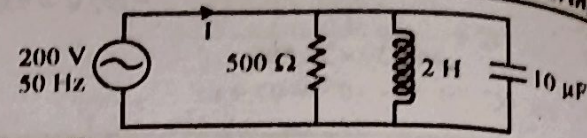
(b) ***A pure inductor, a non inductive resistor and a capacitor are connected in series as shown in fig. below, determine :***

(i) The value of resistance, inductance and capacitance

(ii) Power factor of the circuit



Ans.(a)



In above figure

$$Y_1 = \frac{1}{500\angle 0^\circ} = 0.002\text{ mho}$$

$\left(\begin{array}{l} X_L = 2\pi f L \\ \quad = 2 \times 3.14 \times 50 \times 2 \\ \quad = 628\Omega \\ \omega = 2\pi f \end{array} \right)$

$$Y_2 = \frac{1}{X_L\angle 90^\circ} = \frac{1}{628\angle 90^\circ} = 0.0015\angle -90^\circ\text{ mho}$$

$$Y_3 = \frac{1}{X_C\angle -90^\circ} = \omega C\angle 90^\circ = 0.0031\angle 90^\circ\text{ mho}$$

$\therefore$ Y(net admittance)

$= 0.002\angle 0^\circ + 0.0015\angle -90^\circ + 0.0031\angle 90^\circ$

$= 0.002 - j0.0015 + j0.0031$

$= 0.002 + j0.0016$

$= 0.00256\angle 38.65^\circ$ mho

$\therefore$ Z (net impedance)

$$= \frac{1}{Y} = \frac{1}{0.00256\angle 38.65^\circ}$$

$= 390.625\angle -38.65^\circ\Omega$

Thus the input current (I)

$$= \frac{V}{Z} = \frac{200}{390.625\angle -38.65^\circ}$$

$$I = 0.51\angle 38.65^\circ\text{ A}$$

Complex power (S)

$= VI^* = 200\angle 0^\circ \times 0.51\angle 38.65^\circ$

$= 102\angle 38.65^\circ$ VA

Active power (P)

$= VI\cos\phi = 102\cos 38.65^\circ$

$= 79.66$ Watt

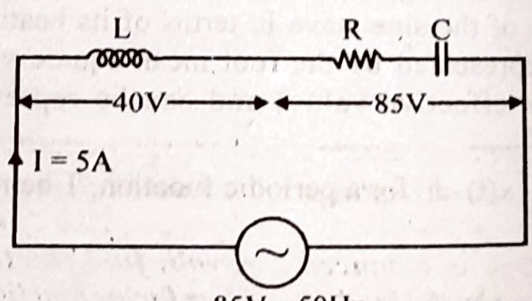
Reactive power (Q)

$= VI\sin\phi = 102\sin 38.65^\circ$

$= 63.7$ VAR

Power factor $= \cos\phi = \cos 38.65^\circ = 0.78$ leading

Ans.(b)



$$V_L = 40V;\ V_{RC} = 85V;\ V = 85V$$

$$V = \sqrt{V_R^2 + (V_L - V_C)^2}$$

$$85 = \sqrt{V_R^2 + (V_L - V_C)^2} \quad ...(1)$$

and

$$V_{RC} = \sqrt{V_R^2 + V_C^2}$$

$$85 = \sqrt{V_R^2 + V_C^2} \quad ...(2)$$

From equation (1) and (2)

$$V_R^2 + (V_L - V_C)^2 = V_R^2 + V_C^2$$

$$V_L - V_C = V_C$$

$$\therefore \quad V_C = \frac{V_L}{2} = \frac{40}{2} = 20V$$

Substitute $V_C = 20V$ in equation (2)

$$85 = \sqrt{V_R^2 + (20)^2}$$

$$V_R = \sqrt{85^2 - 20^2} = 82.61V$$

(i) **Values of R, L and C**

$$R = \frac{V_R}{I} = \frac{82.61}{5} = 16.522\Omega$$

$$X_L = \frac{V_L}{I} = \frac{40}{5} = 8\Omega$$

$$L = \frac{X_L}{2\pi f} = \frac{8}{2 \times 3.14 \times 50} = 0.0254 = 25.4\text{mH}$$

$$X_C = \frac{V_C}{I} = \frac{20}{5} = 4\Omega$$

$$C = \frac{1}{2\pi f X_C} = \frac{1}{2 \times 3.14 \times 50 \times 4} = 796.17\mu F$$

(ii) Power factor of the circuit

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

$$Z = R + jX_L - jX_C$$

$$Z = 16.5 + j8 - j4 = 16.5 + j4$$

$$\phi = \tan^{-1}\left(\frac{4}{16.5}\right) \Rightarrow \phi = 13.627^\circ$$

Power factor

$$\cos\phi = \cos(13.627^\circ) = 0.7 \text{ (Lagging)}$$

Q.19 ***The power readings of two wattmeters are +15 kW and – 4 kW for a three phase load. If the supply voltage is balanced 440 volt, find the true power drawn by the load, the power factor and line current.***

Ans. **True Power** $W = W_1 + W_2$

$$= 15 - 4$$

$$= 11\text{ kW}$$

And power factor angle

$$\phi_0 = \tan^{-1}\left[\sqrt{3}\left(\frac{W_1 - W_2}{W_1 + W_2}\right)\right]$$

$$= \tan^{-1}\left[\sqrt{3}\left(\frac{15+4}{15-4}\right)\right]$$

$$= \tan^{-1}\left[\sqrt{3}\left(\frac{19}{11}\right)\right]$$

$$\phi_0 = \tan^{-1}(2.9916) = 71.51$$

Power Factor

$$(\cos\phi_0) = .317$$

Line Current

$$(W) = \sqrt{3} V_L I_L \cos\phi_0$$

$$11 \times 10^3 = \sqrt{3} \times 440 \times I_L \times 0.317$$

$$I_L = 45.53\text{ A}$$

Q.20 ***Calculate the active and reactive components of current in each phase of a star connected 1000 Volt, 3-phase generator supplying 50 kW at a lagging power factor of 0.8. Find the new output if the current is maintained at the same value with a power factor 0.9 lag.***

Ans. Given : $V_L = 1000$ V, pf = 0.8, P = 50 kW

Total active power

$$P = 3 V_{PH} \cdot I_{PH} \cdot \cos\phi = \sqrt{3} V_L I_L \cos\phi$$

$$I_L = \frac{P}{\sqrt{3} V_L \cos\phi} = \frac{50 \times 1000}{\sqrt{3} \times 1000 \times 0.8}$$

$$I_L = 36.08\text{ A}$$

In star connection

$$I_L = I_{PH} = 36.08\text{ A}$$

Active Component of Current

$$= I_P \cos\phi = 36.08 \times 0.8 = 28.86\text{ A}$$

Reactive Component of Current

$$= I_P \sin\phi = 36.08 \times 0.6 = 21.65\text{ A}$$

Net Power Output when pf = 0.9

$$P = \sqrt{3} V_L I_L \cos\phi$$

$$P = \sqrt{3} \times 1000 \times 36.08 \times 0.9$$

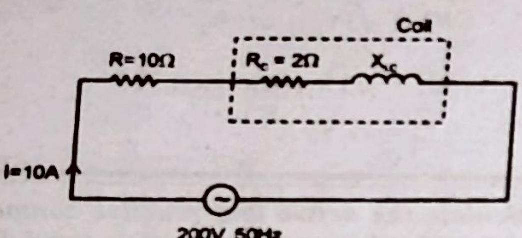
$$P = 56243\text{ W or } 56.24\text{ kW}$$

PART C

Q.21 *(a) A non-inductive resistance of 10Ω is connected in series with an inductive coil across 200V, 50 Hz a.c. supply. The current drawn by the series combination is 10 A. The resistance of the coil is 2Ω. Design a circuit first and then calculate inductance of the coil, power factor of the coil, Power factor of the circuit and voltage across the coil.* **[R.T.U. 2019]**

(b) Distinguish between active powers, reactive power and apparent power with the help of power triangle. **[R.T.U. 2019]**

Ans.(a)



Let the coil has two parameters R_C = 2Ω and X_{LC}.

The resistance R = 10Ω is connected in series with coil.

Due to series circuit, all the elements will have same current.

Now,

$$|Z| = \frac{V}{I} = \frac{200}{10} = 20\Omega$$

(a) Calculation of Inductance of coil

Here, $Z = R + R_C + jX_{LC}$

$Z = 10 + 2 + jX_{LC}$

$$|Z| = \sqrt{(12)^2 + (X_{LC})^2}$$

$$20 = \sqrt{(12)^2 + (X_{LC})^2}$$

$X_{LC} = 16\Omega$

$X_{LC} = WL = 16$

$\Rightarrow 2\pi \times 50\ (L) = 16$

$$\Rightarrow L = \frac{16}{2\pi \times 5\upsilon} = 0.050\ H$$

$= 0.050$ H

(b) Power factor of coil

$$\cos\phi = \frac{R_C}{\sqrt{R_C^2 + X_{LC}^2}}$$

$$= \frac{2}{\sqrt{(2)^2 + (16)^2}} = \frac{2}{16.12} = 0.12$$

$\cos\phi = 0.124$

(c) Power factor of circuit

$$\cos\phi = \frac{R + R_C}{\sqrt{(R + R_C)^2 + X_{LC}^2}}$$

$$= \frac{12}{\sqrt{(12)^2 + (16)^2}} = \frac{12}{20} = 0.60$$

$\cos\phi = 0.60$

(d) Voltage across the coil

$V_L = I\ X_L$

$= (10)(16)$

$V_L = 160$ votls

Ans.(b) Active Power (P) : The real part of complex power is active power. It is the power actually consumed in any electrical circuit. As only resistance consumes or dissipates energy, so the circuit which has no resistance have zero active power. As it is actually utilized by the circuit, it is known as active power or true power or real power.

The active power in any circuit is

$$P = V_{rms} \cdot I_{rms} \cos\phi = I_{rms}^2 \cdot R$$

The unit of active power is Watt. Actually the active power is the (voltage) × (current component), which is in phase with voltage *i.e.* phase difference zero.

Reactive Power (Q) : The inductance and capacitance in half cycle the power is consumed (stored) by the element and in next half cycle, the power is again returned back to the supply, so the circuit actually not consuming any power in complete cycle. As this power is actually not consumed and flowing in the circuit reactive part (reactance) so it is known as "reactive power".

This component does not contribute any real power. This power is only to maintain magnetic or electrostatic field across inductor and capacitor.

The reactive power is

$$Q = V_{rms} \cdot I_{rms} \sin\phi = I_{rms}^2 X$$

The unit of reactive power is VAR (Volt Ampere Reactive). The reactive power only exists when the circuit contains inductor or capacitor. This is the multiplication of voltage and current component (which have 90° phase difference with voltage).

Apparent Power (S) : This is the complex power in the circuit. The vector combination of active power and reactive power is known as apparent power. As we know, the active power is in phase with voltage and reactive power have ± 90° phase difference with voltage and current the apparent power becomes

$$S = \sqrt{(\text{Active power})^2 + (\text{Reactive power})^2}$$

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

$$= \sqrt{(V_{rms} \cdot I_{rms} \cos\phi)^2 + (V_{rms} \cdot I_{rms} \sin\phi)^2}$$

$$= V_{rms} \cdot I_{rms} \sqrt{\cos^2\phi + \sin^2\phi} = V_{rms} \cdot I_{rms}$$

Here V_{rms} and I_{rms} are rms value of voltage and current. The unit of apparent power is volt ampere (VA). Apparent power in complex term is

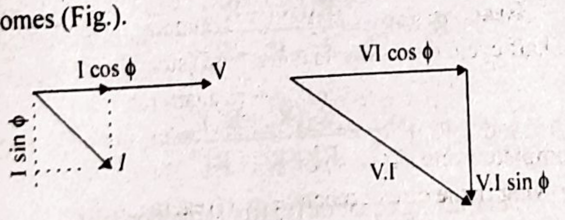
$$S = P + jQ$$

As the active power is $I_{rms}^2 R$ and reactive power is $I_{rms}^2 X$. then

$$S = \sqrt{(I_{rms}^2 R)^2 + (I_{rms}^2 X^2)} = I_{rms}^2 \sqrt{R^2 + X^2} = I_{rms}^2 Z$$

where R is resistance, X is reactance and Z is impedance.

Power Triangle : As the phasor diagram, the voltage and current are known, if the voltage is multiplied by current components ($I\cos\phi$ and $I\sin\phi$), then the active and reactive power are found ($VI\cos\phi$, $VI\sin\phi$), so the phasor diagram becomes (Fig.).



(a) V – I Phasor (b) Power phasor

Fig. 1 : Phasor Diagram

If the voltage is multiplied by current then the apparent power is calculated. The resultant phasor diagram represents active, reactive and apparent power, so it is known as power triangle.

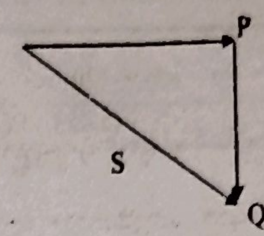


Fig. 2 : Power Triangle

Q.22 ***(a) A 400 V, three-phase supply feeds an unbalanced three-wire star-connected load. The branch impedances of the load are $Z_R = (4 + j8)\ \Omega$. $Z_y = (3 + j4)\ \Omega$ and $Z_B = (15 + j20)\ \Omega$. Find the line current and voltage across each phase impedance. Assume R Y B phase sequence.*** *[R.T.U. 2019]*

(b) Write down star to delta and delta to star transformation. *[R.T.U. 2019]*

Ans.(a) Assuming phase sequence R.Y.B. and taken V_{RY} as reference power then we have,

$$V_{RY} = 400\angle 0^\circ \text{ V}$$

$$V_{YB} = 400\angle -120^\circ$$

$$V_{BR} = 400\angle +120 \text{V}$$

Impedances,

$$Z_R = 4 + j8 = 8.94\angle 63.43$$

$$Z_Y = 3 + j4 = 5\angle 53.13$$

$$Z_B = 15 + j20 = 25\angle 53.13$$

Now line current

$$I_R = \frac{V_{RY}}{Z_R + Z_Y + \frac{Z_R Z_Y}{Z_B}} - \frac{V_{BR}}{Z_B + Z_R + \frac{Z_B Z_R}{Z_Y}}$$

$$= \frac{400\angle 0}{8.94\angle 63.43 + 5\angle 53.13 + \frac{(8.94\angle 63.43)(5\angle 53.13)}{25\angle 53.13}}$$

$$- \frac{400\angle 120}{25\angle 53.13 + 8.94\angle 63.43 + \frac{(25\angle 53.13)(8.94\angle 63.43)}{5\angle 53.13}}$$

$$= \frac{400\angle 0}{15.67\angle 60.16} - \frac{400\angle 120}{78.36\angle 60.16} = 28.42\angle -69.10\text{A}$$

$$I_Y = \frac{V_{YB}}{Z_Y + Z_B + \frac{Z_Y Z_B}{Z_R}} - \frac{V_{RY}}{Z_R + Z_Y + \frac{Z_R Z_Y}{Z_B}}$$

$$= \frac{400\angle -120}{5\angle 53.13 + 25\angle 53.13 + \frac{(5\angle 53.13)(25\angle 53.13)}{8.94\angle 63.43}} - \frac{400\angle 0}{15.67\angle 60.16}$$

$$= \frac{400\angle -120}{43.83\angle 49.86} - \frac{400\angle 0}{15.67\angle 60.16}$$

$$= 29.86\angle 136.56 \text{ A}$$

$$I_B = \frac{V_{BR}}{Z_B + Z_R + \frac{Z_B Z_R}{Z_Y}} - \frac{V_{YB}}{Z_Y + Z_B + \frac{Z_Y Z_B}{Z_R}}$$

$$\Rightarrow \frac{400\angle 120}{78.36\angle 60.16} - \frac{400\angle -120}{43.83\angle 49.86}$$

$$= 13.02\angle 27.53 \text{ Ampere}$$

Voltage drop across impedance,

$$V_R = I_R . Z_R$$

$$= (28.42\angle -69.10) \times 8.94\angle 63.43$$

$$= 254.07\angle -5.67 \text{V}$$

$$V_Y = I_Y . Z_Y$$

$$= (29.86\angle 136.56) \times (5\angle 53.13)$$

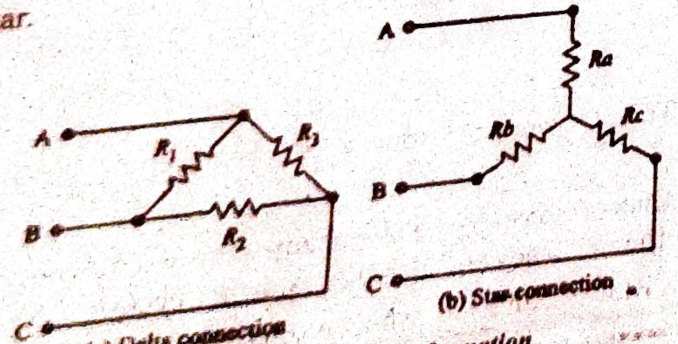
$$= 149.3\angle -170.31 \text{V}$$

$$V_B = I_B . Z_B$$

$$= (13.02\angle 27.53) \times (25\angle 53.13)$$

$$= 325.5\angle 80.66 \text{ Volts}$$

Ans.(b) Delta-Star and Star-Delta Transformation : Delta-star and star-delta transformation is quite useful to simplify certain network problems. When three resistance (R_1, R_2 and R_3) are connected together to form a closed mesh as shown in fig. 1(a), the connection of resistances is called delta. If the three resistances (R_a, R_b and R_c) are connected as per fig. 1(b), the connection of resistances is known as star.



(a) Delta connection

(b) Star connection

Fig. 1: Delta-Star Transformation

Similarly, $$R_b = \frac{R_1R_2}{R_1+R_2+R_3} \quad ...(viii)$$

and $$R_c = \frac{R_2R_3}{R_1+R_2+R_3} \quad ...(ix)$$

The above relationships expressing the equivalent star connected resistances may be remembered by the following statement. The equivalent star resistance connected to a terminal is equal to the product of the two delta resistances connected to the same terminal divided by the sum of the delta resistances.

(ii) Star to Delta Conversion : Now a star connected as shown in fig. 3 will be replaced by the equivalent delta connected network. The basic equations guiding this conversion remain the same as before, i.e., equation (iii), (iv) and (v). Dividing equation (ix) by equation (vii),

$$\frac{R_2}{R_1} = \frac{R_c}{R_a}$$

or $$R_2 = R_1 \times \frac{R_c}{R_a} \quad ...(x)$$

Again, dividing equation (ix) by equation (viii),

$$\frac{R_3}{R_1} = \frac{R_c}{R_b}$$

or $$R_3 = R_1\frac{R_c}{R_b} \quad ...(xi)$$

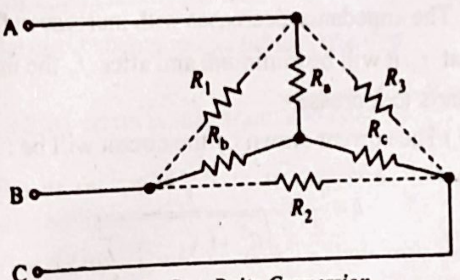


Fig. 3 : Star-Delta Conversion

Substituting the values of R_2 and R_3 from equation (x) and (xi) into equation (vii),

$$R_a = \frac{R_1 \times R_1 \times R_c / R_b}{R_1 + R_1 \times R_c/R_a + R_1 \times R_c/R_b}$$

$$= \frac{R_1 \times R_c/R_b}{1 + R_c/R_a + R_c/R_b}$$

or $$R_a = \frac{R_1 \times R_c/R_b}{(R_aR_b + R_bR_c + R_aR_c)/R_aR_b}$$

$$\therefore \quad R_1 = \left(\frac{R_aR_b}{R_c}\right)\left[\frac{R_aR_b + R_bR_c + R_aR_c}{R_aR_b}\right]$$

or $$R_1 = R_a + R_b + \frac{R_aR_b}{R_c} \quad ...(xii)$$

Similarly, $$R_2 = R_b + R_c + \frac{R_bR_c}{R_b} \quad ...(xiii)$$

and $$R_3 = R_a + R_c + \frac{R_aR_c}{R_b} \quad ...(xiv)$$

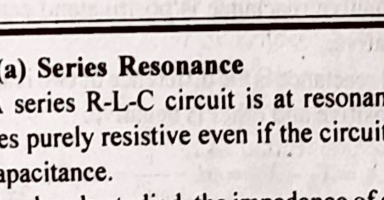
Relationship expressed by equation (xii) to (xiv) are used to convert a star connected network into its equivalent delta and may be remembered by the following statement. The equivalent delta resistance between the two terminals is the sum of two star resistances connected to those two terminals plus the product of these two resistance divided by the remaining third star resistance.

Q.23 ***Draw Frequency response curve of a***

(a) Series R-L-C circuit and discuss the effect of varying frequency over wide range upon the circuit parameters : R, X_L, X_C, X, Z, I and power factor with all necessary graphs. ***[R.T.U. 2018]***

(b) Prove that for the given circuit the resonant frequency

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$$



[R.T.U. 2018]

Ans. (a) Series Resonance

A series R-L-C circuit is at resonance, if the circuit behaves purely resistive even if the circuit have inductance and capacitance.

As already studied, the impedance of series RLC circuit will be

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

The condition for resonance is $Z = R$ so $X = 0$

$$X_L - X_C = 0 \ ; \ X_L = X_C$$

Under resonance, the imaginany terms will be zero.

The frequency at which the resonance occurs in the AC series RLC circuit is known as resonance frequency (f_o).

At resonance condition

As $X_L = X_C$

$$\omega L = \frac{1}{\omega C}$$

So at resonance, resonance frequency f_o will be

$$\omega_0 L = \frac{1}{\omega_0 C} \quad ; \quad \omega_0^2 = \frac{1}{LC}$$

$$\omega_0 = \frac{1}{\sqrt{LC}} \quad ; \quad 2\pi f_o = \frac{1}{\sqrt{LC}}$$

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

The circuit resonance will depends on the three parameters i.e. frequency (f), inductance (L) and capacitance (C). The circuit resonance will not depends on the value of resistance. The resonance in the circuit can be achieved by varying one parameter (f, L, C) and maintaining other two parameters constants.

The circuit impedance will be

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

$$= R + j\left(\omega L - \frac{1}{\omega C}\right) = R + j\left(2\pi fL - \frac{1}{2\pi fC}\right)$$

The following points can be seen

(1) The $X_L = 2\pi fL$, so inductive reactance is directly proportional to frequency i.e.

$$X_L \propto f$$

(2) The $X_C = \frac{1}{2\pi fC}$, so capacitive reactance is inversely proportional to frequency i.e.

$$X_C \propto \frac{1}{f}$$

(3) The inductive reactance is positive and capacitive reactance is negative.

(4) The total reactance is the difference of two reactances because one is positive and other is negative.

$$X = X_L - X_C = \omega L - \frac{1}{\omega C} = 2\pi fL - \frac{1}{2\pi fC}$$

(5) At zero frequency $(f = 0)$

$$X_L = 0; X_C = \infty$$

(6) At infinite frequency $(f \to \infty)$

$$X_L = \infty; X_C = 0$$

(7) As frequency increase from zero, the inductive reactance increase and capacitive reactance decrease.

$$f \uparrow \xrightarrow{\text{then}} X_L (\propto f) \uparrow, X_C \left(\propto \frac{1}{f}\right) \downarrow$$

So the net reactance $X = X_L - X_C$ decreases with increase in frequency.

(8) At resonance frequency $\left(f_o = \frac{1}{2\pi\sqrt{LC}}\right)$, the reactances becomes equal $(X_L = X_C)$, so net reactance will be zero and the circuit impedance will be equal to the resistance. This will be minimum because $Z = \sqrt{R^2 + (X_L - X_C)^2}$, before and after f_o, $(X_L - X_C)$ have some value and that will be squared i.e. always positive.

(9) Before f_o, the capacitive reactance is more than inductive reactance, so circuit behaviour will be capacitive, at f_o, the circuit behaviour will be resistive and after f_o, the circuit behaviour will be inductive.

Frequency	Reactance	Behaviour	Z	I
Before f_o	$X_C > X_L$	Capacitive from ∞	Reduce from 0	Increase
At f_o	$X_L = X_C$	Resistive	R	I_{max}
After f_o	$X_L > X_C$	Inductive towards ∞	go	Decrease towards 0

(10) The net impedance of circuit will be infinity, when $f = 0$ and $f = \infty$.

The impedance decreases with increase in frequency till f_o, at f_o it will be minimum and after f_o the impedance again starts to increase.

(11) The current drawn by the circuit will be :

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

so the current behaviour is just opposite of inductance, it will be zero at $f = 0$ and $f \to \infty$, increase as frequency increase, at f_o it will be maximum $\left(\frac{V}{R}\right)$ and after that again starts decreasing.

The power factor of circuit will be

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

So the power factor will be leading if frequency is small (capacitive), the power factor will be unity at $f_o\left(\frac{R}{R}\right)$ and power factor will be lagging if frequency is large (inductive).

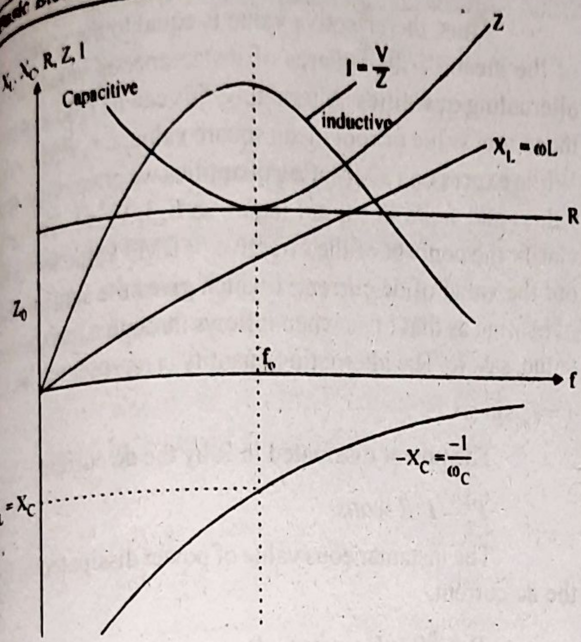


Fig. : Various Parameters at Series Resonance

The main points about from Fig. about series resonance ...e :

(1) Net reactance is zero.

(2) The imaginany part of impedance is zero.

(3) The resonant frequency is $f_o = \frac{1}{2\pi\sqrt{LC}}$.

(4) Impedance of circuit is minimum and equal to the ...sistance of circuit.

(5) The circuit behaviour is purely resistive.

(6) Circuit current is maximum and equal to $\frac{V}{R}$.

(7) Power factor of circuit is unity i.e. voltage and ...rrents are in-phase.

(8) The reactive power is zero i.e. inductive power is ...ual to capacitive power.

(9) Only active power is supplied and it is maximum at ...sonance.

(10) Voltage drop across inductor is equal to voltage drop ...ross capacitor.

(11) The current will be controlled by resistance only.

(12) The voltage and resistance have no effect on ...sonance.

...ns.(b) The condition for resonance can be derived as ...llows :

The admittance of branch containing L and R_L is given

$$Y_L = \frac{1}{R_L + jX_L} = \frac{R_L - jX_L}{R_L^2 + X_L^2}$$

$$= \frac{R_L - j\omega L}{R_L^2 + \omega^2 L^2} \quad ...(1)$$

The admittance of the branch containing C is given by :

$$Y_C = \frac{1}{-jX_C} = j\frac{1}{X_C} = j\frac{1}{\frac{1}{\omega C}} = j\omega C \quad ...(2)$$

Hence, total admittance of parallel circuit is given by :

$$Y = Y_L + Y_C$$

$$\therefore \quad Y = \frac{R_L - j\omega L}{R_L^2 + \omega^2 L^2} + j\omega C$$

$$\therefore \quad Y = \frac{R_L}{R_L^2 + \omega^2 L^2} + j\left[\omega C - \frac{\omega L}{R_L^2 + \omega^2 L^2}\right] \quad ...(3)$$

At resonance, imaginary part i.e. susceptance becomes zero. Let the resonant frequency of parallel resonant circuit be denoted by ω_0. Thus, at $\omega = \omega_0$.

$$\omega_0 C - \frac{\omega_0 L}{R_L^2 + \omega_0^2 L^2} = 0$$

$$\therefore \quad \omega_0 C = \frac{\omega_0 L}{R_L^2 + \omega_0^2 L^2}$$

$$C(R_L^2 + \omega_0^2 L^2) = L$$

$$\therefore \quad R_L^2 + \omega_0^2 L^2 = \frac{L}{C}$$

$$\therefore \quad \omega_0^2 L^2 = \frac{L}{C} - R_L^2$$

$$\therefore \quad \omega_0^2 = \frac{1}{LC} - \frac{R_L^2}{L^2}$$

$$\therefore \quad \omega_0 = \sqrt{\frac{1}{LC} - \frac{R_L^2}{L^2}}$$

$$\text{i.e.} \quad f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R_L^2}{L^2}}$$

Q.24 ***Find the r.m.s. value of sine wave for complete cycle which is clamped to half its negative Maximum Value.*** **[R.T.U. 2018]**

Ans. Effective or RMS Value

The effective value or RMS value of an alternating quantity is determined by considering equivalent heating effect.

The effective value of an alternating quantity (say current) is that the value of dc current when flowing through a given circuit element (say a resistance element) for a given time will produce the same amount of heat as produced by the alternating current when flowing through the same circuit element for the same time.

Let I be the equivalent effective value of the ac flowing through a resistance element R for a time t, then the amount of heat produced, H is expressed as

$$H \propto I^2 Rt = KI^2 Rt \text{ calories} \quad ...(1)$$

Now, let the alternating current i, be passed through the same resistance R for the same time t, as shown in Fig. Current i has been divided into n intervals and the magnitudes are i_1, i_2, i_3 etc. Heat produced in t seconds by the ac is equal to the sum of heat produced in n intervals of time during the time t. This can be expressed as

$$H \propto i_1^2 R\frac{t}{n} + i_2^2 R\frac{t}{n} + i_3^2 R\frac{t}{n} + ... + i_n^2 R\frac{t}{n}$$

$$\propto \frac{\left(i_1^2 + i_2^2 + i_3^2 + ... + i_n^2\right)}{n} Rt$$

$$= K\frac{\left(i_1^2 + i_2^2 + i_3^2 + ... + i_n^2\right)}{n} Rt \quad ...(2)$$

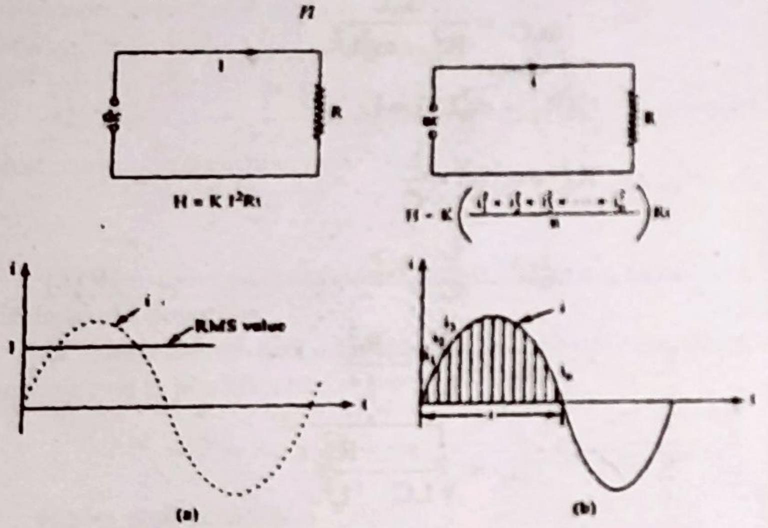


Fig. : *RMS value of an alternating current illustrated*

Equating expressions (1) and (2),

$$I^2 Rt = \frac{\left(i_1^2 + i_2^2 + i_3^2 + ... + i_n^2\right)}{n} Rt$$

or $$I = \sqrt{\frac{\left(i_1^2 + i_2^2 + i_3^2 + ... + i_n^2\right)}{n}}$$

Thus, the effective value is equal to the square root of the mean of the squares of instantaneous values of the alternating quantities. Alternately, this can be read as square mean root value or root mean square value, *i.e.*, RMS value. While expressing alternating quantities we always use RMS values and write in capital letters as E, I, V, etc. To further clarify the concept of the effective or RMS value let us find out the value of dc current, I which gives the same amount of heating as that of ac when it flows through a resistance of value, say, R. The alternating quantity is represented as, say, $i = I_m \sin \omega t$.

The power dissipated in R by the dc current,

$$P_w = I^2 R \text{ watts} \quad ...(3)$$

The instantaneous value of power dissipated in R by the ac current,

$$P = i^2 R = I_m^2 \sin^2 \omega t \times R$$

$$= \frac{I_m^2 R}{2}(1 - \cos 2\omega t)$$

$$= \frac{I_m^2 R}{2} - \frac{I_m^2 R}{2}\cos 2\omega t$$

The average value of the second term is zero as it is a cosine function varying with time.

The average value of power, P for the ac current,

$$P_{av} = \frac{I_m^2 R}{2} \quad ...(4)$$

Equating the power dissipated due to dc current, I and the ac current, i we can get the effective value as

$$I^2 R = \frac{I_m^2 R}{2}$$

or, $$I = \frac{I_m}{\sqrt{2}} = 0.707 I_m$$

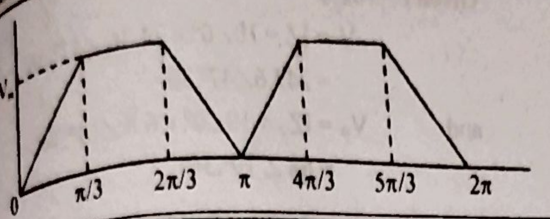
The effective or RMS value of an alternating quantity is either for one-half of a cycle or for a full cycle as

$$I = \sqrt{\frac{1}{T}\int_0^T i^2 dt} \text{ or } I = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i^2 dt}$$

The RMS value of an alternating quantity of any type of wave shapes can be calculated using analytical methods.

Q.25 (a) *What do you mean by Peak, Average and R.M.S values of sinusoidal current.*

(b) *Find the average value of the periodic function shown in figure.*



Ans.(a) Peak value : Peak value is the maximum value obtain by an alternating quantity (v or i) during one cycle. A sinusoidal quantity obtain its peak value at 90°. The peak or maximum value of an alternating voltage and current is represented by E_m and I_m (See Fig.)

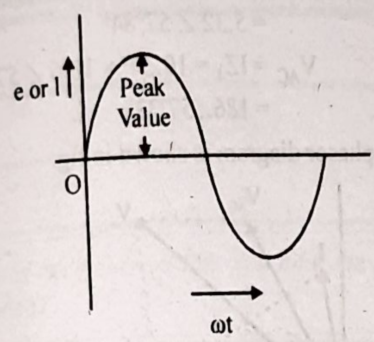


Fig. : Peak Value of Sinusoidal Current

Average Value : *Refer to Q.10(a).*

Effective or RMS Value : *Refer to Q.3.*

Ans.(b) Average value

$$V_{av} = \frac{\text{Area of alternation}}{\text{Base}}$$

Area of alternation

$$= \frac{1}{2}V_m \times \frac{\pi}{3} + V_m\left(\frac{2\pi}{3} - \frac{\pi}{3}\right) + \frac{1}{2}V_m \times \frac{\pi}{3}$$

$$= \frac{\pi V_m}{6} + \frac{\pi V_m}{3} + \frac{\pi V_m}{3}$$

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

Base = π

∴ Average value,

$$V_{av} = \frac{2\pi V_m/3}{\pi} = \frac{2\pi V_m}{3\pi}$$

$$= 0.667\ V_m$$

Q.26(a) ***Define the following with suitable diagram :***

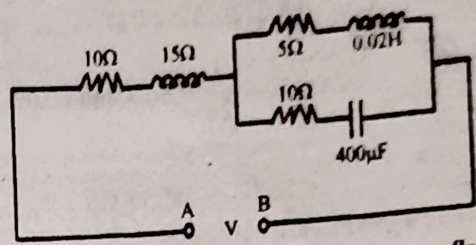
(i) RMS values

(ii) Form factor

(iii) Peak factor

(iv) Phase angle

(b) In the act shown in fig. determine the voltage at a frequency of 50 Hz to be applied across AB in order that current in the circuit is 10A. Draw the phasor dia.



[Note : The inductance value cannot be in Ω and is generally minimal. Here we will consider 15Ω as 0.05H]

Ans.(a)(i) Effective or RMS Value : *Refer to Q.3.*

(ii) Form Factor : *Refer to Q.16.*

(iii) Peak Factor or Crest Factor : The peak factor of an AC wave is the ratio of maximum value of wave to its RMS value

$$K_p = \frac{\text{Maximum Value}}{\text{RMS Value}}$$

(iv) Phase Angle : The phase angle represents initial angle of A.C. waveform. It is equivalent of phase in radians or degrees.

The phase angle is the angle between two alternating quantities. Maximum value of an alternating quality is at a phase angle of π/2 radians or 90°.

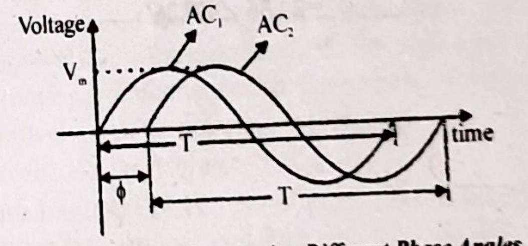


Fig. : Two AC Waveform having Different Phase Angles

Ans.(b) The circuit contains three impedances

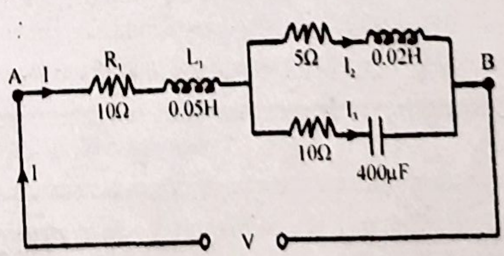


Fig.

$$Z_1 = 10 + j2\pi \times 50 \times 0.05$$
$$= 10 + j\,15.71\ \Omega$$
$$= 18.6\ \angle 57^\circ.33'\ \Omega$$
$$Z_2 = 5 + j2\pi \times 50 \times 0.02$$
$$= 5 + j\,6.28$$
$$= 8.027\ \angle 51^\circ.47'\ \Omega$$

$$Z_3 = 10 - \frac{j}{2\pi} \times 50 \times 400 \times 10^{-6}$$
$$= 10 - j\,7.957$$
$$= 12.77\ \angle -38^\circ.50'\ \Omega.$$

Here Z_2 and Z_3 are in parallel

Hence $$Z_p = \frac{Z_2 Z_3}{Z_2 + Z_3}$$

$$= \frac{8.027\angle 51.47 \times 12.77\angle -38.50}{5 + j6.28 + 10 - j7.957}$$

$$= \frac{102.50\angle 12.97}{15 - j1.677}$$

$$= \frac{102.50\angle 12.97}{15.093\angle -6.379}$$
$$= 6.79\ \angle 19^\circ.34' \approx 6.8\angle 19^\circ.34'$$
$$= 6.406 + j\,2.24\ \Omega$$

Equivalent impedance

$$Z_{eq} = Z_P + Z_1$$
$$= 6.406 + j\,2.24 + 10 + j\,15.71$$
$$= 16.42 + j\,17.96$$
$$= 24.36\ \angle 47^\circ.36'$$

Given $I = 10\angle 0^\circ$

$$\therefore \quad V = IZ = 10\angle 0^\circ \times 24.36\ \angle 47^\circ.36'$$
$$= 243.6\angle 47^\circ.36'$$

and $$V_P = IZ_P = 10\angle 0^\circ \times 6.8\ \angle 19^\circ.34'$$
$$= 68\ \angle\ 19^\circ.34'$$

$$I_2 = \frac{V_o}{Z_2} = \frac{68\angle 19^\circ.34'}{8.027\angle 51^\circ.47'}$$
$$= 8.47\ \angle -32^\circ.13'$$

$$I_3 = \frac{V_P}{Z_3} = \frac{68\angle 19^\circ 34'}{12.77\angle -38^\circ.50'}$$
$$= 5.32\ \angle\ 57^\circ 84'$$
$$V_{AC} = IZ_1 = 10\angle 0^\circ \times 18.6\ \angle\ 57^\circ 33'$$
$$= 186\angle 57^\circ 33'$$

The phasor diagram is shown in fig.

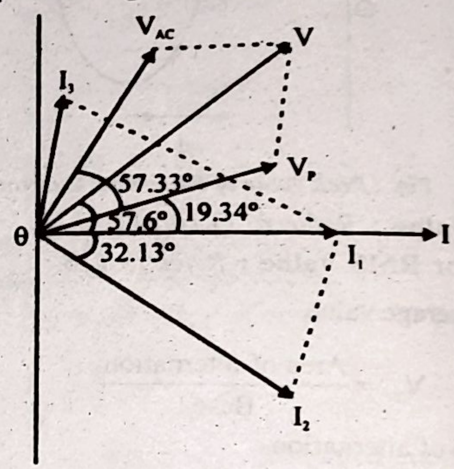


Fig. : Phasor Diagram

□□□

TRANSFORMERS 3

PREVIOUS YEARS QUESTIONS

PART A

Q.1 *What is eddy current loss and how can this loss be reduced?* *[R.T.U. 2019]*

Ans. Currents in the core which are due to induced e.m.f. in the core are called as eddy currents. Due to such currents there is power loss (I^2R) in the core. Such loss is called as eddy current loss. This loss, similar to hysteresis loss, reduces the efficiency.

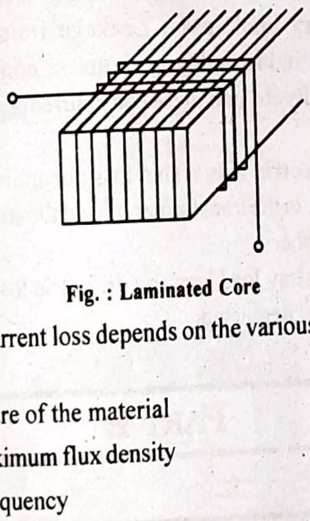


Fig. : Laminated Core

Eddy current loss depends on the various factors which are

(i) Nature of the material

(ii) Maximum flux density

(iii) Frequency

(iv) Thickness of laminations used to construct to core

(v) Volume of magnetic material.

The loss can be reduced by selecting high resistivity magnetic material like silicon. Most popular method used to reduce eddy current loss is to use laminated construction to construct the core. Core is constructed by stacking thin pieces known as laminations as shown in the Fig. The laminations are insulated from each other by thin layers of insulating material like varnish, paper, mica. This restricts the paths of eddy currents, to respective laminations only. So area through which currents flow decreases, increasing the resistance and magnitude of currents gets reduced considerably.

This loss is quantified by using the expression.

Eddy current loss = $K_e (B_m)^2 f^2 t^2 \times$ volume watts

where

K_e = a characteristic constant of material

B_m = maximum flux density

f = frequency

t = thickness of the lamination

Q.2 *Explain Statically and Dynamically induced emf with examples.* **[R.T.U. 2018]**

Ans. Static Induced emf : The emf is induced whenever a conductor is placed in the magnetic field of another conductor without having any relative motion. The name itself indicates static mean it doesn't contain any moving part.

Example : Transformer.

Dynamic Induced emf : Dynamic Induced emf is generated when a current carrying conductor cuts the magnetic flux using relative motion. The name itself indicates the dynamic, it mean having rotating parts in it, inducing emf with respect to moving parts is known as Dynamic Induced emf.

Example : Motor and Generator.

Q.3 *What is Transformer?*

Ans. Transformer : A transformer is a static device, which transfers electrical energy from one electrical circuit to another electrical circuit through the medium of magnetic field and without the change in frequency. Basically, transformer is an electromagnetic energy conversion device, since the energy received by the primary is first converted into magnetic energy and it is then reconverted into useful electrical energy in secondary winding circuit. Thus the primary and secondary windings of a transformer are not electrically connected but are coupled magnetically. The working principle of transformer is based on Faraday's law of electromagnetic induction.

Q.4 *Write the advantages of auto-transformer.*

Ans. Advantage of Auto-Transformer

1. The efficiency of auto-transfomers are more.
2. The size of auto-transfomers are relatively very smaller.
3. The voltage regulation is much better.
4. Lower cost.
5. Low requirements of excitation current.
6. Less copper is used in its design and construction.

Q.5 *Define an auto-transformer.*

Ans. Auto-Transformer : An auto-transformer appears to be similar to a resistance potential divider. A resistive potential divider can't step up the voltage whereas it is possible in an auto-transformer.

Types of auto-transformers are :

1. Step-down transformer
2. Step-up transformer

Q.6 *Define coefficient of coupling (K).*

Ans. Coefficient of Coupling (K) : It is defined as the fraction of total flux that links the other coil i.e.

$$\text{Coefficient of coupling} = \frac{\text{Flux linking with other coil}}{\text{Flux produced by first coil}}$$

or $$\text{Coefficient of coupling (K)} = \frac{\phi_{12}}{\phi_1} = \frac{\phi_{21}}{\phi_2}$$

Since $\phi_{12} \le \phi_1$ and $\phi_{21} \le \phi_2$. Hence the maximum value of K is unity.

Q.7 *The flux ϕ linked with a coil depends on the time t is $\phi = (3t^2 + t + 5)$ weber*

Find the induced emf at time t = 1 sec.

Ans. According to Faraday's law

$$e = \frac{d\phi}{dt} = \frac{d}{dt}(3t^2 + t + 5) = 6t + 1$$

$\therefore$ At time t = 1sec. $e = 6 \times 1 + 1 = 7V$

Q.8 *Define Transformer losses.* **[R.T.U. 2019]**

Ans. Losses in Transformer : In a static transformer, there are no friction or windage losses. Hence, the only losses occurring are:

(i) Core or Iron Loss : It includes both hysteresis loss and eddy current loss. Because the core flux in a transformer remain practically constant for all loads (its variation being 1 to 3% from no load to full load), the core loss is practically the same at all loads.

Hysteresis loss $W_h = \eta B_{max}^{1.6} f V_{watt}$; Eddy current loss

$W_e = P B_{max}^2 f^2 t^2$ watt

These losses are minimized by using steel of high silicon content for the core and by using very thin laminations. Iron or core-loss is found from the O.C. test.

(ii) Copper Loss : This loss is due to the ohmic resistance of the transformer windings. Total Cu loss = $I_1^2 R_1 + I_2^2 R_2 = I_1^2 R_{01} = I_2^2 R_{02}$. It is clear that Cu loss is proportional to (current) or $(kVA)^2$. In other words, Cu loss at half the full-load is one-fourth of that at full-load.

Stray load loss : Leakage fields present in a transformer induce eddy currents in conductors, tanks, channels, bolts etc. and these eddy currents give rise to stray load loss.

Dielectric loss : This loss occurs in the insulating materials, i.e. in the transformer oil and the solid insulation of h. v. transformers.

The stray load loss and dielectric loss are small and are, therefore, neglected.

PART B

Q.9 *Derive EMF equation of single phase transformer. Also explain that why transformer is known as constant flux device.* **[R.T.U. 2019]**

Ans. EMF Equation of Single Phase Transformer : Let the flux in the core be written as

$$\phi = \phi_m \sin \omega t \quad ...(i)$$

Where ϕ_m is the maximum value of flux, ϕ is the stantaneous flux and ω is frequency (radian/sec.). The emf duced in a winding having N turns is

$$e = N\frac{d\phi}{dt} = \omega N\phi_m \cos \omega t$$

$$= 2\pi f N\phi_m \sin\left(\omega t + \frac{\pi}{2}\right) \quad ...(ii)$$

Peak value of induced emf = $2\pi\phi N\phi_m$

RMS value of induced emf

$$= \frac{1}{\sqrt{2}}(2\pi f N\phi_m) = 4.44 f N\phi_m \text{ Volts} \quad ...(iii(a))$$

Therefore RMS value of induced emf in primary winding

$$= E_1 = 4.44 f N_1 \phi_m \text{ Volts} \quad ...(iii(b))$$

RMS value of induced emf in secondary winding

$$= E_2 = 4.44 f N_2 \phi_m \text{ Volts} \quad ...(iii(c))$$

Therefore $= \frac{E_2}{E_1} = \frac{N_2}{N_1} = K$

This constant K is known as voltage transformation ratio

(i) if $N_2 > N_1$ i.e. $k > 1$ then transformer is called step up transformer

(ii) if $N_2 < N_1$ i.e. $k < 1$ then transformer is known as step down.

Again for an ideal transformer

$$V_1 I_1 = V_2 I_2$$

$$\frac{I_2}{I_1} = \frac{V_1}{V_2} = \frac{1}{K}$$

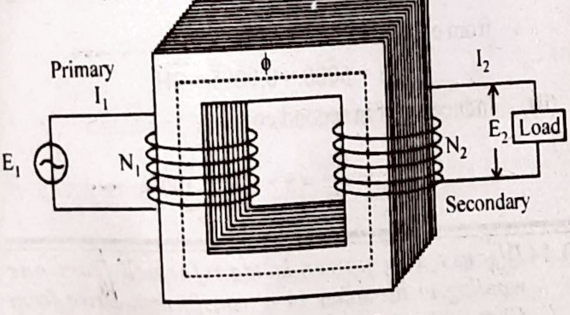


Fig. : Two Winding Transformer

Hence currents are in the inverse ratio of (voltage) transformation ratio.

When a transformer is connected to the supply at no-load a flux is set-up in the core called main flux (mutual flux).

When load is applied on the secondary, the secondary ampere-turns (N_2I_2) set-up a flux in the core in opposite direction to the main field which reduces the main field momentarily and hence reduces the self-induced emf E_1.

Instantly, primary draws extra current I'_1 from the main to counter balance the secondary ampere-turns, such that $I_1N_1 = I_2N_2$.

Hence, the resultant flux in the core remains the same irrespective of the load.

Thus a transformer is called a constant flux device.

Q.10 ***Explain in detail the construction, working principle and emf equation of a single phase transformer.***
[R.T.U. 2019]

OR

Explain in detail the construction, working principle and emf equation of a single phase transformer.
[R.T.U. 2018]

Ans. Construction of a Single Phase Transformer : The two basic parts of a transformer construction are magnetic core and windings or coils. The core of transformer is either square or rectangular in size. It is further divided into two parts-vertical and horizontal. The vertical portion on which coils are wound, is called limb while horizontal portion is called yoke. Core has of laminated core type construction that reduce the eddy current losses. Generally high grade silicon steel lamination is used to laminate the core. Conducting material is used in the winding of the transformer. The coils are wound on the limbs and insulated from each side. Two different windings are wound on two different limbs. These two coils have very high mutual induction. One of the two coils is connected to the alternating voltage. This coil, in which electrical energy is fed with the help of a source is called primary winding and the other winding, connected to a load, is called secondary winding.

Working Principle of a Single Phase Transformer : The operation principle of transformer is based on two Laws :

1. Faraday's First Law : It states that "whenever there is a change of flux linkage in a coil or conductor, an emf is induced in the coil or conductor". In general, we can say that changing magnetic field generates electricity.

2. Faraday's Second Law : The second law is related to magnitude of induced emf. It states that "the magnitude of induced emf in a coil or conductor is directly proportional to the rate of change of flux linkage" *i.e.* at any instant t, the induced emf will be

$$e \propto \frac{d\psi}{dt} \quad ...(1)$$

where, ψ is the flux linkage of coil or conductor

Total flux linkage (ψ) of coil or conductor is given as

$$\psi = N\phi \quad ...(2)$$

where, N is the total number of conductors.

Equation (1) can be written as

$$e = K\frac{d}{dt}(N\phi)$$

K is the constant of proportionality and in SI system, its value is unity.

$$\therefore \quad e = N\frac{d\phi}{dt}\left\{\because \phi\frac{dN}{dt} = 0\right\} \quad ...(3)$$

Equation (3) is called mathematical form of Faraday's law.

In general, the law of induction can be expressed as

$$e = -N\frac{d\phi}{dt} \quad ...(4)$$

where negative sign shows that induced emf opposes its cause according to Lenz's Law, i.e. change of flux, which produces it.

Emf Equation of a Single Phase Transformer : *Refer to Q.9.*

Q.11 ***Define voltage regulation of a transformer.***

Ans. Voltage Regulation of a Transformer : The change in secondary terminal voltage from no load to full load at any particular load is termed as voltage regulation. It is usually expressed as a percentage or a fraction of the rated no load terminal voltage.

So, percentage regulation =

$$\frac{\text{Terminal voltage at no load} - \text{Terminal voltage on load}}{\text{Terminal voltage at no load}} \times 100$$

$$= \frac{\text{Voltage drop in transformer at load}}{\text{No load rated voltage (secondary)}} \times 100$$

$$= \frac{I_2 R_{o2}\cos\phi + I_2 X_{o2}\sin\phi}{\text{No load rated voltage (secondary)}} \times 100 \quad ...(i)$$

When the power factor is leading, the percentage regulation is expressed as :

$$\%\text{ regulation} = \frac{I_2 R_{o2}\cos\phi - I_2 X_{o2}\sin\phi}{\text{No load rated voltage (secondary)}} \times 100 \quad ...(ii)$$

Q.12 ***The secondary current of a 2300/230V transformer is 35A. Determine the turn ratio, primary current and the KVA rating of the transformer.***

Ans. Given : $V_1 = 2300$ volts, $V_2 = 230$ Volts, $I_2 = 35A$

$$\text{Turn ratio} = \frac{V_2}{V_1} = \frac{230}{2300} = 0.1$$

$$\text{Primary current } I_1 = \frac{V_2 I_2}{V_1}\left[\because \frac{V_1}{V_2} = \frac{I_2}{I_1}\right]$$

$$\Rightarrow \quad I_1 = \frac{230 \times 35}{2300} = 3.5\text{Amp}$$

$$\text{KVA rating} = V_1 I_1 \qquad [\text{KVA rating} = V_1 I_1 = V_2 I_2]$$

$$= 2300 \times 3.5 = 8.05 \text{ KVA}$$

Q.13 ***The self inductance of a coil of 500 turns is 0.25H. If 60% of flux of coil is linked with a second will of 10,000 turns, calculate – (i) The mutual inductance of two coils, (ii) Emf induced in second coil, when current in first coil charges 100A/sec.***

Ans. Given $\quad N_1 = 500; \quad L_1 = 0.25$ H

$$N_2 = 10{,}000 \quad \frac{di_1}{dt} = 100 \text{ A/sec}$$

(i) Mutual flux

$$d_2 = 60\% \text{ of } d_1$$

or $\quad d_2 = 0.6\, d_1$

$$\text{mutual inductance between coils } M = N_2\frac{d_2}{i_1}$$

$$M = 10{,}000 \times 0.6\frac{d_1}{i_1} = 6000\frac{d_1}{i_1} \quad ...(1)$$

$$Md_1 = L_1 i_1$$

$$= \frac{\phi_1}{i_1} = \frac{L_1}{N_1} = \frac{0.25}{500} = 0.0005 \quad ...(2)$$

from equation (1) and (2)

$$M = 6000 \times 0.0005 = 3\text{H}$$

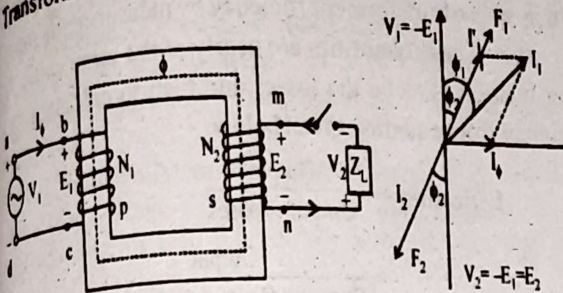
(ii) Induced emf in second coil

$$E_2 = \frac{di_1}{dt} = 3 \times 100 = 300 \text{ volts}$$

Q.14 ***Discuss how power is transformed from one winding to the other in a transformer. Drive from first principle the e.m.f. equation of 1-ϕ transformer.***

Ans. A transformer is a device that transfers electrical power from one electrical circuit to another electrical circuit through the medium of magnetic field and without a change in the frequency.

Let us assume that secondary current I_2 lags behind V_2 by an angle θ_2. Phasor diagram under load for an ideal Transformer is shown in Fig.



(a) (b)

Fig.

Since mmfs F_1 and F_2 tend to magnetize the core in opposite directions, they are shown in phase opposition in Fig.(b). The total primary current I_1 is the phasor sum of I'_1 and I_ϕ.

$$\bar{I} = \bar{I}'_1 + \bar{I}_\phi$$

The power factor on the primary side of the ideal transformer is $\cos\theta_1$. If the magnetizing current I_ϕ is neglected then

$$I_1N_2 = I_2N_1 \qquad \text{...(i)}$$

i.e. primary ampere turns = secondary ampere turns thus for an ideal transformer with $I_\phi = 0$. we have

$$\frac{V_1}{V_2} = \frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{I_1}{I_2}$$

$$E_1I_1 = E_2I_2$$

$$V_1I_1 = V_2I_2$$

i.e. primary volt amperes = secondary volt amperes.

As we know

$$V_1 = N_1\frac{d\phi}{dt}$$

$$V_2 = N_2\frac{d\phi}{dt}$$

$$\frac{V_1}{N_1} = \frac{V_2}{N_2} \qquad \text{...(ii)}$$

Equation (i) in terms of instantaneous value is

$$I_1N_1 = I_2N_2 \qquad \text{(iii)}$$

Multiplication of equation (ii) and (iii) gives

$$V_1I_1 = V_2I_2 \qquad \text{(iv)}$$

This means that instantaneous power input into primary equals the instantaneous power output from the secondary. Hence power is transformed from one winding to another winding.

E.M.F. Equation : *Refer to Q.9.*

Q.15 ***A 200/27.5 V, 400 Hz, step down transformer is to be operated at 60 Hz. Find***

(i) The highest safe input voltage.

(ii) Transformation ratio in both frequency situations.

Ans. Given that

200/27.5 V, 400 Hz

Now if it works on 60 Hz

We know that $\frac{V}{f}$ ratio for a transformer is constant.

(i) Highest Safe Input Voltage : Highest safe input voltage is the voltage value at which transformer works safely which means the transformer cannot tolerate the voltage beyond highest safe input voltage and it will burn beyond this voltage.

So with the help of constant $\frac{V}{f}$ ratio. We can write

So $$\frac{V_1}{f_1} = \frac{V_2}{f_2}$$

$$V_1 = 200 \text{ Volts; } f_1 = 400 \text{ Hz}$$

$$V_2 = ?; \; f_2 = 60\text{Hz}$$

$$\Rightarrow \quad \frac{200}{400} = \frac{V_2}{60}$$

so $$\frac{1}{2} = \frac{V_2}{30} \Rightarrow V_2 = 30 \text{ Volt}$$

Hence the highest safe input voltage = 30 Volts.

(ii) Transformation Ratio : Transformation ratio is the ratio of secondary turns to the primary turns i.e. $\left(\frac{N_2}{N_1}\right)$ or secondary voltage to primary input voltage i e. $\frac{V_2}{V_1}$ or primary current to secondary current i.e. $\frac{I_1}{I_2}$. Hence we can say η (transformation ratio) $\frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$.

Transformation ratio does not depends on frequency hence transformation will become same in both frequency situations.

Q.16 ***A 200 kVA, 6600/400 V, 50 Hz single phase transformer has 80 turns on the secondary. Neglecting losses, calculate:***

(i) The full load primary and secondary currents.

(ii) The number of primary turns.

(iii) The maximum value of flux in the core.

Ans. (i) $I_2 = \frac{200,000}{400} = 500A$

Assuming I/P kVA to be equal to the O/P kVA, we have

Secondary Current

$$I_2 = \frac{200,000}{6600} = 30.4\,A$$

(ii) $$K = \frac{N_2}{N_1} = \frac{E_2}{E_1}$$

$$\therefore \frac{80}{N_1} = \frac{400}{6600}$$

or Number of Primary Turns

$$N_1 = 1320$$

(iii) Using volt equation of T/F, we get

$$E_1 = 4.44\, f\, N_1\, \phi_m$$

$$\Rightarrow 6600 = 4.44 \times 50 \times 1300 \times \phi_m$$

$\therefore$ Maximum flux density,

$$\phi_m = 22.25\text{ mWb.}$$

Q.17 ***A 250 kVA, 11000 V/415 V, 50 Hz, single phase transformer has 80 turns on the secondary. Calculate:***

(i) The approximate values of full load primary and secondary currents.

(ii) The approximate no. of primary turns.

(iii) The maximum value of the flux.

Ans. (i) $$I_2 = \frac{250,000}{415} = 6024\,A$$

(ii) $$K = \frac{415}{11000} = \frac{83}{2200}; \frac{N_1}{N_2} = \frac{80}{N_1} = \frac{83}{2200}$$

$$N_1 = 2121$$

$$I_1 = KI_2 = \left(\frac{83}{2200}\right)6024 = 227.27\,A$$

(iii) $$11000 = 4.44 \times 50 \times 212\, \phi_m$$

$$[E_1 = 4.44\, FN_1\phi_m]$$

$$\phi_m = 11000/470862 = 0.0235\text{ Wb}$$

Q.18 ***What losses are present in a transformer? Discuss a method to determine the efficiency of a transformer.***

Ans. Losses in Transformer : *Refer to Q.8.*

Efficiency of a transformer : The efficiency of a transformer at a particular load and power factor is defined as the output divided by the input, the two being measured in the same units (either watts or kilowatts).

$$\therefore \text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

But transformer being a highly efficient piece of equipment, has very small looses, hence, it is impractical to try to measure transformer efficiency by measuring its input and output. These quantities are nearly of the same value. A better method is to be the losses and then to calculate the efficiency from equation given below.

$$\text{Efficiency} = \frac{\text{Output}}{\text{Output + losses}}$$

$$= \frac{\text{Output}}{\text{Output + Cu losses + Iron loss}}$$

or $$\eta = \frac{\text{input} - \text{losses}}{\text{input}} = 1 - \frac{\text{losses}}{\text{input}}$$

It may be noted here that efficiency is based on power output in watts and not on volt-amperes, although losses are proportional to VA. Hence, at any volt-ampere load; the efficiency depends on power factor, being maximum at a power factor of unity.

Efficiency can be computed by determining core loss from no-load or open-circuit test and Cu loss from the short-circuit test.

Q.19 ***Derive the condition under which a transformer operates at maximum efficiency.***

Ans. Transformer Efficiency : The efficiency of a transformer (or any other device) is defined as the ratio of output power to input power. Thus

Efficiency

$$\eta = \frac{\text{Output power}}{\text{Input Power}} = \frac{V_2 I_2 \cos\theta_2}{V_2 I_2 \cos\theta_2 + P_c + I_2^2 r_{e2}}$$

Where P_c = Total core loss

$I_2^2 r_{e2}$ = Total ohmic losses

$\cos\theta_2$ = Load p.f.

As described before, stray load losses and dielectric losses are small and have been ignored. The efficiency can also be expressed as

$$\eta = \frac{\text{Output power}}{\text{Input power}}$$

$$= \frac{\text{Input power} - \text{losses}}{\text{Input power}} = \frac{\text{losses}}{\text{Input power}}$$

The efficiencies of power and distribution transformers are usually very high (95 to 99%). It is, therefore,

...re accurate to determine the efficiency from the ...asurement of losses. Due to primary leakage impedance ...op, the e.m.f. E_1 (or E_2) and therefore, the mutual flux ϕ_m ...creases for lagging power factor loads and may increase ...r leading power factor loads. Under normal operating ...nditions, the variation in the mutual flux ϕ_m is not more ...an 2 or 3%. Consequently the core losses can be assumed ...nstant at all loads. In other words, it can be stated that ...ansformer core loss is almost independent of load current. The ohmic losses depend on the load current. For example, if I^2r_e is the ohmic loss at full load, then at half load, the ohmic ...oss will be $4\,I^2r_e$.

Condition for maximum efficiency : P_c is constant and the load voltage V_2 remains practically constant. At a specified value of load p.f. $\cos\theta_2$, the efficiency will be maximum when $\frac{d\eta}{dI_2}=0$. Therefore, $\frac{d\eta}{dI_2}$.

$$\frac{d\eta}{dI_2} = \frac{-V_2I_2\cos\theta_2(V_2\cos\theta_2+2I_2r_{e2})}{(V_2I_2\cos\theta_2+P_c+I_2^2r_{e2})^2}=0$$

$$\Rightarrow V_2\cos\theta_2[P_c - I_2 2r_{e2}] - 2V_2I_2^2r_{e2}\cos\theta_2 = 0$$

$$P_c\cdot V_2\cos\theta_2 = I_2^2r_{e2}\cdot V_2\cos\theta_2$$

$$\Rightarrow \quad P_c = I_2^2r_{e2}$$

Hence the maximum efficiency occurs when the variable ohmic loss $I_2^2r_{e2}$ is equal to the fixed core loss P'_c the load current I_2 at which maximum efficiency occurs is given by

$$I_2 = \sqrt{\frac{P_c}{r_{e2}}} = I_{fl}\sqrt{\frac{P_c}{I_{fl}^2r_{e2}}}$$

If both sides of above equation are multiplied by $E_2/1000$, we get

$$\frac{E_2I_2}{1000} = \frac{E_2I_{fc}}{1000}\sqrt{\frac{P_c}{\text{Full load ohmic losses}}}$$

$\therefore$ kVA load for maximum η = (rated transformer kVA) $\times\left(\sqrt{\frac{\text{Core loss}}{\text{Ohmic losses at rated current}}}\right)$

$$\text{or } (\text{kVA})_{\max\eta} = (\text{kVA})\sqrt{\frac{P_c}{I_{fl}^2r_{e2}}}$$

Determination of the transformer efficiency without loading it. It has already been pointed out that the wattmeter reading in the open circuit test records the core loss P_c and during the short circuit test at rated current, it registers the full load ohmic loss P_{sc}. Thus the total losses (P_c+P_{sc}) at full load are known from these two tests without loading the transformer and the efficiency can be calculated as follows:

$$\eta \text{ at full load} = 1 - \frac{P_c+P_{sc}}{(\text{Rated VA})\cos\theta_2+P_c+P_{sc}}$$

At any other load current, say n/p, the efficiency is given by

$$\eta = 1 - \frac{P_c+n^2P_{sc}}{n(\text{Rated VA})\cos\theta_2+P_c+n^2P_{sc}}$$

As before, maximum efficiency occurs when Ohmic loss = Core loss

PART C

Q.20 ***Write short notes on Ideal Transformer on load***

[R.T.U. 2019]

Ans. Elementary Theory of an Ideal Transformer: Let us first consider an ideal transformer, that is, on in which the resistance of the windings is negligible and the core has no losses.

Let the secondary be open Fig.1 and let a sine wave of potential difference v_1 Fig.2(a) be impressed upto the primary. The impressed potential difference causes an alternating current to flow in the primary winding

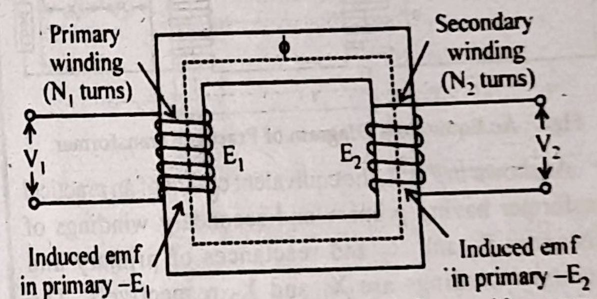


Fig. 1 : Elementary diagram of an ideal transformer with an open secondary winding

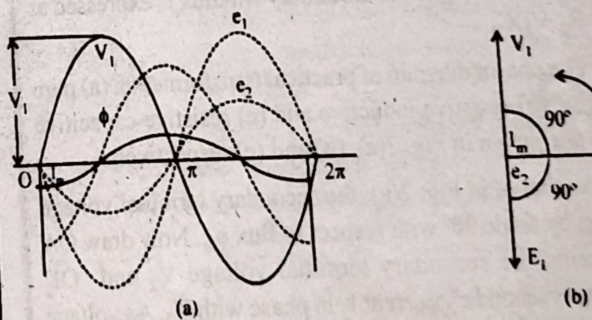


Fig. 2 : Current, voltage and flux curves of an ideal (no loss) transformer

Since the primary resistance is negligible and there are no losses in the core, the effective resistance is zero and the circuit is purely reactive. Hence the current wave i_m lags the impressed voltage wave v_1 by 90 time degrees, as shown in Fig.2(a) reactance of circuit is very high and the magnetizing current is very small. This current in the N_1 turns of the primary the core and produces a flux ϕ that is at all times proportional to the current (if the permeability of the circuit is assumed to be constant), and therefore in time phase with the current, the flux, by its rate of change, induces in the primary winding E, which at every instant of time is opposite in direction to V_1. It is called counter e.m.f. of the primary.

Since the flux also threads (or links) the secondary winding a voltage E_2 is induced in the secondary. This voltage is likewise proportional to the rate of change of flux and so is in time phase with E_1, but it may have any value depending upon the number of turns N_2 in the secondary.

Q.21 *Explain Principle of operation of Transformer and Draw its Phasor diagram referred to secondary side, supplying Leading Power factor Load.* **[R.T.U. 2018]**

Ans. *Refer to Q.10.*

Phasor Diagram of a Transformer Referred to Secondary Side

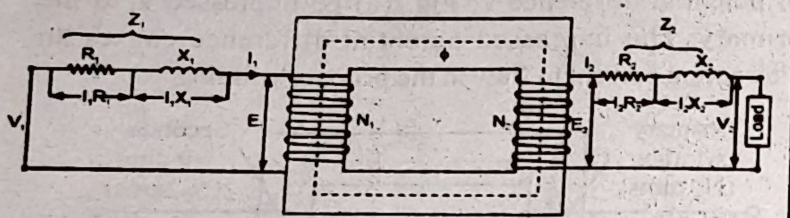


Fig.1 : An Equivalent Diagram of Practical Transformer

As shown in Fig. 1, the equivalent circuit of an practical transformer having primary and secondary windings of resistances R_1 and R_2 and reactances of primary and secondary windings are X_1 and X_2 respectively. The impedance of primary winding is expressed as $Z_1 = R_1 + jX_1$ whereas of impedance of secondary winding is expressed as $Z_2 = R_2 + jX_2$.

The phasor diagram of practical transformer on (a) pure resistive (b) resistive inductive and (c) resistive-capacitive loads are shown in Fig. 2(a), (b) and (c) respectively.

As shown in Fig. 2(a), the secondary terminal voltage V_2 lags by angle 90° with respect to flux ϕ_m. Now draw OA repressing the secondary terminal voltage V_2 and OI_2 represents secondary current I_2 in phase with V_2. As voltage drops due to secondary winding resistance and reactance are I_2R_2 in phase with current I_2 and I_2X_2 leading current I_2 by $\frac{\pi}{2}$ respectively. So AB is drawn parallel to OI_2 and equal I_2R_2 in magnitude representing resistive drop in secondary winding and BC is drawn perpendicular to AB and equal to I_2X_2 in magnitude representing reactance drop of secondary winding. Since induced emf E_2 in the secondary winding is the phasor sum of terminal voltage V_2, secondary resistive drop I_2R_2 and secondary reactive drop I_2X_2, so phasor OC represents secondary induced emf E_2. Therefore

$$E_2 = V_2 + I_2(R_2 + jX_2) = V_2 + jZ_2 \quad ...(1)$$

The induced emf E_1 in primary winding is in phase with secondary induced emf E_2 and equal to $\frac{N_1}{N_2} \cdot E_2$ in magnitude

so, draw $OD = \frac{N_1}{N_2} \cdot OC$ represents E_1.

Now produce DO to D', taking OD' = OD, hence representing $(-E_1)$. The primary current I'_1 is equal to $-I_2\frac{N_2}{N_1}$. So OI'_1 is drawn as equal to $OI_2 \times \frac{N_2}{N_1}$ by producing line I_2O. Now draw line OI_o, represents no load current in magnitude as well as in phase. The phasor sum of induced primary current I'_1 and no load current I_o gives primary current, shown by OI_1 in Fig.2(a).

Since voltage drop due to primary winding resistance I_1R_1 in phase with primary current I_1 so D'F is drawn parallel to OI_1 and equal to I_1R_1 in magnitude representing the resistive drop in primary winding. Similar the voltage drop due to primary winding reactance I_1X_1 is leading the current I_1 by $\frac{\pi}{2}$, so FG is drawn perpendicular to D'F and equal to I_1X_1 in magnitude representing the reactive drop in primary winding.

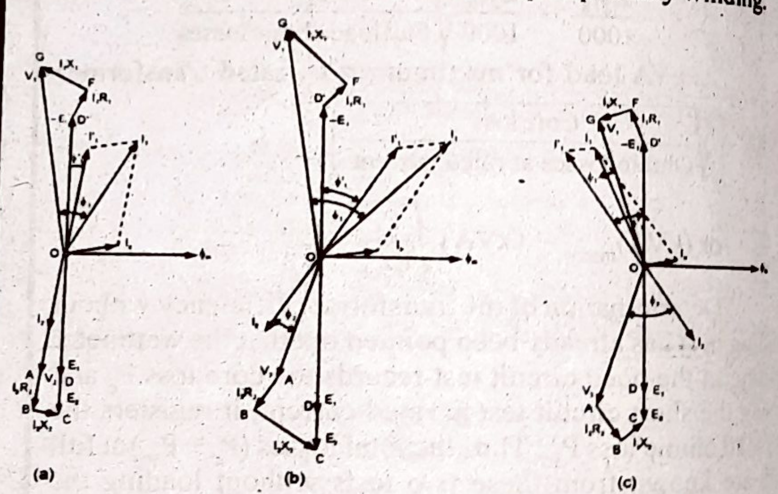


Fig. 2 : Phasor Diagram of Practical Transformer

As the phasor sum of $(-E_1)$, primary resistive drop and primary reactive drop gives the applied voltage V_1 to primary winding, hence phasor OG represents applied voltage V_1 in magnitude as well as in phase. Therefore,

$$V_1 = -E_1 + I_1(R_1 + jX_1) = -E_1 + I_1Z_1 \quad \text{...(2)}$$

The phase angle ϕ_1 between V_1 and I_1 gives the power factor of the transformer. Since no load current I_0, resistive drops I_1R_1 and I_2R_2 and reactive drops I_1X_1 and I_2X_2 are very small, so neglecting those we have $\phi_2 = \phi'_1 = \phi_1 = \phi$, the phase angle of the load. Now from phasor diagram.

(i) For pure resistive load [Fig. 2(a)]

$$E_2 = \sqrt{(V_2 + I_2R_2)^2 + (I_2X_2)^2} = V_2 + I_2R_2 \quad \text{...(3)}$$

$$E_1 = \frac{E_2}{K} \quad \text{...(4)}$$

$$\text{and } V_1 = \sqrt{(E_1 + I_1R_1)^2 + (I_1X_1)^2} = E_1 + I_1R_1 \quad \text{...(5)}$$

(ii) For resistive – inductive load [Fig.2(b)]

$$E_2 = \sqrt{(V_2 + I_2R_2\cos\phi + I_2X_2\sin\phi)^2 + (I_2X_2\cos\phi - I_2R_2\sin\phi)^2}$$

$$= V_2 + I_2R_2\cos\phi + I_2X_2\sin\phi \quad \text{...(6)}$$

$$E_1 = \frac{E_2}{K}$$

and

$$V_1 = \sqrt{(E_1 + I_1R_1\cos\phi + I_1X_1\sin\phi)^2 + (I_1X_1\cos\phi - I_1R_1\sin\phi)^2}$$

$$= E_1 + I_1R_1\cos\phi + I_1X_1\sin\phi \quad \text{...(7)}$$

(iii) For resistive - capacitive load [Fig.2(c)]

$$E_2 = \sqrt{(V_2 + I_2R_2\cos\phi - I_2X_2\sin\phi)^2 + (I_2X_2\cos\phi + I_2R_2\sin\phi)^2}$$

$$= V_2 + I_2R_2\cos\phi - I_2X_2\sin\phi \quad \text{...(8)}$$

$$E_1 = \frac{E_2}{K}$$

$$\text{and } V_1 = \sqrt{(E_1 + I_1R_1\cos\phi - I_1X_1\sin\phi)^2 + (I_1X_1\cos\phi + I_1R_1\sin\phi)^2}$$

$$= E_1 + I_1R_1\cos\phi - I_1X_1\sin\phi \quad \text{...(9)}$$

Q.22 *(a)* ***What is meant by ideal transformer? Explain and derive the phasor diagram for ideal transformer on load.***

(b) ***For a single phase transformer derive the expression for emf equation.***

Ans. (a) Elementary Theory of an Ideal Transformer : *Refer to Q.20.*

Transformer on Load: The transformer is said to be loaded when the secondary circuit of a transformer is completed through an impedance or load. The magnitude, and phase of secondary current I_2 with respect to secondary terminal voltage will depend upon the characteristic of load, i.e. current I_2 will be in phase, lag behind and lead the terminal voltage V_2 respectively when the load is purely resistive, inductive and capacitive.

The secondary current I_2 sets up its own ampere-turns (N_2I_2) and creates its own flux ϕ_2 opposing the main flux ϕ_0 created by no-load current I_0. The opposing secondary flux ϕ_2 weakens primary flux ϕ_0 momentarily hence primary counter or back e.m.f. E_1 tends to be reduced. V_1 gains the upper hand over E_1 momentarily and hence causes more current to flow in primary. Let this additional primary current be I_2. It is known as load component of primary current. The additional primary m.m.f. $N_1I'_2$ sets up its own flux ϕ'_2 which is in opposition to ϕ_2 (but is in the same direction as ϕ_0) and is equal to it in magnitude. Hence these cancel each other.

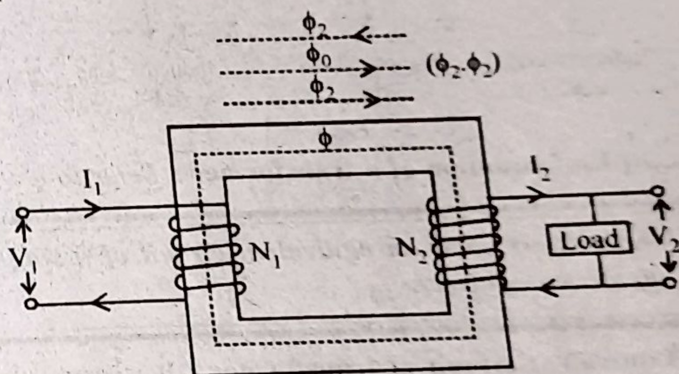


Fig. 1 : An ideal transformer on load

From above discussion it can be concluded that

- Whatever be the load conditions,, the net fl passing through the core is approximate sa as at no load.
- Since the core flux remains constant a loads, the core loss almost remains con under different loading conditions.

$$\text{Since} \quad \phi_2 = \phi'_2$$

$$\therefore \quad N_2I_2 = N_1I'_2$$

$$\text{i.e.} \quad I'_2 = \frac{N_2}{N_1} \times I_2 = KI_2$$

The total primary current is the vector sum c I'_2 the current I'_2 is in anti-phase I_2 and K times in ma

The components of primary current can be shown as below :

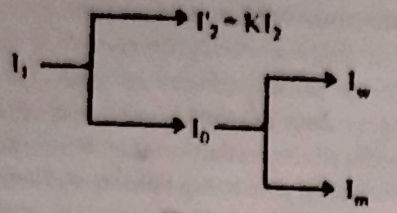


Fig.2

The vector diagrams for transformer on noninductive, inductive and capacitive loads a shown in Fig.3(a, b, c)

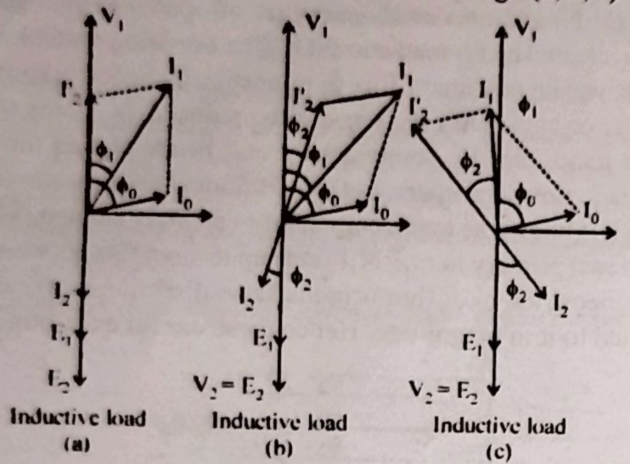


Fig.3

Ans.(b) Emf equation of a transformer : *Refer to Q.9.*

Q.23 ***Write short notes on equivalent circuit of a single phase transformer.***

Ans. Equivalent circuit of transformer : It is useful to describe the behaviour of an electrical equipment in terms of an equivalent circuit. Using the equivalent circuit, the analysis of the equipment can be done by the methods of circuit theory.

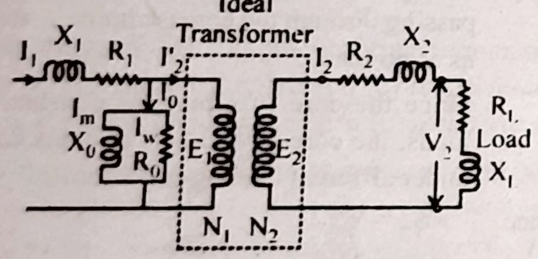


Fig. 1 : Equivalent circuit of a transformer

The equivalent circuit of a transformer is drawn by assuming the transformer to be ideal as shown in Fig.1. Resistance R_0 represents the effect of core losses. The reactance X_0 accounts for magnetizing current I_m. Winding resistances and leakage reactances are shown separately. It is possible to transfer R_2 and Y_2 to the primary side in such a way that the ratio E_1/E_2 is not affected in magnitude or phase. Let R'_2 be the resistance added in primary circuit to cause the same copper-loss as caused by resistance R_2 in the secondary circuit. Since the current I_2 when transferred to primary appears as I'_2 this additional resistance causes a copper-loss

Therefore

$$(I'_2)^2 R'_2 = I_2^2 R_2 \text{ or } R'_2 = R_2\left(\frac{I_2}{I_1}\right)^2$$

$$\text{But} \quad \frac{I_2}{I_1} = \frac{N_1}{N_2}; \text{ Therefore } R'_2 = R_2\left(\frac{N_1}{N_2}\right)^2$$

$$\text{Similarly } X'_2 = X_2\left(\frac{N_1}{N_2}\right)^2$$

The load impedance $R_L + jX_L$ can also be transferred to the primary circuit. Fig.2 shows the exact equivalent circuit with all parameters transferred to the primary circuit.

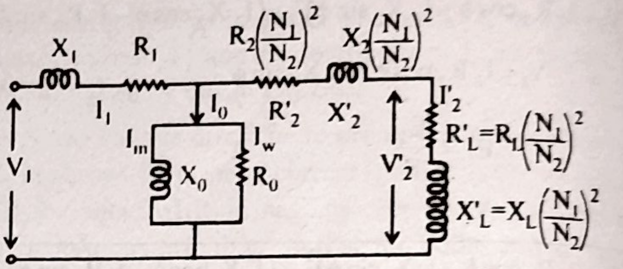


Fig. 2 : Equivalent circuit of a transformer with all impedances transferred to primary side

It is also possible to transfer primary winding resistance R_1 and leakage reactance X_1 to the secondary circuit. These parameters. when transferred to secondary are

$$R'_1 = R_1\left(\frac{N_2}{N_1}\right)^2; X'_1 = X_1\left(\frac{N_2}{N_1}\right)^2$$

where R'_1 and X'_1 are the primary winding resistance and leakage reactance as transferred to the secondary circuit.

Approximate equivalent circuit : The transformer model represented by the equivalent circuit of Fig.3 is rather complex. Since the magnitude of I_0 is very small. the equivalent circuit can be simplified by shifting. the parallel branch of R_0 and X_0 to the extreme left position as shown in Fig.3. This approximation leads to simplicity of analysis without loss of accuracy. Sometimes the parallel branch consisting of R_0 and X_0 is completely neglected in the analysis.

Equivalent Resistance and Reactance : In the approximate equivalent circuit of Fig.3 the resistance R_1 and R_2' can be combined into a single resistance R_{e1} i.e. equivalent resistance as referred to winding 1 (or primary winding). Similarly, X_1 and X_2' can be combined into a single reactance X_{e1}, i.e equivalent reactance as referred to winding 1. Thus

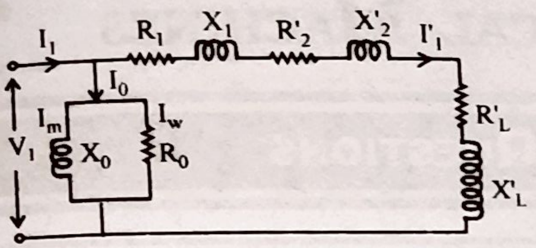


Fig. 3 : Approximate Equivalent Circuit of a Transformer

$$R_1 = R_2' + R_1 + R_2\left(\frac{N_1}{N_2}\right)^2$$

$$X_{e1} = X_1 + X_1' = X_1 + X_2\left(\frac{N_1}{N_2}\right)^2$$

Likewise we can also find the equivalent resistance and reactance as referred to secondary winding (i.e. winding 2). Thus

$$R_{e2} = R_2 + R_1' = R_2 + R_1\left(\frac{N_2}{N_1}\right)^2,$$

$$X_{e2} = X_2 + X_1' = X_2 + X_1\left(\frac{N_2}{N_1}\right)^2$$

□□□

ELECTRICAL MACHINES 4

PREVIOUS YEARS QUESTIONS

PART A

Q.1 ***What is meant by slip of an induction motor?*** *[R.T.U. 2019]*

OR

Explain the term "slip". *[R.T.U. 2018]*

Ans. Slip is defined as, at which rate, rotor is behind to N_s, slip (s) is expressed as :

$$\text{Slip (s)} = \frac{N_s - N_r}{N_s}$$

$$\text{Percentage Slip (\% s)} = \frac{N_s - N_r}{N_s} \times 100$$

At the time of starting, slip will be 1 and at synchronous speed, slip be 0, so slip always lies between 0 and 1, in case of motor.

At Starting, $N_r = 0$

$$s = \frac{N_s - N_0}{N_s} = 1$$

At synchronous speed,

$$N_r = N_s \Rightarrow s = \frac{N_s - N_s}{N_s} = 0$$

Generally at full speed, slip lies between 0.04 to 0.06.

Q.2 ***What is the difference between a generator and a motor?***

Ans. An electrical generator converts mechanical energy into electrical energy while a motor converts electrical energy into mechanical energy.

Q.3 ***Write the types of DC generator.***

Ans. Types of DC Generator : According to the connection of field winding, the DC generator is classified into the following types :

1. Separately excited DC generator
2. Self excited DC generator
   - (i) Shunt wound or Shunt Generator
   - (ii) Series wound or Series Generator
   - (iii) Compound wound DC Generator
     - (a) Long Shunt
     - (b) Short Shunt

Q.4 ***Compare squirrel cage induction motor and slipring induction motor.***

Ans. Comparison of Squirrel Cage Induction Motor and Slip Ring Induction Motor :

S. No.	Squirrel Cage Induction Motor	Slip Ring Induction Motor
(1)	They are simple in construction.	They are complicated in construction.
(2)	No external resistance is connected with rotor winding.	External resistance is connected with help of slip rings.
(3)	They are economically cheap.	They are costly.
(4)	They have low starting torque.	They have high starting torque.
(5)	They are used in water pump, fan, mills etc.	They are used in lift, cranes, traction etc.

Q.5 *Explain why three phase synchronous motor is not self starting.*

Ans. When 3-ϕ supply fed to the stator and DC supply is fed to the rotor then due to the interaction between rotor and stator poles, torque is produced. After half revolution, i.e. 10m sec; stator poles keep interchanging their position while rotor cannot pick up such a high speed suddenly due to its inertia. So direction of torque developed is reversed and hence torque developed is reversed at after each half cycle, therefore rotor is not able to rotate and average starting torque is zero, so synchronous motor is not self starting.

PART B

Q.6 *Explain in detail the construction and principle of working of a three-phase Induction motor.* *[R.T.U. 2019]*

Ans. The working principle of induction motor is based upon the principle of mutual inductance between stator and rotor.

Stator of an induction motor is stationary part, which is fixed in nature. 3-phase supply fed to an induction motor is through stator, which is wound by 3-phase balance windings. As stator is excited by 3-phase balance current, current flows in windings and it feels a magnetic force, which is called magneto motive force (m.m.f.). This m.m.f. is equal to the product of number of turns in winding and the current flow (F = NI) in that winding. This m.m.f. is rotating in nature, i.e. magnetic field develops around the winding, all 3-phase winding are not physically rotating. So, only stator field is rotating with respect to stator and the speed of this stator field is expressed as:

$$N_s = \frac{120f}{P}$$

where f = frequency of 3-phase supply, P = No. of stator poles, N_s = speed of stator field with respect to stator

This stator field speed of induction motor is called synchronous speed.

Rotor is wound with 3–phase balance windings and these are short circuited by end rings in case of squirrel cage and short circuited through external resistance, in case of wound rotor.

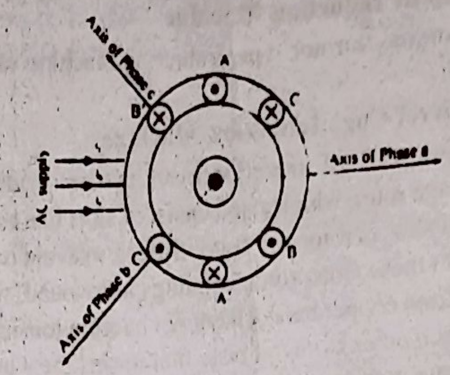


Fig. 1 : Three Phase mmf

Initially, rotor is stationary that means speed of rotor at starting is zero (N_r = 0). When supply is fed to the stator, field of stator rotates with speed N_s *i.e.* synchronous speed. So, at the time of starting, there is a relative motion between rotor windings and stator magnetic field is synchronous speed N_s.

Due to relative motion, emf is induced in rotor windings and as rotor windings are short circuited, there are induced current in rotor winding, which are shown in Fig.2.

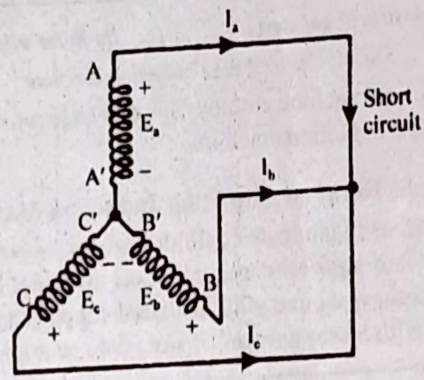


Fig. 2 : Current in rotor winding of induction machine

According to Lenz's law, the direction of rotor current opposes the cause of its production. In the case of induction motor, cause of production is relative speed between rotor windings and stator field. Hence, induced current opposes relative motion between stator field and rotor windings.

So, rotor also starts rotating in same direction as that of stator field at speed N_r, which always tries to reduce relative speed.

The rotor always rotates at a speed N_r, which is always less than synchronous speed of stator field ($N_r < N_s$). If rotor rotates at speed equal to synchronous speed N_s, there will be no relative motion between rotor conductors and stator field, hence no induced emf or current, so there will be no rotation in rotor and no torque will be produced by the rotor.

Relative speed between rotor winding and stator field is $N_s - N_r$.

Slip of Induction Motor : *Refer to Q.1.*

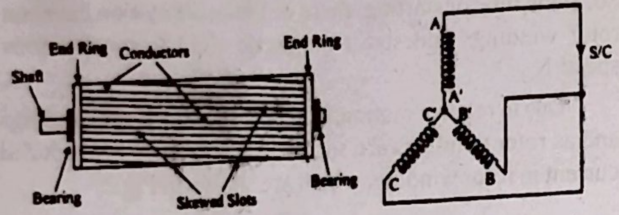
Types of Induction Machine

According to rotor type, induction machine can be of two types:

(i) Squirrel Cage Induction Machine

Almost 85% of induction machines are made up by squirrel cage rotor, which also consist of slots like stator but number of slots in rotor and stator differs, to avoid magnetic locking. In these slots, rotor windings are wound, which is made up from copper bars. All copper bars are joined at both ends to each other by metal ring, that means the winding in squirrel cage rotor are short circuited at both end as shown in Fig.3 (a)

The rotor is like as cage bars that's why it is called squirrel cage.



(a) Constructional view *(b) Rotor winding*

Fig. 3 : Squirrel cage induction machine

Induction machine employs squirrel cage rotor, is called squirrel cage induction machine.

(ii) Wound Rotor or Slip Ring Induction Machine

It consists of laminated cylindrical core, which has slots like stator and squirrel cage induction machine. In wound rotor, the rotor is wound with insulated copper winding like stator but with lesser number of slots than stator.

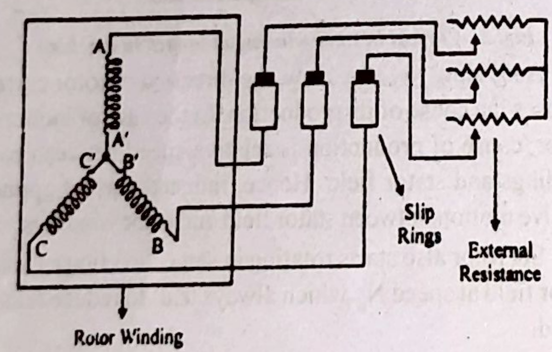


Fig. 4 : Rotor winding of wound rotor induction machine

Generally winding is star connected, whose one end is short circuited at common point and at other end, external resistance is connected through slip rings as shown in Fig.4. External resistance increases the starting torque of machine as well as reduces starting current.

Construction of slip ring or wound rotor is complicated and expensive. It is used, where large starting torque is required like cranes, lifts, traction systems etc.

Q.7 *Distinguish between self-excited and separately excited DC machine. How the self-excited DC machines are classified.* **[R.T.U. 2019]**

Ans. Separately Excited DC Machine : As the name suggests, in case of a separately excited DC machine the supply is given separately to the field and armature windings. The main distinguishing fact in these types of DC motor is that, the armature current does not flow through the field windings, as the field winding is energized from a separate external source of DC current as shown in the fig.1.

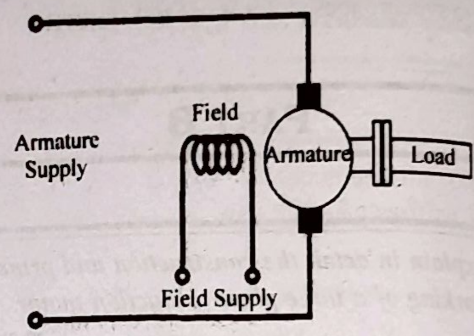


Fig. 1 : Separately Excited DC Motor

Self Excited DC Machine : In case of self excited DC machine, the field winding is connected either in series or in parallel or partly in series, partly in parallel to the armature winding. Based on this, self excited DC machine can be classified as:

1. Shunt wound DC motor
2. Series wound DC motor
3. Compound wound DC motor

1. Shunt Wound DC Motor : In case of a shunt wound DC motor or more specifically shunt wound self excited DC motor, the field windings are exposed to the entire terminal voltage as they are connected in parallel to the armature winding as shown in the fig. 2.

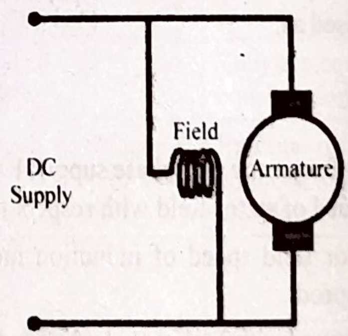


Fig. 2 : Shunt Wound DC Motor

To understand the characteristic of these types of DC motor, lets consider the basic voltage equation given by,

$$E = E_b + I_a R_a \quad ...(1)$$

[Where, E, E_b, I_a, R_a are the supply voltage, back emf, armature current and armature resistance respectively]

Now, $E_b = k_c\phi\omega$ ...(2)

[since back emf increases with flux ϕ and angular speed ω]

Now substituting E_b from equation (2) to equation (1) we get,

$$E = k_a\phi\omega + I_aR_a$$

$$\therefore \quad \omega = \frac{E - I_aR_a}{k_a\phi} \quad ...(3)$$

The torque equation of a DC motor resembles,

$$T_g = K_a\phi I_a \quad ...(4)$$

This is similar to the equation of a straight line and we can graphically representing the torque speed characteristic of a shunt wound self excited DC motor as

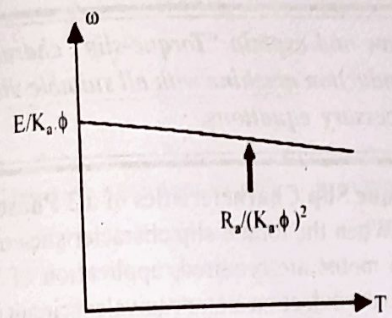


Fig. 3 : Torque Speed Characteristics

The shunt wound DC motor is a constant speed motor, as the speed does not vary here with the variation of mechanical load on the output.

2. Series Wound DC Motor : In case of a series wound self excited DC motor or simply series wound DC motor, the entire armature current flows through the field winding as its connected in series to the armature winding. The series wound self excited DC motor is diagrammatically represented below for clear understanding.

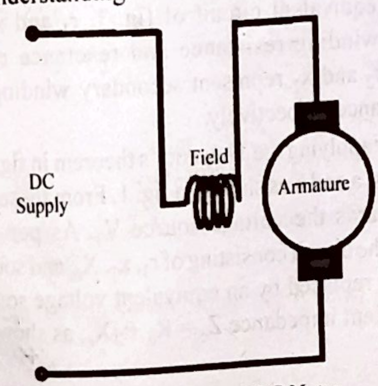


Fig. 4 : Series Wound DC Motor

Now to determine the torque speed characteristic of these types of DC motor, lets get to the torque speed equation.

From the circuit diagram we can see that the voltage equation gets modified to

$$E = E_b + I_a(R_a + R_s) \quad ...(5)$$

Where as back emf remains $E_b = k_a\phi\omega$

Neglecting saturation we get,

$$\phi = K_1I_f = K_1I_a$$

[since field current = armature current]

Therefore, $E_b = k_aK_1I_a\omega = K_sI_a\omega$ ...(6)

From equation (5) and (6)

$$\omega = \frac{E}{K_sI_a} - \frac{R_a + R_s}{K_s}$$

From this equation we obtain the torque speed characteristic as,

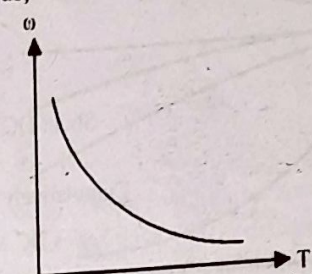


Fig. 5 : Torque Speed Characteristics

In a series wound DC motor, the speed varies with load and operation wise this is its main difference from a shunt wound DC motor.

3. Compound Wound DC Motor : The compound excitation characteristic in a DC motor can be obtained by combining the operational characteristic of both the shunt and series excited DC motor. The compound wound self excited DC motor or simply compound wound DC motor essentially contains the field winding connected both in series and in parallel to the armature winding as shown in the fig. 6.

The excitation of compound wound DC motor can be of two types depending on the nature of compounding.

(i) Cumulative Compound DC Motor : When the shunt field flux assists the main field flux, produced by the main field connected in series to the armature winding then its called cumulative compound DC motor.

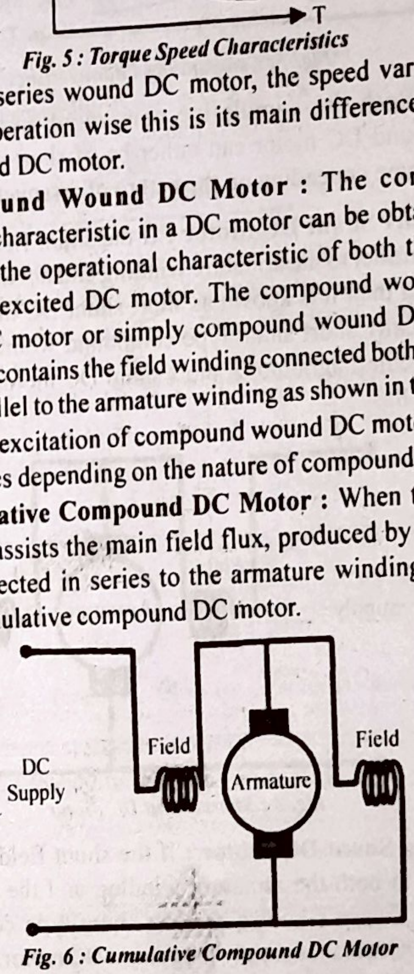


Fig. 6 : Cumulative Compound DC Motor

$$\phi_{total} = \phi_{series} + \phi_{shunt}$$

(ii) Differential Compound DC Motor : In case of a differentially compounded self excited DC motor i.e. differential compound DC motor, the arrangement of shunt and series winding is such that the field flux produced by the shunt field winding diminishes the effect of flux by the main series field winding.

$$\phi_{total} = \phi_{series} - \phi_{shunt}$$

The net flux produced in this case is lesser than the original flux and hence does not find much of a practical application. The compounding characteristic of the self excited DC motor is shown in the fig. 7.

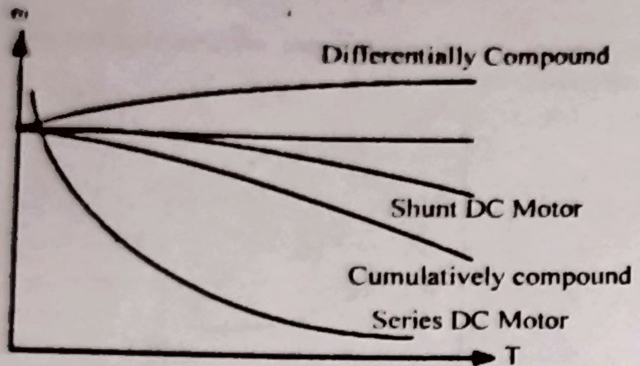


Fig. 7 : Compunding Characteristics

Both the cumulative compound and differential compound DC motor can either be of short shunt or long shunt type depending on the nature of arrangement.

(a) Short Shunt DC Motor : If the shunt field winding is only parallel to the armature winding and not the series field winding then it is known as short shunt DC motor or more specifically short shunt type compound wound DC motor. The circuit diagram of a short shunt DC motor is shown in the fig. 8.

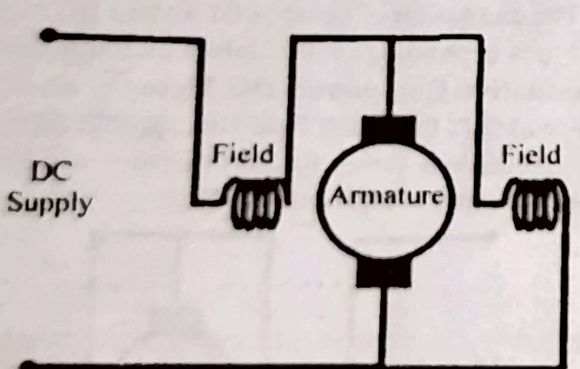


Fig. 8 : Short Shunt DC Motor

(b) Long Shunt DC Motor : If the shunt field winding is parallel to both the armature winding and the series field winding then it's known as long shunt type compounded wound DC motor or simply long shunt DC motor. The circuit diagram of a long shunt DC motor is shown in the fig. 9.

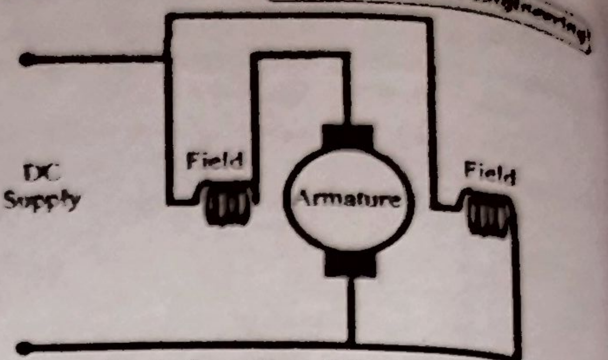


Fig. 9 : Long Shunt DC Motor

Q.8 ***Explain the construction of three phase induction motor with suitable diagrams.*** **[R.T.U. 2019]**

Ans. *Refer to Q.6.*

Q.9 ***Draw and explain "Torque-slip" characteristics of a induction machine with all suitable diagrams and necessary equations.*** **[R.T.U. 2018]**

Ans. Torque Slip Characteristics of a 3 Phase Induction Motor : When the torque slip characteristics of a 3 phase induction motor are required, application of Thevenin's theorem to the induction motor equivalent circuit as shown in fig. 1. reduces the computation labour considerably.

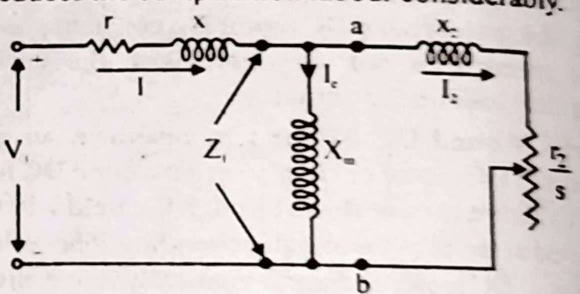


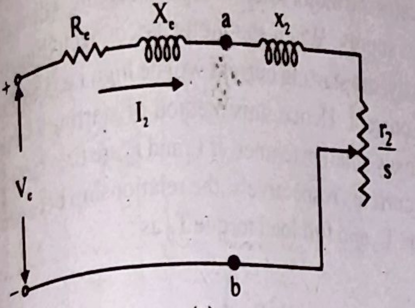
Fig. 1 : Induction Motor Equivalent Circuit without Core Loss

In equivalent circuit of fig. 1, r_1 and x_1 represent primary winding resistance and reactance respectively whereas r_2 and x_2 represent secondary winding resistance and reactance respectively.

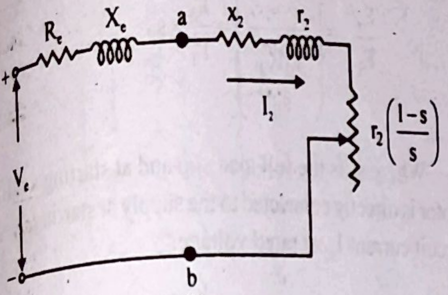
For applying the Thevenin's theorem in fig. 1, consider two points, a and b as shown in fig. 1. From these two points view towards the voltage source V_1. As per Thevenin's theorem, the circuit consisting of r_1, x_1, X_m and source voltage V_1 can be replaced by an equivalent voltage source V_e and an equivalent impedance $Z_e = R_e + jX_e$, as shown in fig. where

$$V_e = \frac{V_1(jX_m)}{r_1 + j(x_1 + X_m)} \quad ...(1)$$

and
$$Z_e = \frac{(r_1 + jx_1)(jX_m)}{r_1 + j(x_1 + X_m)} \quad ...(2)$$



(a).



(b)

Fig. 2 : Thevenin's Equivalent Circuits of an Induction Motor

Here V_e is voltage appearing across terminals a and b with the rotor circuit disconnected from these two points. Equivalent stator impedence Z_e is the impedance viewed from terminals a and b towards the voltage source and with the source voltage short circuited.

For most induction motors, $(x_1 + X_m)$ is much greater than r_1. In view of this, r_1 can be neglected in the denominator of both the equations (1) and (2), without causing any noticeable error.

$$V_e = \frac{V_1 X_m}{x_1 + X_m} = \frac{V_1 X_m}{X_1} \quad ...(3)$$

and
$$Z_e = R_e + jX_e = \frac{r_1 X_m}{x_1 + X_m} + \frac{jx_1 X_m}{x_1 + X_m}$$

$$= \frac{r_1 X_m}{X_1} + \frac{jx_1 X_m}{X_1} \quad ...(4)$$

Here, $X_1 = x_1 + X_m$ is the stator self reactance per phase.

From the equivalent circuit of Fig. 2(a), rotor current is given by

$$I_2 = \frac{V_e}{\left(R_e + \frac{r_2}{s}\right) + j(x_2 + X_e)} \quad ...(5)$$

and torque is expressed as

$$T_e = \frac{m}{\omega_s} \cdot \frac{V_e^2}{\left(R_e + \frac{r_2}{s}\right) + (x_2 + X_e)^2} \cdot \frac{r_2}{s} \text{ N-m} \quad ...(6)$$

$$\left[\text{As } T_e = \frac{1}{\omega_s} . I_2^2 \frac{r_2}{s}\right]$$

Here m is the number of stator phase. For convenience Equation (6) can be re-written as

$$T_e = \frac{K_t}{\left(R_e + \frac{r_2}{s}\right)^2 + X^2} \cdot \frac{r_2}{s} \text{ N-m} \quad ...(7)$$

Where $k_t = \frac{mV_e^2}{\omega_s} = \frac{mV_e^2}{2\pi n_s}$

and $X = x_2 + X_e$

The variation of torque with slip or speed of an induction motor can be plotted from Eq. (5) for different values of slips and with the motor connected to constant frequency voltage source. A general shape of the torque speed or torque slip curve is shown in Fig. 3.

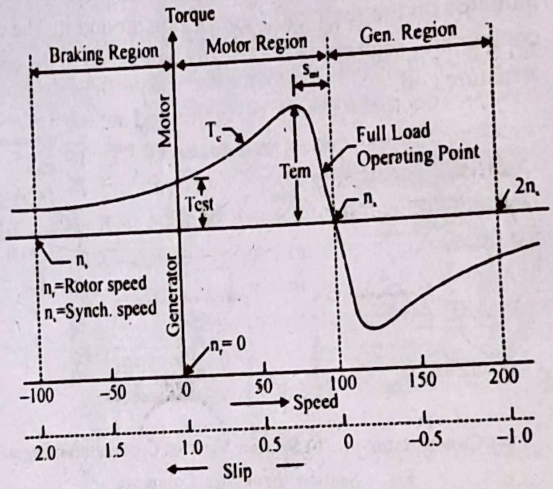


Fig. 3 : Torque-slip curve for an induction machine

Q.10 ***(a) State Fleming's Left hand rule.***

(b) Explain commutator working in DC Motor.

[R.T.U. 2018]

Ans.(a) Direction of the force in a machine can be determined with the help of Fleming's left hand rule.

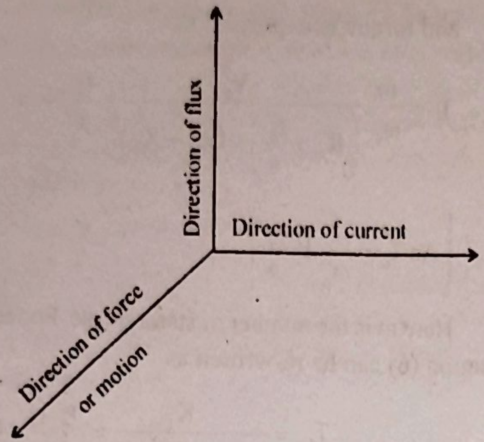
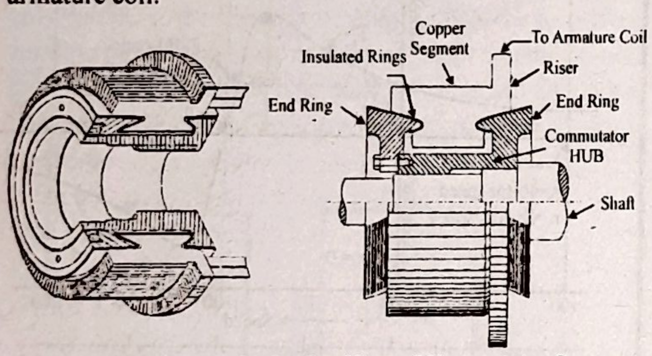


Fig. : Fleming's Left Hand Rule

According to Fleming's left hand rule, "if we stretch the thumb, forefinger and middle finger of our left hand such that they are mutually perpendicular to each other and if forefinger points to the direction of flux, middle finger points to the direction of current then the thumb gives the direction of force."

Ans.(b) Commutator : As the emf induced in the coil is alternating, so to get direct current in the external circuit, commutator is used. The commutator is made of wedge-shaped, hard drawn copper segments, insulated from each other and from the shaft (armature). The commutator is rigidly mounted on the shaft and forms a ring around it. The each commutator segment is electrically connected to the end of armature coil.



(a) Commutator **(b) Section View of Commutator Segments**

Fig. : Section through a Commutator

Q.11 ***Name the types of starting mathod and explain any one method.***

Ans. Starting of Induction Motors

Induction motors, when direct switched, take five to seven times their full load current and develop only 1.5 to 2.5 times full load torque. This initial excessive current is objectionable because it will produce large line voltage drop, which will affect the operation of other electrical equipment connected to same lines.

Direct online starting : In this method, as the name indicates the motor is started by connecting it directly to three phase supply. When the motor is connected to the supply directly, the starting current will be high i.e. 5 to 7 times full load current. Hence, this method of starting is suitable for relatively small machines. If I_{st} and I_{fl} are the starting and full load currents respectively, the relationship between starting torque T_{st} and full load torque T_{fl} as :

$$\frac{T_{st}}{T_{fl}} = \left(\frac{\dfrac{3I_{st}^2 R_2'}{1}}{\dfrac{I_{fl}^2 R_2'}{s_{fl}}}\right) = \frac{I_{st}^2}{I_{fl}^2} \times s_{fl} \quad ...(1)$$

Where s_{fl} is the full load slip and at starting $s = 1$. If the motor is directly connected to the supply at starting, I_{st} = short circuit current I_{sc} at rated voltage.

$$\frac{T_{st}}{T_{fl}} = \frac{I_{sc}^2}{I_{fl}^2} \times s_{fl} \quad ...(2)$$

If I_{sc} is six times the full load current and the full load slip $s_{fl} = 0.04$ then

$$\frac{T_{st}}{T_{fl}} = 36 \times 0.04 = 1.44$$

i.e. starting torque is 1.44 times full load torque but the starting current is six times the full load current.

The methods of starting for an induction motor are:

Squirrel cage motors

(i) Stator resistance starting or primary resistance starter

(ii) Autotransformer starting

(iii) Star delta starting

Slip ring rotor

(i) Rotor resistance starting

Methods of Starting Squirrel Cage Motors

Stator Resistance Starting or Primary Resistance Starter : In this method, the external resistances are connected in series with each phase of stator winding. Their purpose is to drop some voltage hence reduce the voltage applied across the motor terminals. The connection diagram is shown in Fig.

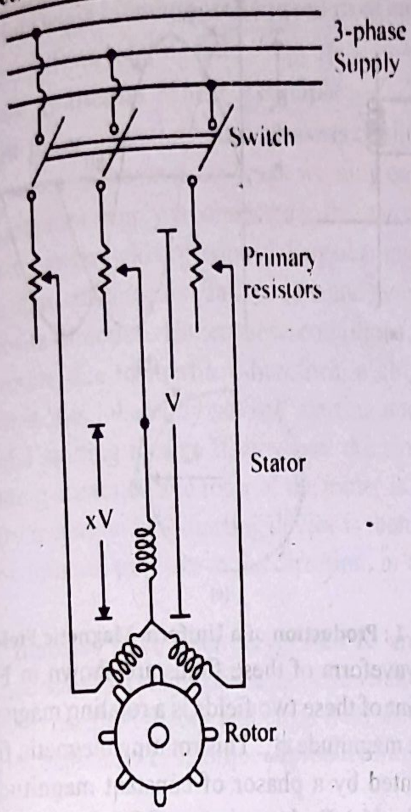


Fig. : Connection Diagram of Primary Resistors

Therefore the initial current drawn by motor is reduced. The main drawback of this method is that the current varies directly with the square of applied voltage. If the voltage applied across the motor is reduced by 50%, starting current is reduced by 50% but the torque is reduced by 25%. Another drawback of this method is that a lot of power is wasted in starting resistance. Hence this method is useful for smooth starting of small machines only.

Let V be the supply voltage per phase. A fraction of this voltage equal to KV (K<1) is applied to the stator, at the starting. The starting current per phase will be $I_{st} = KI_{sc}$, where I_{sc} is the starting current (short circuit current) with applied voltage V.

$$\text{So} \quad \frac{T_{st}}{T_{fl}} = \left(\frac{I_{st}}{I_{fl}}\right)^2 . s_{fl} \qquad \text{...(3)}$$

$$= \left(\frac{KI_{sc}}{I_{fl}}\right)^2 . s_{fl}$$

$$= K^2\left(\frac{I_{sc}}{I_{fl}}\right)^2 s_{fl} \qquad \text{...(4)}$$

Q.12 How the speed of induction motor control?

Ans. Speed Control of Induction Motors

The speed of induction motor can be expressed as

$$n_r = n_s(1-s)$$

$$\text{Or} \quad n_s = \frac{120f}{p}(1-s)$$

Thus speed of induction motor depends upon the frequency, no of poles and slip s. Generally the methods of speed control are distinguished according to main action on the motor i.e.

(i) From the stator side

(ii) From rotor side

1. Various methods of speed control from the stator are :

(a) Changing no of poles

(b) Varying the line frequency

(c) Varying the applied voltage

2. From the rotor side, the methods are

(a) Varying the rotor circuit resistance

(b) Injecting voltage of suitable frequency into rotor circuit.

It should be noted that the methods a,b,c are applicable to both squirrel cage and wound rotor induction motor whereas methods d and e can be used only for wound rotor induction motor.

Speed Control from the Stator Side

(a) Changing no of poles : A change in no of poles, changes the synchronous speed i.e. $n_s = \frac{120f}{p}$ and therefore the induction motor operating speed or rotor speed. Since the no. of poles can be changed only by even numbers, the speed control is not continuous but a stepped one. The no of induction motor stator poles can be changed as follows :

By providing the stator with independent windings, each wound for different number of poles i.e. for 2 speed motor, there must be two separate windings with each winding designated for different number of poles. Three terminals from each winding i.e. total of 6 terminals are brought out. 3 terminals from one winding designated as low speed terminals and another 3 as high speed terminals. Change over from one to another speed is made by switch. The idle winding is kept open circuited, to avoid the circulating currents.

(b) Varying the line frequency : The synchronous speed of induction motor is expressed by n_s

$= \frac{120f}{p}$. It is clearly observed, speed of induction motor can be changed by varying the line frequency but this method is rarely used.

(c) **Varying the applied voltage :** By varying the applied voltage to induction motor, the speed of the motor can be changed. This method is very easy and cheapest. This method is rarely used because a large change in the voltage is required for a small change in speed.

Speed Control from the Rotor Side

(a) **Varying the rotor circuit resistance :** The slip ring or wound rotor motor speed, is reduced by introducing an external resistance in series with rotor circuit. To change the rotor resistance, rotor starter may be used. The disadvantage of this method is that with increase in rotor resistance, I^2R losses will increase. Therefore, operating efficiency of the motor decreases.

(b) **Injecting voltage of suitable frequency by into rotor circuit:** The speed of the induction motor is controlled by injecting a voltage in the rotor circuit. The injected voltage should have the same frequency as the slip frequency. When injected voltage, which is phase opposition to the rotor induced emf, it decreases the speed of the motor. When injected voltage, which is in phase with the induced rotor emf, speed will be increased.

Q.13 ***Explain the principle of 1-ϕ induction motor.***

Ans. Single Phase Induction Motor

The single phase motors are small size motors of fractional kilowatt ratings. Domestic appliances like fans, washing machines, mixers, refrigerators and other kitchen equipments employ these motors. These motors also find applications in air conditioning fan, blowers, small power tools etc.

Production of Rotating Field

Consider two windings A and B, so displaced that they produce magnetic fields 90° apart in space, as shown in Fig. 1(a). Suppose these windings produce magnetic fields equal in magnitude and 90° apart in time given by

$$\phi_A = \phi_m \sin \omega t$$
$$\phi_B = \phi_m \sin (\omega t + 90°) \quad ....(1)$$

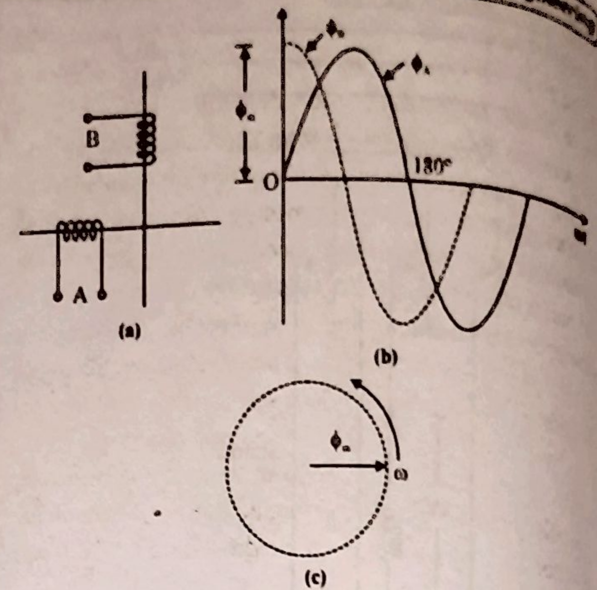


Fig. 1 : Production of a Uniform Magnetic Field

The waveform of these fields are shown in Fig. 1(b). The resultant of these two fields is a rotating magnetic field of constant magnitude ϕ_m. This rotating magnetic field may be represented by a phasor of constant magnitude ϕ_m as shown in Fig. 1(c). Each revolution of the phasor corresponds to one cycle of supply frequency.

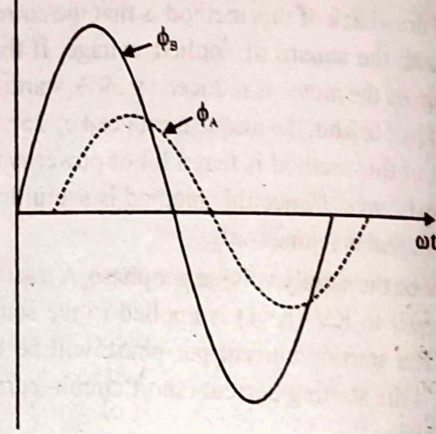


Fig. 2 : Single Phase Induction Motor Principle

Suppose that windings A and B are displaced 90° in space but produce fields that are either not equal or not 90° apart in time as shown in Fig. 2. The resultant of these two fields is again a rotating field but this field is variable in magnitude throughout each revolution.

Similarly the resultant of two fields displaced both in time space by same angle other than 90 degrees is a non uniform rotating field. A non uniform magnetic field produces a non uniform torque, which makes the operator of motor noisy. The other effect of non uniform field is upon the starting torque. A motor having a more uniform rotating field, has the proper starting torque in comparison to a motor of same rating having a non uniform rotating field.

Single Phase Induction Motor Principle

A single phase induction motor consists of single phase winding mounted on the stator and cage winding on the rotor. When a single phase supply is connected to the stator winding, a pulsating magnetic field is produced. By pulsating field, i.e. field builds up in one direction, falls to zero and then builds up in the opposite direction. Under these conditions, the rotor does not rotate due to inertia. Therefore, a single phase induction motor is inherently not self starting and requires some special starting means. If, however the single phase stator winding is excited and rotor of the motor is started by an auxiliary means and the starting device is then removed, the motor continues to rotate in the direction, in which it is started.

Two theories have been suggested to analyse the performance once of a single phase induction motor, namely double revolving field theory and cross field theory. These two theories explains why a torque is produced in rotor once it is turning.

Q.14 ***Can we control the speed of separately excited D.C. motor? Explain.***

Ans. Speed Control of Separately Excited D.C. Motor

The speed of d.c. motor is given by the relationship :

$$N = \frac{V - I_a R_a}{K\phi} \quad \ldots(1)$$

Eq.(1) shows that the speed is dependent upon the supply voltage V, the armature circuit resistance R_a, and the field flux ϕ, which is produced by the field current. In practice, the variation of these three factors is used for speed control. Thus, there are three general methods of speed control of d.c. motors.

1. Variation of resistance in the armature circuit.

This method is called armature resistance control (Rheostatic control)

2. Variation of field flux ϕ

This is called field flux control.

3.Variation of applied voltage (Armature voltage control)

Armature Resistance Control (Rheostatic Control)

In this method, a variable series resistor R_e is put in the armature circuit. Fig. 1 shows the method of connection for separately excited d.c. motor. Here, the speed is controlled by varying the source voltage to armature. Generally a variable resistance R_e provides the variation in armature resistance.

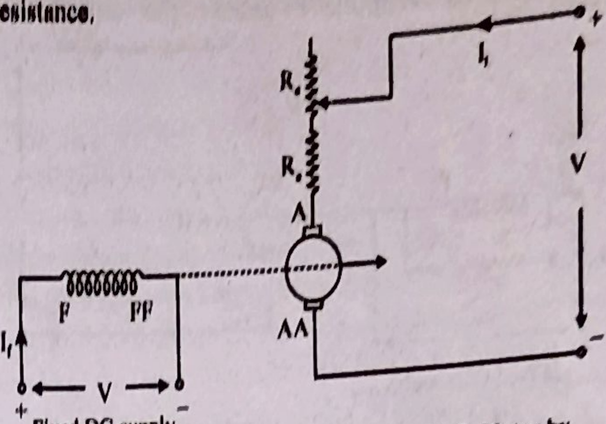


Fig. 1 : Speed Control of Separately Excited D.C. Motor by Armature Resistance Control

Fig. 1 shows the method of connection of external resistance R_e in the armature of separately excited d.c. motor.

In this case, the current and hence the flux are affected by the variation of the armature circuit resistance. The voltage drop in R_e reduces the voltage applied to the armature and therefore the speed is reduced. Fig. 2 shows typical speed/ current characteristics for separately excited d.c. motor. In both the cases, the motor runs at a lower speed as the value of R_e is increased. Since R_e carries full armature current.

This method suffers from the following drawbacks :

(i) A large amount of power is wasted in external resistance R_e.

(ii) Control is limited to give speeds below normal and increase of speed cannot be obtained by this method.

(iii) For a given value of R_e, speed reduction is not constant but varies with the motor load.

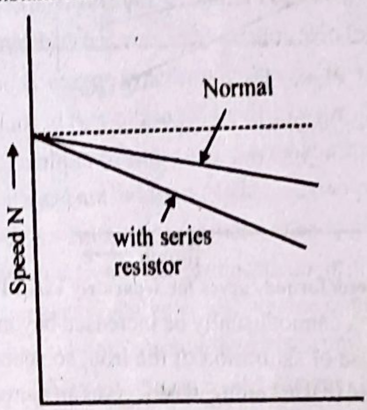


Fig. 2 : Speed/Current Characteristics of Separately Excited D.C. Motor

2. Variation of Field Flux f (Field Flux Control)

Weakening of field causes increase in speed of the motor while strengthening the field causes decrease the speed. Here a variable resistance is connected in series with the field coil. Thus the speed is controlled by means of flux variation.

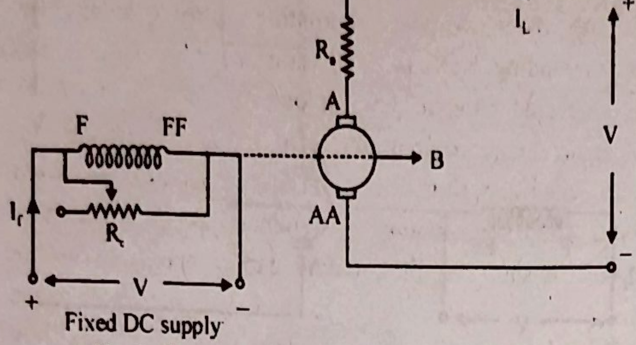


Fig. 3 : Speed Control by Variation of Field Flux

Reluctance Control involving variation of reluctance of magnetic circuit of motor. Field voltage control by varying the voltage at field circuit while keeping armature terminal voltage constant.

In this method, the connection of R_c in the field reduces the field current and hence the flux ϕ is also reduced. The reduction in flux will result in an increase in the speed. Consequently, the motor runs at a speed higher than normal speed. For this reason, this method of speed control is used to give motor speeds above normal or to correct for a fall in speed due to load.

The typical speed/torque curves for separately excited d.c. motor in shown in Fig.4; whose speeds are controlled by the variation of the field flux.

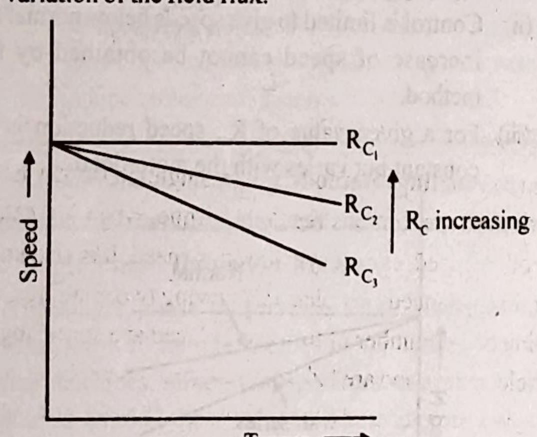


Fig. 4 : Speed/Torque curves for separately excited D.C. motor

The flux cannot usually be increased beyond its normal value because of saturation of the iron, so speed control by flux is limited to weakening, which gives an increase in speed. It is applicable over a limited range, because is the field is weakened to much there is a loss of stability.

Q.15 *Describe the principle of operation of 3-phase synchronous generator.*

Ans. Working Principle of 3-ϕ Synchronous Generator

The synchronous generator works on the principle of **electromagnetic induction.** When there is a relative motion between the conductors and the flux, e.m.f. gets induced in the conductors. The d.c. generators also work on the same principle. The only difference in practical synchronous generator and a d.c. generator is that in synchronous generator, the conductors are stationary and field is rotating. But for understanding purpose, we can always consider relative motion of conductors with respect to the flux produced by the field winding.

Consider a relative motion of a single conductor under the magnetic field produced by two stationary poles. The magnetic axis of the two poles produced by field is vertical, shown dotted in the Fig.1

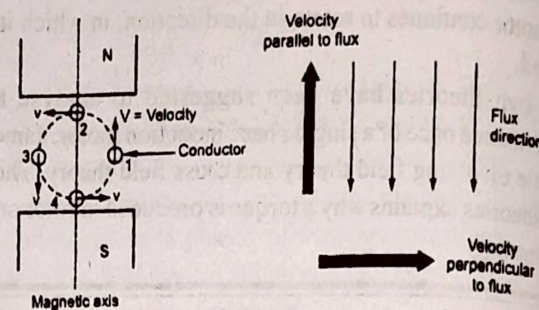


Fig.1 : Two pole generator

Let conductor starts rotating from position 1. At this instant, the entire velocity component is parallel to the flux lines. Hence, there is no cutting of flux lines by the conductor. So, $d\phi/dt$ at this instant is zero and hence, induced e.m.f. in the conductor is also zero.

As the conductor moves from position 1 towards position 2, the part of the velocity component becomes perpendicular to the flux lines and proportional to that, e.m.f. gets induced in the conductor. The magnitude of such an induced e.m.f. increases as the conductor moves from position 1 towards 2.

At position 2, the entire velocity component is perpendicular to the flux lines. Hence, there exists maximum cutting of the flux lines. And at this instant, the induced e.m.f. in the conductor is at its maximum.

As the position of conductor changes from 2 towards 3, the velocity component perpendicular to the flux starts decreasing and hence induced e.m.f. magnitude also starts decreasing. At position 3, again the entire velocity component is parallel to the flux lines and hence at this instant, induced e.m.f. in the conductor is zero.

As the conductor moves from position 3 towards 4, the velocity component perpendicular to the flux lines again starts increasing. But the direction of velocity component now is opposite to the direction of velocity component existing during the movement of the conductor from position 1 to 2. Hence, the induced e.m.f. in the conductor increases but in the opposite direction.

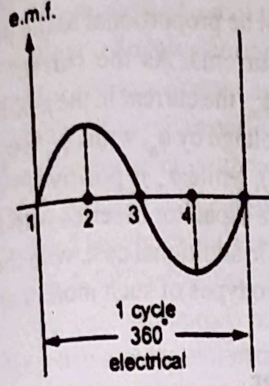


Fig. 2 : Alternating nature of the induced e.m.f.

At position 4, it achieves maxima in the opposite direction, as the entire velocity component becomes perpendicular to the flux lines.

Again from position 4 to 1, induced e.m.f. decreases and finally at position 1, again becomes zero. This cycle continues as conductor rotates at a certain speed.

So, if we plot the magnitudes of the induced e.m.f. against the time, we get an alternating nature of the induced e.m.f. as shown in the Fig. 2.

PART C

Q.16 Explain the torque - speed characteristic and speed control of separately excited DC motor. *[R.T.U. 2019]*

Ans. *Refer to Q.14.*

Q.17 (a) Write short notes onCommutator *[R.T.U. 2019]*

(b) Synchronous generator

Ans. (a) *Refer to Q.10(b).*

(b) *Refer to Q.15.*

Q.18 (a) Explain the construction and working of a single phase induction motor with all necessary diagrams and suitable equations. *[R.T.U. 2018]*

(b) Explain the starting and speed control methods of single-phase Induction motor with all necessary diagrams and suitable equation. *[R.T.U. 2018]*

Ans.(a) Construction of Single Phase Induction Motor : The main components of a Single Phase Induction Motor are stator and rotor. Stator is known as the stationary part. Usually, the single phase alternating supply is given to the stator winding. Rotor is the rotating part of the motor. Rotor is connected to the mechanical load with the help of a shaft. A squirrel cage rotor is used here. It has a laminated iron core with many slots. Rotor slots are closed or semi-closed type. The rotor windings are symmetrical and at the same type it is short circuited. An air gap is there between the rotor and the stator. The stator winding in the single phase induction motor has two parts: main winding and auxiliary winding. Usually, the auxiliary winding is perpendicular to the main winding. In single phase induction motor the winding with more turns is known as main winding while the other winding is called as auxiliary winding.

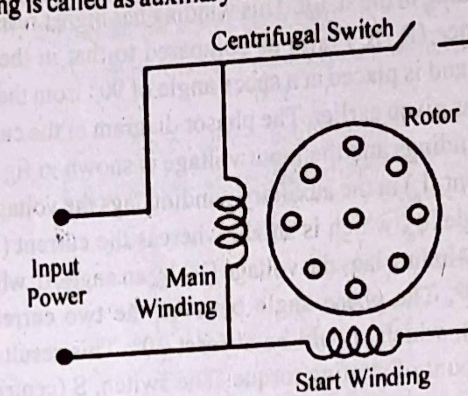


Fig.

Working : *Refer to Q.13.*

Ans.(b) Starting Methods : The single-phase IM has no starting torque, but has resultant torque, when it rotates at any other speed, except synchronous speed. It is also known that, in a balanced two-phase IM having two windings, each having equal number of turns and placed at a space angle of 90°(electrical), and are fed from a balanced two-phase supply, with two voltages equal in magnitude, at an angle of 90°, the rotating magnetic fields are produced, as in a three-phase IM. The torque-speed characteristic is same as that of a three-phase one, having both starting and also running torque as shown earlier. So, in a single-phase IM, if an auxiliary winding is introduced in the stator, in addition to the main winding, but placed at a space angle of 90° (electrical), starting torque is produced. The currents in the two (main and auxiliary) stator windings also must be at an angle of 90°, to produce maximum starting torque, as shown in a balanced two-phase stator.

Thus, rotating magnetic field is produced in such motor, giving rise to starting torque. The various starting methods used in a single-phase IM are described here.

Resistance Split-Phase Motor

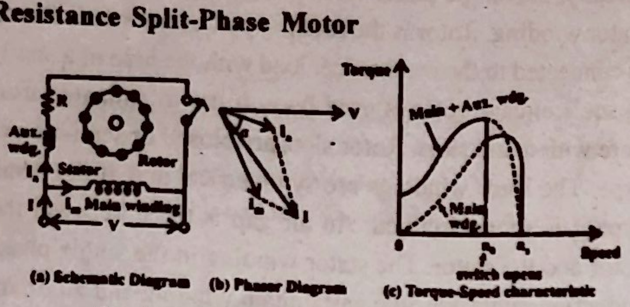


Fig. 1 : Resistance split-phase induction motor

The schematic (circuit) diagram of this motor is given in fig. 1(a). As discussed earlier, another (auxiliary) winding with a high resistance in series is to be added along with the main winding in the stator. This winding has higher resistance to reactance (R_a/X_a) ratio as compared to that in the main winding, and is placed at a space angle of 90° from the main winding as given earlier. The phasor diagram of the currents in two windings and the input voltage is shown in fig. 1(b). The current (I_a) in the auxiliary winding lags the voltage (V) by an angle, ϕ_a, which is small, whereas the current (I_m) in the main winding lags the voltage (V) by an angle, d, which is nearly 90°. The phase angle between the two currents is (90° – ϕ_a), which should be at least 30°. This results in a small amount of starting torque. The switch, S (centrifugal switch) is in series with the auxiliary winding. It automatically cuts out the auxiliary or starting winding, when the motor attains a speed close to full load speed. The motor has a starting torque of 100 – 200% of full load torque, with the starting current as 5-7 times the full load current. The torque-speed characteristics of the motor with/without auxiliary winding are shown in fig. 1(c). The change over occurs, when the auxiliary winding is switched off as given earlier. The direction of rotation is reversed by reversing the terminals of any one of two windings, but not both, before connecting the motor to the supply terminals. This motor is used in applications, such as fan, saw, small lathe, centrifugal pump, blower, office equipment, washing machine, etc.

Capacitor Split-Phase Motor : The motor described earlier, is a simple one, requiring only second (auxiliary) winding placed at a space angle of 90° from the main winding, which is there in nearly all such motors as discussed here. It does not need any other thing, except for centrifugal switch, as the auxiliary winding is used as a starting winding. But the main problem is low starting torque in the motor, as this torque is a function of, or related to the phase difference (angle) between the current in the two windings. To get high starting torque, the required phase difference is 90° Fig. 2(b), when the starting torque will be proportional to the product of the magnitudes of two currents. As the current in the main winding is lagging by ϕ_m, the current in the auxiliary winding has to lead the input voltage by ϕ_a, with ($\phi_m + \phi_a = 90°$) ϕ_a, is taken as negative (–ve), while ϕ_m is positive (+ve). This can be achieved by having a capacitor in series with the auxiliary winding, which results in additional cost, with the increase in starting torque, The two types of such motors are described here.

Capacitor-start Motor

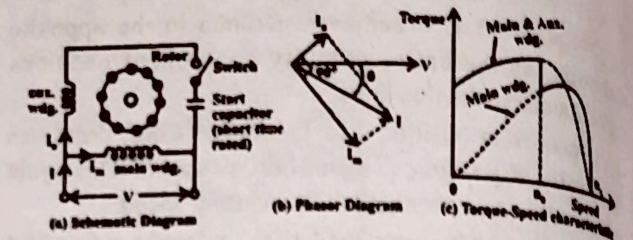


Fig. 2 : Capacitor-Start Induction Motor

The schematic (circuit) diagram of this motor is given in Fig. 2(a). It may be observed that a capacitor along with a centrifugal switch is connected in series with the auxiliary winding, which is being used here as a starting winding. The capacitor may be rated only for intermittent duty, the cost of which decreases, as it is used only at the time of starting. The function of the centrifugal switch has been described earlier. The phasor diagram of two currents as described earlier, and the torque-speed characteristics of the motor with/without auxiliary winding, are shown in fig. 2(b) and fig. 2(c) respectively. This motor is used in applications, such as compressor, conveyor, machine tool drive, refrigeration and air-conditioning equipment, etc.

Capacitor-start and Capacitor-run Motor

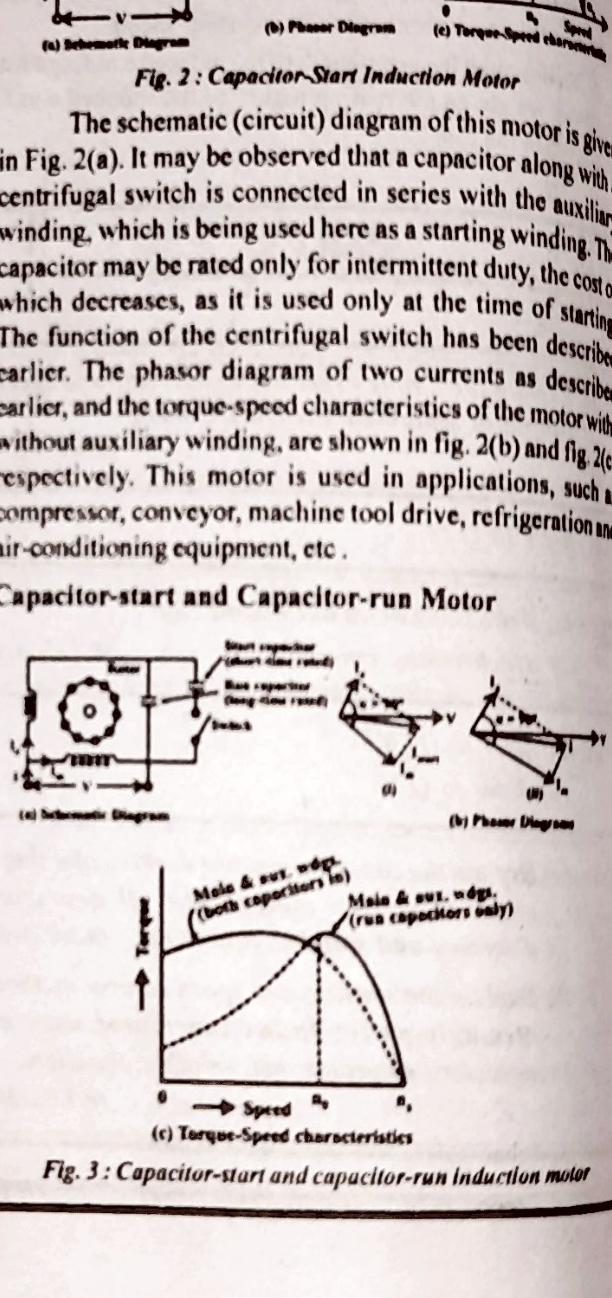


Fig. 3 : Capacitor-start and capacitor-run induction motor

In this motor two capacitors- C_s for starting, and C_r for running, are used. The first capacitor is rated for intermittent duty, as described earlier, being used only for starting. A centrifugal switch is also needed here. The second one is to be rated for continuous duty, as it is used for running. The phasor diagram of two currents in both cases, and the torque-speed characteristics with two windings having different values of capacitors, are shown in fig. 3(b) and fig. 3(c) respectively. The phase difference between the two currents is $(\phi_m + \phi_a > 90°)$ in the first case (starting), while it is 90° for second case (running). In the second case, the motor is a balanced two phase motor, the two windings having same number of turns and other conditions as given earlier, are also satisfied. So, only the forward rotating field is present, and the no backward rotating field exists. The efficiency of the motor under this condition is higher. Hence, using two capacitors, the performance of the motor improves both at the time of starting and then running. This motor is used in applications, such as compressor, refrigerator, etc.

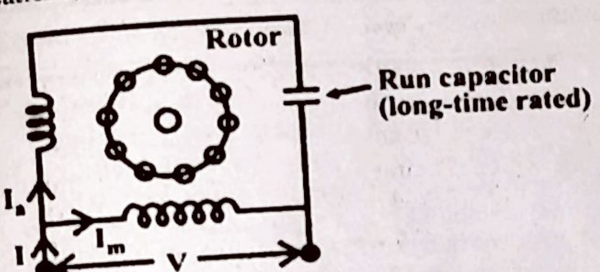


Fig. 4 : Schematic diagram of capacitor-run induction motor

Besides the above two types of motors, a Permanent Capacitor Motor as shown in Fig. 4 with the same capacitor being utilised for both starting and running, is also used. The power factor of this motor, when it is operating (running), is high. The operation is also quiet and smooth. This motor is used in various applications, such as ceiling fan, air circulator, blower etc.

Q.19 (a) ***Explain Principle, construction and working of 3-Phase Induction Motor, with suitable diagram.***

(b) ***Explain the Principle of operation of D.C. generator and also derive its E.M.F. equations.*** **[R.T.U. 2018]**

Ans. (a) *Refer to Q.6.*

Ans. (b) Principle of D.C. Generator :"Whenever a conductor cuts the magnetic field, an emf is induced in the conductor *i.e.* whenever the magnetic flux linking with any conductor changes, an emf is induced in the circuit."

The magnitude of this induced emf can be calculated as

$e = \frac{d\phi}{dt}$ where, ϕ is the flux linkage of the coil and e is the induced emf.

EMF Equation of DC Machine

In generator, as armature rotates, an emf is generated across its coils and it is called **generated emf**. In motor, due to the rotation (due to current in conductor) there is also an induced emf and it is known as **back emf**. The expression for the generated emf or back emf is same.

Let,

ϕ = Flux per pole (webers)

P = Number of Poles

Z = Total number of armature conductors

A = Number of parallel paths in armature between brushes of opposite polarity

C = Number of series path of coils

N = Armature rotation speed in revolutions per minute (RPM)

E_c = Emf induced across a single coil

E = Emf induced across armature

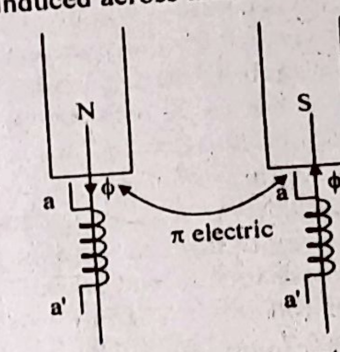


Fig. : Flux linkage through magnetic field

From N pole to S pole, flux linking with coil changes from $+\phi$ to $-\phi$.

Rate of change of flux is given by

$$\frac{\Delta\phi}{\Delta t} = \frac{-\phi-(+\phi)}{\Delta t} = -\frac{2\phi}{\Delta t}$$

ϕ = flux/pole in time Δt

Coil moves from N to S pole *i.e.* travel a distance or π electrical

So $\Delta t = \frac{\pi}{\omega_e}$

where, ω_e is speed of rotor in electrical radian/sec.

If number of turns per coil is N_C, induced emf across a single coil can be expressed as :

$$E_C = -N_C \frac{\Delta\phi}{\Delta t}$$

$$E_C = \frac{2N_C\phi}{\Delta t} = \frac{2N_C\phi}{\pi/\omega_e}$$

$$E_C = \frac{2N_C\phi\omega_e}{\pi}$$

Now $\omega_e = \frac{P}{2}\omega_m$

where ω_m is angular speed of rotor in degree.

so, $E_C = \frac{PN_C\phi}{\pi}\omega_m$

Speed of Rotor $\omega_m = 2\pi n$

where n = Rotation per second (rps)

$$\boxed{E_C = (2P\phi n)N_C}$$

Let, Number or parallel paths = A, Number or coil in series = C

So, induced emf in armature is expressed as :

$$E = CE_C$$

$$E = (2P\phi n)\ CN_C$$

Total number of coils in armature winding = CA

Total number of turns in armature = CAN_C

In each turn, there are 2 conductors

So, total number of armature conductors $Z = 2\ (CAN_C)$

$$CN_C = \frac{Z}{2A}$$

or $E = (2P\phi n)CN_C$

or $E = (2P\phi n)n\frac{Z}{2A}$

or $E = \frac{NP\phi Z}{60A}\left(\because n = \frac{N}{60}\right)$

This is the emf equation of DC machine (motor or generator)

□□□

Power Converters and Electrical Installations 5

Previous Years Questions

Part A

xplain PN Junction diode. *[R.T.U. 2019]*

-N Junction Diode

When a P-type material is joined to N-type, P-N on is formed. Basically merely joining the two pieces, nction cannot be formed due to surface films and other rities, which produce major discontinuities in the crystal re. Thus P-N junction is formed from a piece of nductor by diffusing P-type material to the half side -type material to other half side. The plane, which s the two zones is known as a junction.

raw and explain MCB. *[R.T.U. 2019]*

Miniature Circuit Breaker (MCB) : MCB or ture Circuit Breaker is an electromagnetic device which ts an electric circuit from the over current automatically. ain function of MCB is to disconnect the circuit from i.e. open the circuit automatically when the current g through MCB exceeds the specified value. It can e switched ON and OFF manually.

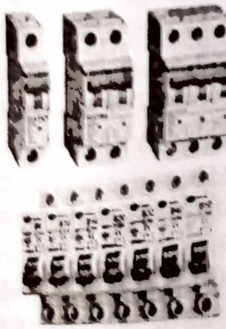


Fig. : MCB

Q.3 ***Distinguish between a Rectifier and an Inverter.*** ***[R.T.U. 2019]***

Ans.

Basis of Comparision	Rectifier	Inverter
Definition	Rectifier is a device which converts AC power into DC power.	Inverter is a device which converts DC Power to AC Power of desired output voltage and frequency.
Another Name	AC - DC Converter	DC - AC Converter
Types	1. Half-Wave Rectifier 2. Full-Wave Rectifier 3. Bridge Rectifier	1. Voltage Source Inverters (VSI) 2. Current Source Inverters (CSI)
Applications	1. Pulse Generating Circuit 2. Voltage Multiplier	1. Adjustable speed AC drives 2. Uninterruptible Power Supply (UPS)

Q.4 ***What do you mean by earthing?*** ***[R.T.U. 2018]***

Ans. An electrical system is said to be earthed, if the outer surface or non-electrical part is not carrying any current and are connected to earth so that the potential is almost zero. The main purpose of earthing is to ensure that all parts of the system except live-parts (parts which are carrying currents) are at zero potential.

Earthing is done by electrically connecting the outer parts of the system or equipment to electrical conductors or electrodes placed near the soil or below the ground level.

The earthing electrode under the ground level has flat iron riser through which all the non-live parts of the equipment are connected. When the fault occurs in the system, the fault current from the equipment flows through the earthing system directly to the earth and thereby protect the equipment from the fault current.

Q.5 ***Write short note on switch fuse unit.***

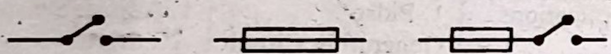
Ans. Switch Fuse Unit (SFU)

Switch fuse units are used for protecting power and control the electric circuit depending on the current rating.

A fuse is a calibrated conductor which melts with increase in temperature and breaks the circuit. A switch is a device used to isolate the circuit manually for repairs and maintenance.

The switch fuse unit has one switch unit and one fuse unit. The advantage of using switch fuse unit is that it is a combination of switch and fuse. The supply can be isolated by switching SFU to OFF position. When the switch is in ON position, the supply will pass through the fuse unit to protect the circuit from over current. If the electric current drawn by circuit exceeds the specified limit, the fuse will melt and breaks the circuit.

The fuse has accurate current limiting operation and high braking capacity. The switch has manual operation for manual isolation and maintenance. SFU is a combination of fuse and switch for providing an economical unit with best performance of fuse and switch. The symbols of switch, fuse and SFU shown in figure.



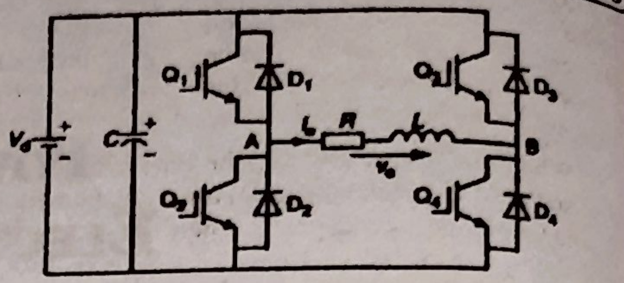
(a) Switch (b) Fuse (c) SFU

Fig. : Switch Fuse Unit

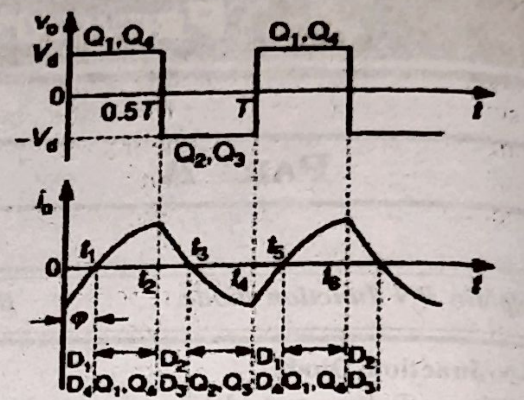
PART B

Q.6 ***Explain the working of a single-phase full bridge Inverter with the help of circuit diagram and output voltage waveform.*** **[R.T.U. 2019]**

Ans. Construction: A single-phase full-bridge inverter is depicted by Figure, where there are four power switches: $Q_1 - Q_4$.



(a) Full-bridge inverter



(b) waveforms of the output voltage and current

Fig. : Single-phase full-bridge inverter and output waveforms

The switch pairs (Q_1, Q_4) and (Q_2, Q_3) conduct in turn. The two terminals of the load are connected to the middle points of the left-hand leg and right-hand leg of the bridge circuit, respectively. The load considered is RL load with the impedance phase angle ϕ. Moreover, there are four diodes, D_1-D_4, which are employed to provide the paths for the load current driven by the stored energy in the load inductor. The period of a cycle is denoted by T.

The operation principle of the single-phase full-bridge inverter is illustrated as follows.

During the interval $0 \le t < t_1$, the switch pairs (Q_1, Q_4) and (Q_2, Q_3) are both OFF, but the diode pair (D_1, D_4) is forced ON by the energy remaining in the load inductor. Therefore, at this time, the output voltage V_o is V_d, and the inductor current i_o reduces gradually in amplitude.

At the time instant t_1, the load current i_o becomes zero so that the diodes D_1 and D_4 are OFF, but the switches Q_1 and Q_4 are switched ON by triggering.

Therefore, during the time interval $t_1 \le t < t_2$, the voltage across the load is still $V_o = V_d$, but the direction of the current i_o is changed to positive.

At the time instant t_2, the trigger signals are sent in order to switch OFF Q_1 and Q_4, but to switch ON Q_2 and Q_3. The switches Q_1 and Q_4 are thus turned OFF immediately, but Q_2

Q_3 cannot be turned ON immediately as the energy stored ...e load inductor forces the diodes D_2 and D_3 on. At this ...ent, the load voltage V_o becomes-V_d, but the load current ...eps the flow direction, but reduces its magnitude as times ...s by.

When the time reaches t_3, the load current reduces to ...o so that the diodes D_2 and D_3 are OFF, but the switches ...and Q_3 are ON by triggering. Therefore, at the interval t_3 ...$< t_4$, the output voltage across the load is still -V_d, but the ...d current changes direction and increases its amplitude as ...e goes by.

At the time instant t_4, the trigger signals switch OFF Q_2 ...d Q_3, but cannot turn ON Q_1 and Q_4 immediately, as the ...ergy stored in the load inductor forces the diodes D_1 and ...to turn ON. Therefore, within the interval $t_4 \le t < t_5$, the ...tput voltage V_o is changed to V_d, but the load current keeps ...e previous direction but reduces its amplitude as time goes ...

The inverter during $t_4 \le t < t_5$ repeats the operation ...ocess of the inverter during the interval $0 \le t < t_1$.

When either the switch pair (Q_1, Q_4) or (Q_2, Q_3) is turned ...n, the load voltage V_o and the load current i_o have the same ...olarity, which means the DC source provides the power to ...e load. On the other hand, when either the diode pair (D_1, ...D_4) or (D_2, D_3) is turned on, the load voltage V_o and the load ...urrent i_o have opposite polarity, which indicates the load feeds ...ack the power to the DC side.

The Fourier series of the output voltage signal V_o can ...e given by:

$$V_O = \frac{4V_d}{\pi}\left(\sin(\omega t) + \frac{1}{3}\sin(3\omega t) + \frac{1}{5}\sin(5\omega t) + \cdots\right)$$

From the above Equation, one can obtain the peak and ...ffective values of the fundamental component of the output ...s:

$$V_{O1m} = (4V_d/\pi) \approx 1.27\ V_d \text{ and}$$

$$V_{O1} = \left(V_{O1m}/\sqrt{2}\right) = \left(2\sqrt{2}V_d/\pi\right) \approx 0.9V_d.$$

Q.7 *Draw the input and output characteristics of common emitter configuration and explain active saturation and cut-off region.* *[R.T.U. 2019]*

Ans. Characteristics of Common Emitter (CE) Configuration : The characteristic of the common emitter transistor circuit is shown in fig. 1. The base to emitter voltage varies by adjusting the potentiometer R_1 and the collector to emitter voltage varied by adjusting the potentiometer R_2. For the various setting, the current and voltage are taken from the milliammeters and voltmeter. On the basis of these readings, the input and output curve plotted on the curve.

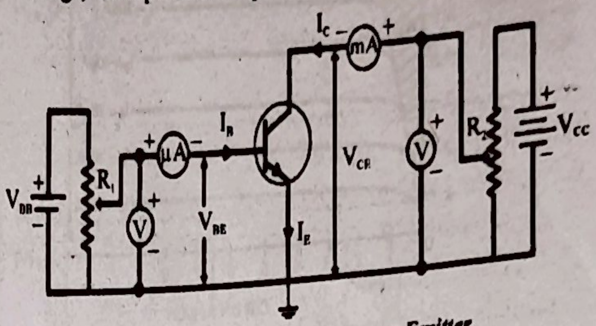


Fig. 1 : Characteristics of Common Emitter

Input Characteristic Curve : The curve plotted between base current I_B and the base-emitter voltage V_{EB} is called input characteristics curve. For drawing the input characteristic the reading of base currents is taken through the ammeter on emitter voltage V_{BE} at constant collector-emitter current. The curve for different value of collector-base current is shown in fig. 2.

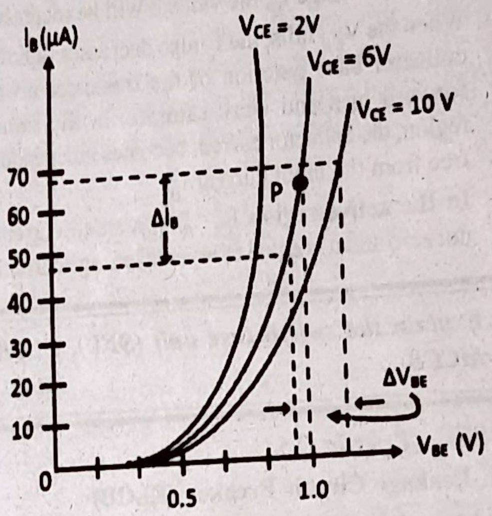


Fig. 2 : Input Characteristic Curve

The curve for common base configuration is similar to a forward diode characteristic. The base current I_B increases with the increases in the emitter-base voltage V_{BE}. Thus the input resistance of the CE configuration is comparatively higher that of CB configuration. The effect of CE does not cause large deviation on the curves, and hence the effect of a change in V_{CE} on the input characteristic is ignored.

Output Characteristic : In CE configuration the curve draws between collector current I_C and collector-emitter voltage V_{CE} at a constant base current I_B is called output characteristic. The characteristic curve for the typical NPN transistor in CE configuration is shown in the fig. 3.

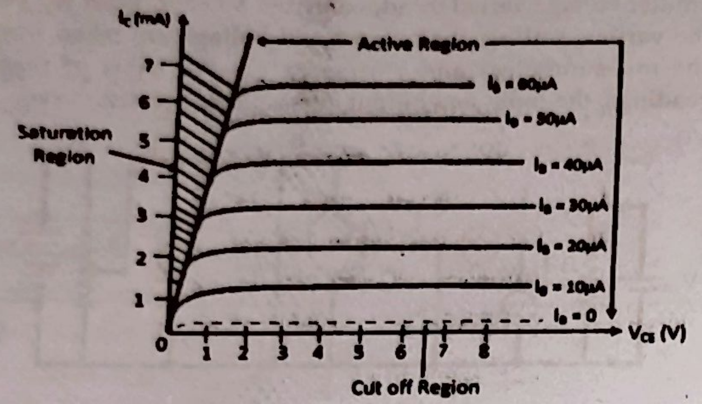


Fig. 3 : Output Characteristic Curve

- In the active region, the collector current increases slightly as collector-emitter V_{CE} current increases. The slope of the curve is quite more than the output characteristic of CB configuration. The output resistance of the common base connection is more than that of CE connection. The value of the collector current I_C increases with the increase in V_{CE} at constant voltage I_B, the value β will be increases.
- When the V_{CE} falls, the I_C also decreases rapidly. The collector base junction of the transistor always in forward bias and work saturate. In the saturation region, the collector current becomes independent and free from the input current I_B.
- **In the active region** $I_C = \beta I_B$, a small current I_C is not zero and it is equal to reverse leakage current I_{CEO}.

Q.8 Explain the switch fuse unit (SFU), ELCB and MCCB. *[R.T.U. 2019]*

Ans. SFU : *Refer to Q.5.*

Earth Leakage Circuit Breaker (ELCB)

The Earth Leakage Circuit Breaker (ELCB) is residual current device. If any current leaks from any electrical circuit, there is a insulation failure, this must be properly detected and prevented else there is a high probability of electrical shock. An Earth Leakage Circuit Breaker (ELCB) is used to detect the current leakage.

There are two types of ELCB :

1. Voltage Earth Leakage Circuit Breaker
2. Current Earth Leakage Circuit Breaker

1. Voltage Earth Leakage Circuit Breaker

In voltage ELCB, the device is connected between the wires coming from the earth rod to the wire attached to the external metallic body, i.e. one terminal of the relay coil **(ELCB) is connected to the metal body of the equipment against earth leakage and other terminal is connected to the earth directly.**

If any insulation failure occurs or live phase wire touches the metal body, there is a voltage difference appears across the terminals of coil connected to the equipment body and earth. This voltage difference produces a current to flow in the relay coil. When the potential difference reaches a predetermined limit, the current through the relay becomes sufficient to actuate the relay for tripping the associated circuit breaker and disconnect supply from the device.

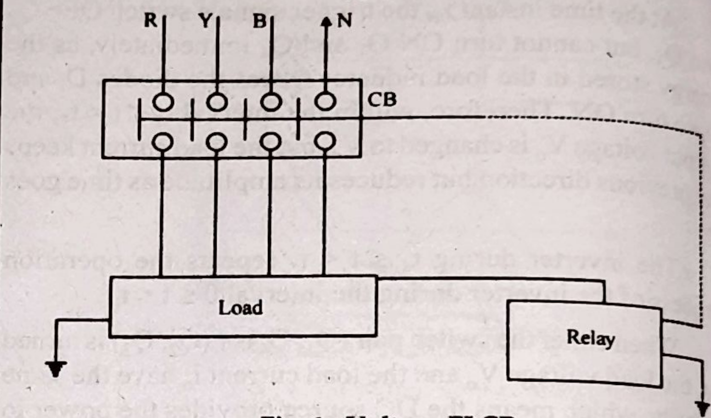


Fig. 1 : Voltage ELCB

The main disadvantages of ELCB are that it can detect and protect only that equipment with which it is attached. ELCB does not work properly, if earth connection is not proper. ELCB is unable to detect fault if someone touch the live phase wire. To overcome these disadvantages, the current ELCB is used.

2. Current Earth Leakage Circuit Breaker

Current earth leakage circuit breaker is also known as Residual Current Circuit Breaker (RCCB). Generally, voltage ELCB is referred as ELCB and current ELCB is referred as RCCB.

RCCB work on the assumption that the current going to the device must come out from neutral wire. The RCCB measure the current going inside the device and coming out from the device. RCCB consists of one current transformer (CT) energized from phase wire and neutral wire. In normal condition, the phase and neutral wiring mmf oppose each other. In normal condition, the device have same phase and neutral current and resultant mmf is zero-ideally. When any earth leakage occurs, there is a difference between phase and neutral current. Due to this the resultant mmf will not be zero and this is sense by the CT. The signal from CT is fed to the circuit breaker circuit and it open the main power contacts. RCCB is some time also referred as Residual Current Device (RCD) when the circuit breaker is removed.

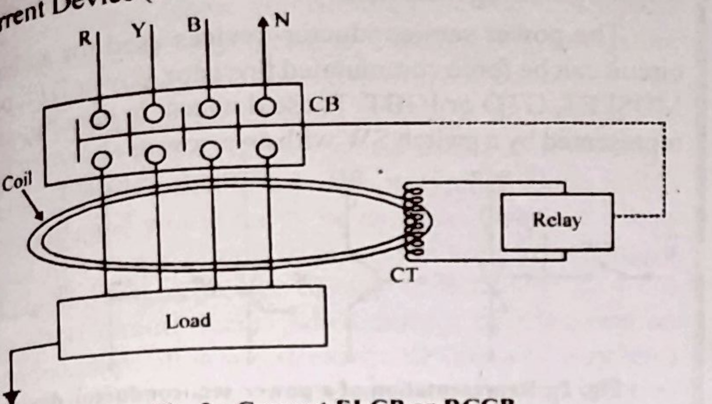


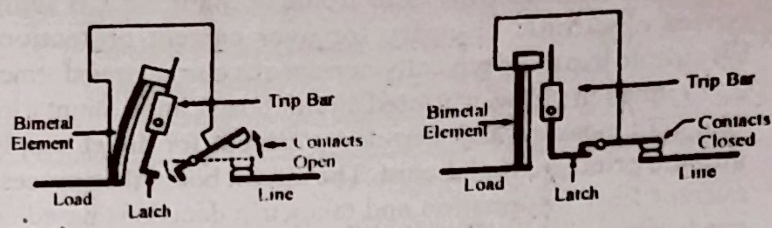
Fig. 2 : Current ELCB or RCCB

Molded Case Circuit Breaker (MCCB) : Molded Case Circuit Breaker (MCCB) is electro mechanical device which protect the circuit from over current and short circuit. An MCCB provides protection by combining a temperature sensitive device with a current sensitive electromagnetic device. Both these devices act mechanically on the trip mechanism. MCCB is an alternative to a fuse device since it does not require replacement once overload is detected and can be easily reset.

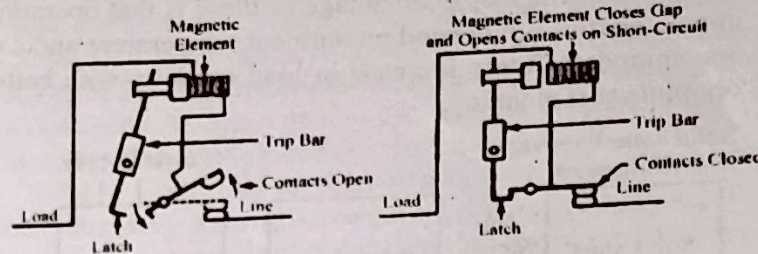
Fig. 3 : MCCB

The MCCB are classified on the basis of the trip actions :

1. Thermal Trip Unit : During Overload, the excess current flowing through a piece of bimetal is heated. The bimetal is made with two strips of different metal bonded together. As shown in fig. 4(a), heat will cause the bimetal to bend. The bimetal strip having the greater rate of expansion is on the outside of the bend curve. To trip the CB, this bimetal must deflect enough to physically push the trip bar and disconnect the circuit.



(a) Thermal



(b) Electromagnetic

Fig. 4 : MCCB Trip Action

2. Electromagnetic Trip Unit : Short-circuit trip action uses an electromagnetic winding, which is connected in series with the load current. During short circuit, the current flowing through the windings increase, which increase the magnetic field strength of the electromagnet and attract the armature, as shown in fig. 4(b). Due to this, the armature rotates the trip bar and circuit breaker trip. The only time delay factor involves in this process is the time require by the contacts to physically open and extinguish the arc.

3. Thermal Magnetic Trip Unit : Thermal-magnetic circuit breakers use bimetals and electromagnetic assemblies to provide over current protection. A thermal magnetic trip unit is best suited to most general-purpose applications due to its temperature sensitive and automatically action. Their characteristic inverse time tripping under overload conditions is ideally suited for many applications varying from residential to heavy industrial loads. For higher level (short circuit) over currents, instantaneous trip characteristics allow MCCB to interrupt with no intentional delay. The minor disadvantage is the operating characteristics of the breaker, which varies the ambient temperature.

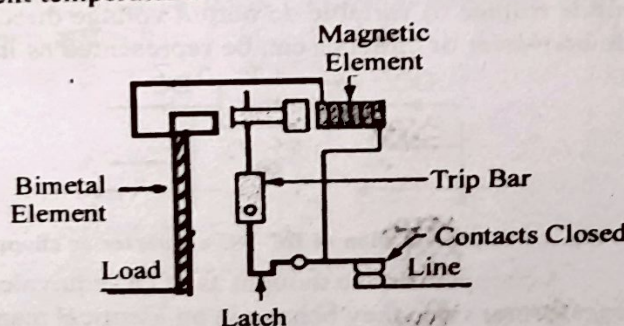


Fig. 5 : Thermal Magnetic Contact

4. Electronic Trip Unit : Electronic or Static MCCB apply power electronic circuitry for over current protection. Electronic trip units typically-consist of a current transformer (CT) for each phase, a printed circuit board, and a shunt trip. The CTs measure and step-down current for direct supply into the printed circuit board. The circuit board then process current flow information and takes trip decisions based on predetermined parameters, and tells the shunt trip unit to trip the breaker. The major advantage of these is that operating characteristics not depend on ambient temperature and can accommodate future increase in load capacity with better optimum cost planning.

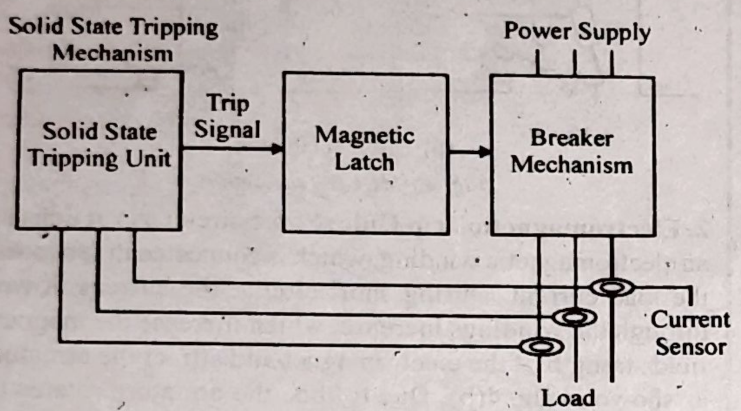


Fig. 6 : Electronic Trip MCCB

5. Microprocessor Trip Unit : Microprocessor release MCCB use microprocessors to provide overcurrent protection. The Microprocessor trip circuit works on current R.M.S value, which is calculated from peak values. Due to use of microprocessor, the system have high flexibility through multiple adjustments of protection settings, high repeat accuracy and high reliability.

Q.9 ***Write short notes on DC – DC Converter. [R.T.U. 2019]***

OR

Write basic structure of DC to DC converter.

Ans. It is also termed as D.C. chopper, which converts fixed dc input voltage to variable dc output voltage directly. The dc-dc converter or chopper can be represented as in Fig. 1.

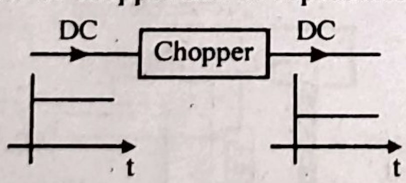


Fig. 1 : Representation of DC-DC converter or chopper

A chopper may be thought as of DC equivalent of an ac transformer since they behave in an identical manner. As chopper involves one stage conversion, these are more efficient. They are used in trolley cars, marine hoists etc. Chopper system offers smooth control, high efficiency, fast response and regeneration.

The power semiconductor devices used for a chopper circuit can be force commutated thyristor, power BJT, power MOSFET, GTO or IGBT. These devices, in general, can be represented by a switch SW with an arrow as shown in Fig. 2.

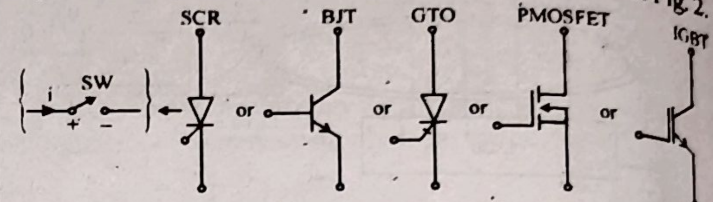


Fig. 2 : Representation of a power semiconductor device

When the switch is off, no current can flow. When the switch is on, current flows in the direction of arrow only. The power semiconductor devices have on state voltage drops of 0.5 V to 2.5 V across them. For simplicity, this voltage drop across these devices is neglected.

Basically chopper can be used to step down or step up the fixed d.c. input voltage. So there are two types of chopper configurations i.e. step down and step up chopper.

PART C

Q.10 ***(a) Why protective devices are used for overload and short - circuit protections? Why do we use an ELCB in an electrical installation?*** ***[R.T.U. 2019]***

(b) Calculate the energy consumed per month by the following loads- ***[R.T.U. 2019]***

(i) 4 tube lights of 40 W used on an average of 8 hours per day.

(ii) 3 fans of 8 W used on an average of 10 hours per day.

(iii) 1 fridge of ¼ kW rating operating 12 hours per day.

The supply voltage is 230 V, 50 Hz. Also calculate the electricity bill if cost of one unit of energy is Rs. 5/- only.

Ans. (a) As we know, overcurrent or excess current is a situation where a larger than intended electric current exists. This leads to the excessive generation of heat and the risk of fire or damage to equipment and potential injury for workers. Ensuring you have the proper protection in place can not only protect workers from injury, it can also prevent downtime and maintenance.

Overload protection is a protection against a continuous overcurrent. Overload protection typically operates on an inverse time curve where the tripping time becomes less as the current increases. This means an overload relay isn't going to trip on momentary or short-term overcurrent events that are normal for the piece of equipment it is protecting. For example some equipment may cause inrush currents as it starts up. However, this inrush current typically lasts only a few seconds and would rarely be an issue. Overload relays are used in a motor circuit to protect motors from damage caused by prolonged periods of overcurrent.

A short circuit occurs when current travels along an unintended path, often where essentially no (or a very low) electrical impedance is encountered. Short circuit protection is protection against excessive currents or current beyond the acceptable current rating of equipment and it operates instantly. As soon as an overcurrent is detected, the device trips and breaks the circuit.

Reason of Using ELCB : *Refer to Q.8.*

Ans. (b) The following table gives wattage and daily usage time of the appliance. Therefore, the total Energy consumption per month is calculated as follows :

Appliance	Watts	Nos.	Hours	Watt × Hours	Units/ day
Tube light	40	4	8	1280	1.28
Fans	8	3	10	240	0.240
Fridge	$\frac{1}{4}\times 1000$ $= 250$	1	12	685	0.685
Total					2.205

Note : For a fridge of capacity 200 to 350 Watts, the annual consumption is 500 units, running 24 hours daily for 365 days in a year. This information is obtained from Govt. of India's Bureau of Energy Efficiency.

Thus, dividing 500 by 365 gives the daily power consumption of fridge as 1.37 units a day (i.e. 24 hrs)

But according to question fridge is operated for 12 hours,

therefore power consumption $= \frac{1.37}{2}$

$= 0.685$ kW-hr

⇒ Therefore, total energy consumed in 1 day = 2.205 units

in 30 days i.e. 1 month = 2.205 × 30

= 66.15 units

⇒ If the cost of one unit of energy is Rs. 5/-

than,

Monthly Electricity bill = 66.15 × 5

= Rs. 330.75

Q.11 ***What is a SCR? Sketch static I-V characteristics of a thyristor. Label the various voltages, currents and the operating modes on this sketch.*** *[R.T.U. 2019]*

Ans. SCR : A Silicon Controlled Rectifier (SCR) is a 3 terminal and 4 layer semiconductor current controlling device. It is mainly used in the devices for the control of high power. Silicon controlled rectifier is also sometimes referred to as SCR diode, 4-layer diode, 4-layer device, or Thyristor. It is made up of a silicon material which controls high power and converts high AC current into DC current (rectification). Hence, it is named as silicon controlled rectifier.

Silicon controlled rectifier is a unidirectional current controlling device. Just like a normal p-n junction diode, it allows electric current in only one direction and blocks electric current in another direction.

Silicon Controlled Rectifier Symbol : The schematic symbol of a silicon controlled rectifier is shown in the below figure. A SCR diode consists of three terminals namely anode (A), cathode (K), Gate (G). The diode arrow represents the direction of conventional current.

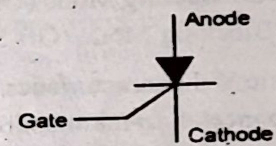


Fig. 1

Construction of Silicon Controlled Rectifier : A silicon controlled rectifier is made up of 4 semiconductor layers of alternating P and N type materials, which forms NPNP or PNPN structures. It has three P-N junctions namely J1, J2, J3 with three terminals attached to the semiconductors materials namely anode (A), cathode (K), and gate (G). Anode is a positively charged electrode through which the conventional current enters into an electrical device, cathode is a negatively charged electrode through which the conventional current leaves an electrical device, gate is a terminal that controls the flow of current between anode and cathode. The gate terminal is also sometimes referred to as control terminal.

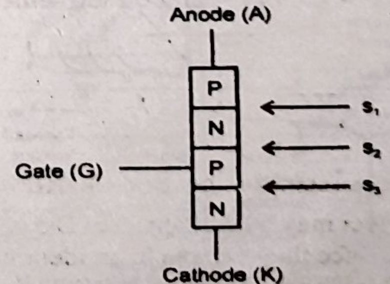


Fig. 2

The anode terminal of SCR diode is connected to the first p-type material of a PNPN structure, cathode terminal is connected to the last n-type material, and gate terminal is connected to the second p-type material of a PNPN structure which is nearest to the cathode.

In silicon controlled rectifier, silicon is used as an intrinsic semiconductor. When pentavalent impurities are added to this intrinsic semiconductor, an N-type semiconductor is formed. When trivalent impurities are added to an intrinsic semiconductor, a p-type semiconductor is formed.

When 4 semiconductor layers of alternating P and N type materials are placed one over another, three junctions are formed in PNPN structure. In a PNPN structure, the junction J1 is formed between the first P-N layer, the junction J2 is formed between the N-P layer and the junction J3 is formed between the last P-N layer. The doping of PNPN structure is depends on the application of SCR diode.

Modes of Operation in SCR : There are three modes of operation for a Silicon Controlled Rectifier (SCR), depending upon the biasing given to it.

(1) Forward Blocking Mode (Off State)
(2) Forward Conducting Mode (On State)
(3) Reverse Blocking Mode (Off State)

To obtain Static V–I characteristics of thyristor, anode and cathode are connected to main source (E) as shown in Fig.3(a).

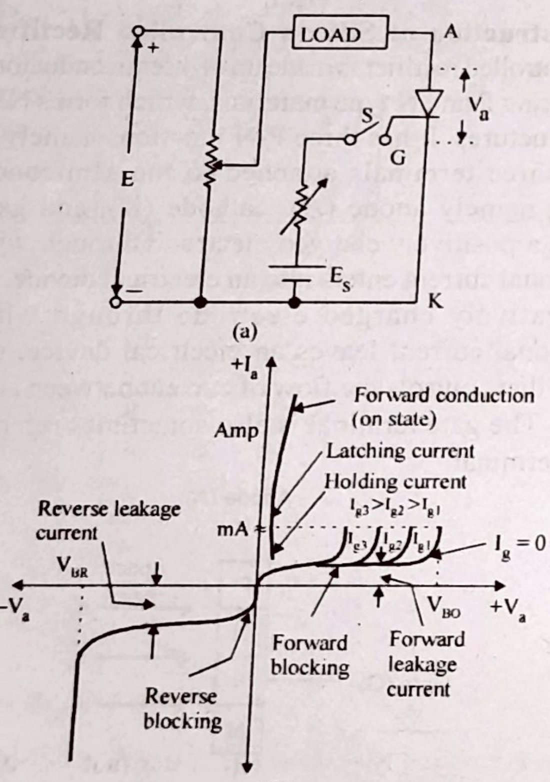


Fig. 3 : (a) Elementary circut for obtaining V–I characteristics (b) Static V–I characteristics of thyristor

Gate and cathode are fed from a source E_s, which provides gate current. Static V–I characteristics is basically a plot between anode voltage (V_a) and anode current (I_a), which is shown in Fig.3(b). It has basically three modes namely reverse blocking mode, forward blocking (off–state) mode and forward conduction (on-state) mode.

Q.12 ***Write short notes on following :***

(a) IGBT

(b) Layout of LT switchgear. ***[R.T.U. 2018]***

Ans.(a) Insulated Gate Bipolar Transistor (IGBT) : Bipolar junction transistor has power losses but has long switching time (Especially at turn off). MOSFET has very fast switching characteristics (low turn on and turn off times) but has high power losses. Insulated gate bipolar transistor facilitates the advantages of BJT and MOSFET. Thus an IGBT has low switching time as well as low power losses.

Configuration of IGBT

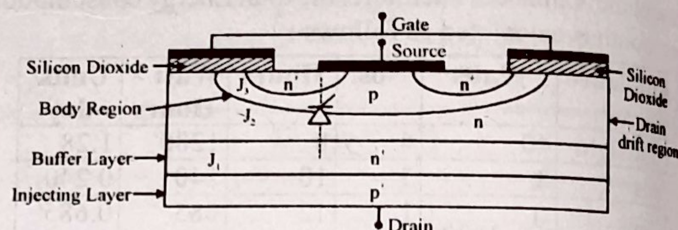


Fig. 1 : Vertical cross section of IGBT

Fig. 1 shows the configuration of an IGBT. The presence of p^+ layer in IGBT forms the drain. This p^+ layer is also termed as injecting layer. The next layer is n^+ layer, which is termed as buffer layer. There is a p-n junction J_1 between these two layers and also two more junctions termed as J_2 and J_3, as shown in fig. 1. Therefore, IGBT configuration has a parasitic SCR. Turn ON of this SCR is undesirable and the body region of IGBT is made to avoid this turn ON.

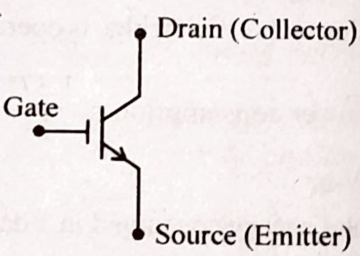


Fig. 2 : Symbol of n channel IGBT

Fig. 2 shows the symbol of an IGBT. This symbol pertains to n-channel device. For p-channel IGBT, direction of arrows would be opposite as shown in fig. 2.

Ans.(b) Low Tension (LT) switchgear, also known as low voltage (LV) switchgear, covers a wide range of equipment

...rmed with switching and interrupting current under both ...able and unfavourable conditions, these include ...es, fuse, circuit breakers, relays and other equipment.

Switch : A switch is a device used for opening and closing of electrical circuit. Switch operates on full load or no-load condition but not on fault condition.

Fuse : A short piece of wire on thin strip, which melts when excess current flow through it under fault condition for sufficient time. Fuse is connected in series with the circuit. The melting of fuse element is due to the increase in temperature.

Circuit Breaker : Circuit breakers are designed to operate on all circuit conditions. The circuit breakers are designed to operate manually under normal operating condition and automatically under fault conditions.

Relay : Relay is a device to detect the fault and give the required information to the breakers for circuit interruption.

A typical low voltage switchgear is shown in fig. 1. ...ain incomer comes from the LV side of a transformer. ...hrough an isolator and MCCB (Molded Case Circuit ...er) feeds the incomer bus. Two sub-incomers are ...ted to incomer bus. These sub-incomers are protected ...er switch fuse unit or circuit breakers. The load feeders ...nected to any section of feeder bus. The load can be ...heater, domestic lighting and AC loads.

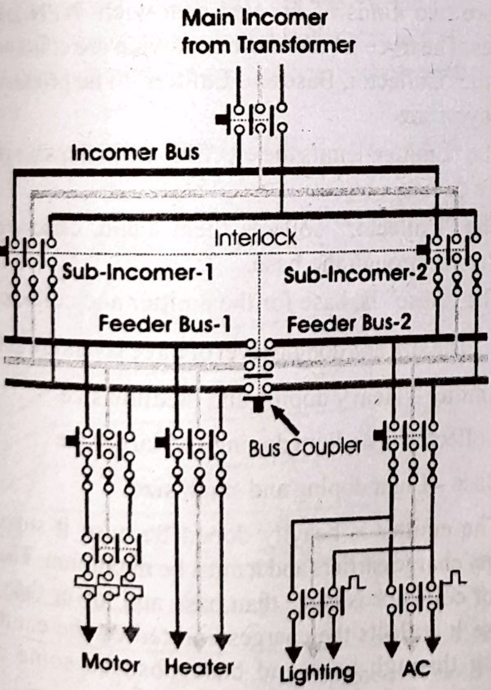


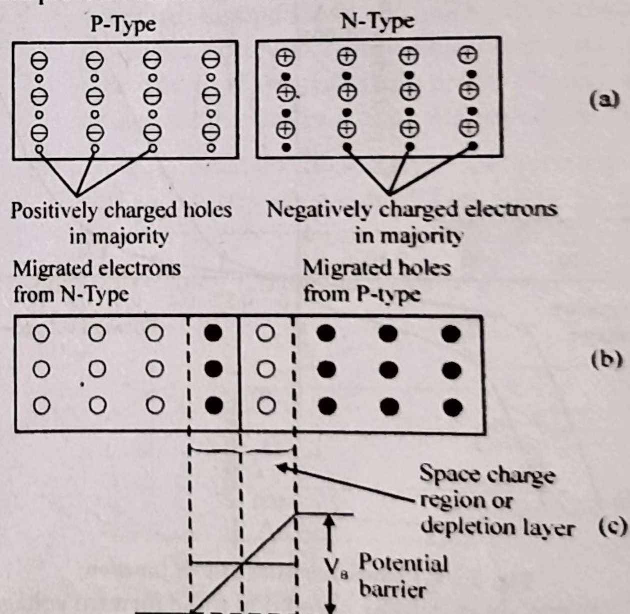
Fig. : LV Switchgear Layout

Q.13(a) ***Explain Principle of operation and characteristics of P-N junction diode.***

(b) ***Explain Principle of operation and characteristics of BJT.*** **[R.T.U. 2018]**

Ans.(a) P-N Junction Diode

When a P-type material is joined to N-type, P-N junction is formed. Basically merely joining the two pieces, P-N junction cannot be formed due to surface films and other irregularities, which produce major discontinuities in the crystal structure. Thus P-N junction is formed from a piece of semiconductor by diffusing P-type material to the half side and N-type material to other half side. The plane, which divides the two zones is known as a junction. In P-N junction, where two pieces are joined together, as shown in Fig.5.10. P type material has a high concentration of holes and N-type material has high concentration of free electrons, so there is a tendency of holes to diffuse over to N-side and electrons to P-side. This process is known as diffusion. Due to diffusion, some holes from P-side cross over to N-side where they combine with electrons and become neural. In the same manner, some electrons from N side cross over to P-side where they combine with holes and become neutral. In such way, region known as depletion layer or charged free region or space charge region is formed because there is no charge available for conduction. Holes & electrons continues to diffuse till a potential barriers is developed in charged free region, which prevents further neutralization or diffusion.



(a) P-type and N-type semiconductor (not joined)
(b) P-N junction (after joining, (c) Potential barrier

Fig. 1 : P-N Junction

V-I Characteristics of P-N Junction Diode

(a) Forward bias : When the P–type is connected to the positive terminal and N type is connected to the negative terminal of a battery, the P–N junction is called forward biased as shown in Fig. 2. The potential divider is used to vary the potential at P–N junction. Potential barrier is eliminated at some forward voltage (0.3 V for Ge and 0.7 V for Si) and current starts flowing. This voltage, at which current starts flowing is called threshold voltage (V_{th}) or cut–in voltage or knee voltage. The value of this threshold voltage is practically equal to barrier voltage (V_B). When $V < V_{th}$ the current flow is negligible and when the applied voltage increases the threshold voltage in forward bias, the forward current rises exponentially as shown in Fig.3.

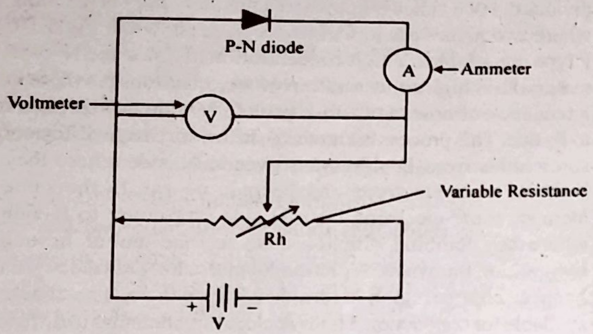


Fig. 2 : Forward Biased PN junction diode

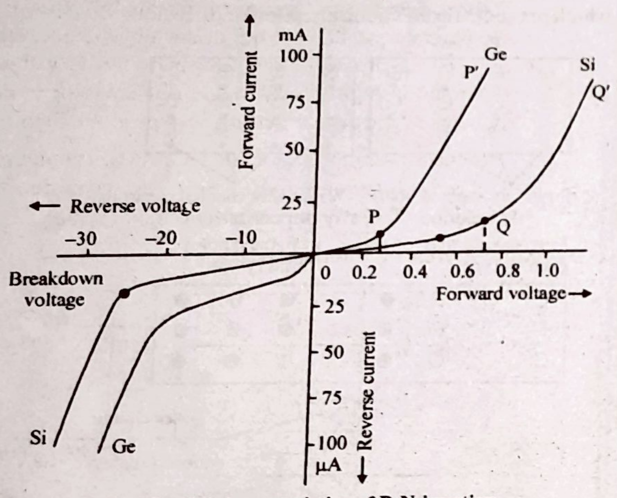


Fig. 3 : V-I characteristics of P-N junction

Here it should be noted that if the forward voltage is increased beyond a certain safe value, an extremely large current is produced, which may destroy the junction due to overheating.

(b) Reverse Bias : When the P–type is connected to the negative terminal and N type is connected to the positive terminal of a battery, the P–N junction is called reverse biased. The potential divider is used to vary the potential at P–N junction. In such case the junction resistance becomes very high and no current flows through the circuit. Practically a small current of μA order flows in the circuit because of minority carriers. This minor current is known as reverse current, as shown in Fig.3. When the reverse voltage is increased from zero, the reverse current quickly rises to its saturation or maximum value. The minor increase in current is due to impurities on the surface of the semiconductor that behaves as a resistor and follows Ohm's law, this rise in current is called surface leakage current. This current depends on reverse voltage but is independent of temperature. After a certain rise in the reverse voltage, the kinetic energy of electron (minority carrier) increases so much that they knock out electrons from the semiconductor atoms. At this point, breakdown of junction occurs and there is a sudden rise of reverse current and the junction is permanently destroyed.

Ans.(b) Bipolar Junction Transistor (BJT)

A transistor is basically a silicon or germanium crystal containing three separate regions. Bipolar transistors are so named because they conducts by both majority and minority carriers *i.e.* electrons and holes. A bipolar transistor essentially consists of a pair of PN junction diodes, that are joined back–to–back. This forms a sort of sandwich, where one kind of semiconductor is placed in between two others. There are therefore two kinds of bipolar sandwich, NPN and PNP, varieties. The three layers of the sandwich are conventionally called the "Collector, Base and Emitter". The primary role of three layers are

- The "Emitter" emits the electrons, which passes through the device.
- The "Collector" collects them again, once they have passed through the base.
- The "Base" is, base for the emitter and collector.

The size and doping level of three layers are as follows:

- Emitter – Heavy doping and medium size
- Collector – Medium doping and large size
- Base – Light doping and small size

The emitter is heavily doped because it supplies the majority charge carriers and it must be maximum. The doping level of collector is more than base and lower than emitter because it collects the charges emitted by the emitter after passing through base and base absorbs some charges (electrons or holes).

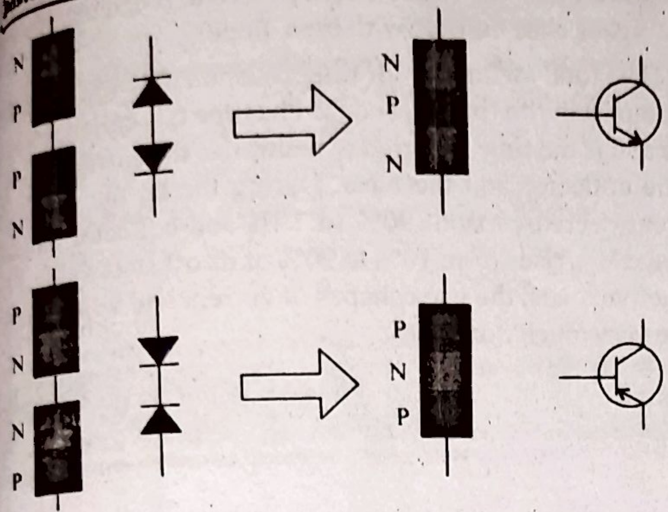


Fig. 1 : Bipolar junction transistors

The size of the collector is made larger because it collects the charge carriers (about 90%) holes or electrons and due to the recombination of these, heat is produced and it must be dissipated. For dissipate the heat, the area of the collector must be largest.

Base has lightest doping level, to avoid the recombination of all charge carriers, emitted by emitter and passes most of the charge carriers to the collector. The size of the base is very small, so the charge carriers have to travel very small distance. The emitter and collector would then form a continuous piece of semiconductor, so current would flow between them, whatever is the base potential. If thickness of base region is large then electrons entering the base from the emitter would not be able to reach the collector as it would be too far from the emitter. So, the current would all be between the emitter and the base and there will be no emitter collector current.

Characteristics of Power BJT

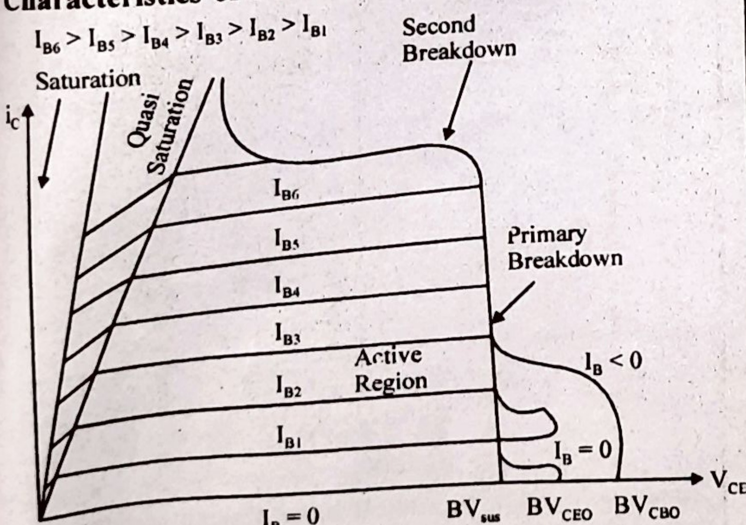


Fig. 2 : Output characteristics of NPN power BJT

Fig. 2 shows output characteristics of NPN power BJT. As in case of lower power BJT, these characteristics depicts the relationship between collector current i_c and collector to emitter voltage V_{CE} for different values of base current i_B. The characteristics of darlington pair are similar to Fig. 2. It is seen that these characteristics have some special features, very different from those for lower power BJT, are as under :

(1) For substantial values of collector current, there is a maximum value of collector emitter voltage, which the device can sustain. This is denoted by BV_{sus} in Fig.2. If base current is zero, this maximum voltage can be sustained by the device increases to BV_{CEO} (collector emitter voltage, when the base is open circuited). The voltage BV_{CBO} is the breakdown voltage when emitter is open circuited.

(2) The primary breakdown is due to avalanche breakdown of C-B junction. In this region, the current and power dissipation can be very high. Therefore, this region should be avoided.

(3) In the region marked second breakdown, the C-E voltage decreases substantially and collector current is high. This region is due to thermal run away. A cumulative process (power dissipation causes increases in temperature, which further increases power dissipation and so on) occurs in this region and the device gets destroyed. In this breakdown, the power dissipation is not uniformly spread over the entire volume of the transistor but is rather restricted to highly localized areas. Therefore, the chances of the device getting destroyed are high.

(4) The quasi saturation region (region between saturation and active region) exists. This region is due to presence of lightly doped drift collector region.

Dynamic Switching Characteristics of Power BJT's

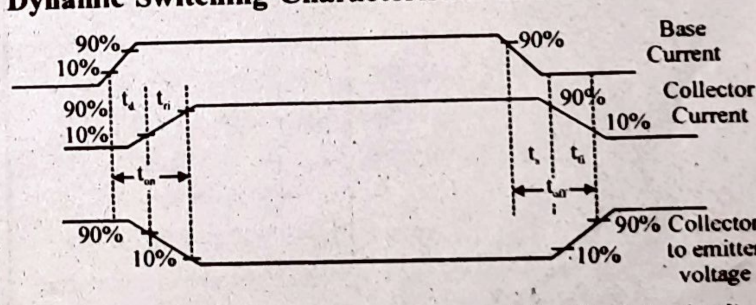


Fig. 3 : BJT dynamic switching characteristics (Resistive load)

A power BJT cannot be switched on and switched off instantaneously. It requires a finite time to change from off to on and on to off states. Most of the losses in a power BJT also occur during the switching process. Fig. 3, shows the switching characteristics for resistive load.

The rise and fall of currents and voltages have been shown as linear. However, in actual practice, the characteristics are non-linear. The time for switching on is denoted by t_{on}. It can be broken into two components t_d and t_{ri}. The delay time t_d is the time required to discharge the capacitance of junction base-emitter. The time t_{ri} is the time taken by collector current to rise from 10% to 90% of its final value. During time t_{ri}, the collector emitter voltage V_{CE} falls from 90% to 10% of its off state value. The time t_d depends on the magnitude of base current. It can be reduced by a higher base current with high slope.

The total switching off time is denoted by t_{off}. It can be decomposed into times t_s and t_{fi}. The time t_s is called storage time and is the time required to neutralize the carriers stored in the collector and the base. During the t_{fi}, the collector current decreases from 90% to 10% and collector emitter voltage V_{CE} rises from 10% to 90% of its off state value. For inductive loads, the waveshapes of current and voltage tend to be very much distorted.

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