

BASIC ELECTRICAL ENGINEERING

2088f PDF  BEE 10 PDF

DC CIRCUITS

1

PREVIOUS YEARS QUESTIONS

SHORT ANSWER TYPE QUESTIONS

Prob.1 Describe Ohm's Law.

1. Ohm's law is defined as "the ratio of potential difference between any two points on a conductor to the current (I) 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.

Prob.2 Define electrical power and energy.

1. **Electrical Energy** : When a potential difference (V) is applied across a resistance, a current (I) flows through it 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.

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

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".

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.

Prob.3 State Faraday's first law.

Sol. Faraday's first law states that, "whenever relative motion exists between a conductor/coil and a magnetic field, a voltage is induced in the circuit." In other words whenever there is a change of flux linkage in a conductor/coil, a voltage is induced in the conductor/coil.

Prob.4 Define inductance and also describe the energy stored in inductor.

Sol. The inductance is the property of a circuit element by virtue of which it opposes the change of current through it and is capable to store electric energy in the form of magnetic field. The unit of inductance is Henry (H) -

$$L = \frac{N^2 \mu A}{l}$$

The inductor is an element, which stores the energy by virtue of current flowing through it.

Energy in inductor

$$E = L \int i \frac{di}{dt} dt = L \int i di$$

$$= \frac{1}{2} Li^2 \text{ Joules}$$

Prob.5 State maximum power transfer theorem.

Sol. Maximum Power Transfer Theorem : A resistive load, being connected to dc network, receives maximum power when load resistance is equal to the internal resistance (Thevenin's equivalent resistance) of the source network as seen from the load terminals.

Prob.6 What do you understand by active elements?

Sol. Active Elements : The elements which are source of energy and always supply energy to the network are called active elements. The energy source can be supplying voltage or current. An element which can increase the power level of the circuit, is known as active element. A transistor is an active element as it can amplify the power level in the circuit. Transformer is not an active element as it can not modify the power level.

Examples : Batteries, cell, alternators, etc.

Prob.7 State and explain Kirchhoff's Current Law (KCL).

Sol. Kirchhoff's Current Law (KCL) : KCL states that "In any electrical network, the algebraic sum of all currents meeting i.e., terminating at a point (or node) at any instant is zero".

Alternatively, it states that "In any electrical network, the sum of all current flowing towards a junction (entering) is equal to the current flowing outwards from a junction (leaving)".

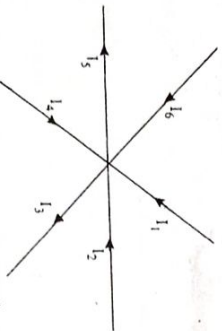


Fig. : One node with terminating branches

According to KCL, the sum of the currents flowing towards the node must be equal to sum of currents flowing out of node.

In Fig., outgoing currents are I_4, I_5 and incoming currents are $I_1, I_2, I_3, I_4, I_5, I_6$. So according to KCL

$$I_1 + I_2 + I_3 + I_4 + I_5 + I_6 = I_4 + I_5$$

$$\sum I = 0$$

18. LONG ANSWER TYPE QUESTIONS

Prob.1(a) State and explain Norton's theorem.

(b) Find the load current I_L in R_L .

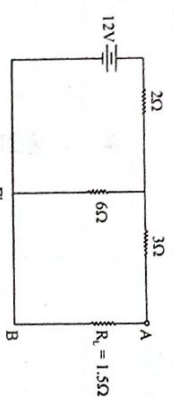


Fig.

Sol.(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_n in parallel with the single resistance R_{th} ", where I_n is the short circuit current through the short circuited terminals ab and R_{th} is the equivalent resistance as viewed from the terminal when all the independent sources are reduced to zero i.e. leaving their internal resistances.

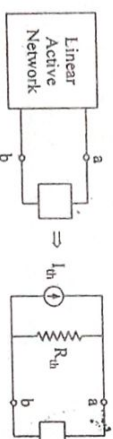


Fig. 1 : Norton's equivalent circuit

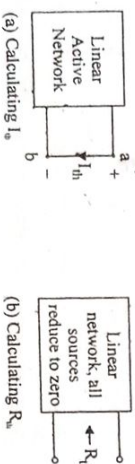
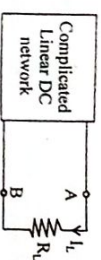


Fig. 2 : Finding I_n and R_{th}

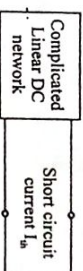
The Norton's theorem is not applicable in following conditions :

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.
4. If the circuit resistance is infinity.

Steps to apply Norton's Theorem

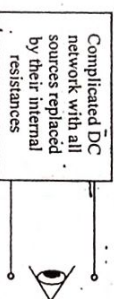


Step - 1 : Remove the load resistance i.e. the resistance across which the response is to be found. The terminals will be short circuited.



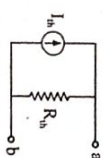
Step - 2 : Using any method like, nodal or loop analysis, find the current flowing through the short circuited terminals.

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_n 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.

Sol.(b)

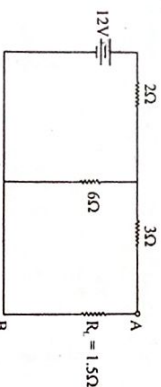
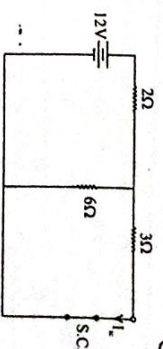


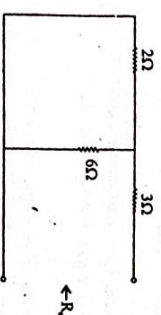
Fig.

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



$$I_{sc} = \frac{12}{(3 \parallel 6) + 2} = \frac{12}{4} = 3 \text{ Amp.} \quad \therefore \frac{3 \times 6}{3 + 6} = 2$$

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

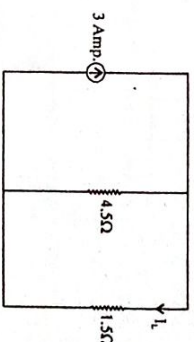


$$R_{eq} = (2 \parallel 6) + 3$$

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

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

Step-3 : Equivalent ckt



By current division rule-

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

$$I_L = 2.25 \text{ Amp.}$$

Prob.2(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.

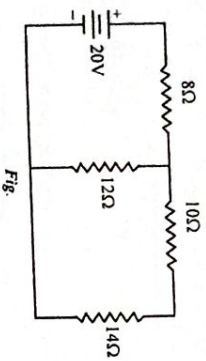
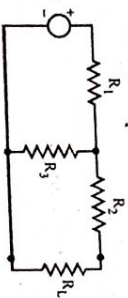


Fig.

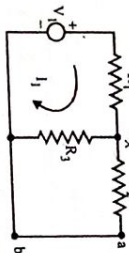
Sol.(a) Refer to Long Answer Prob. 1(a).

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 current 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

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

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

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

Step 4 - The Norton's equivalent circuit is



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

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

Sol.(b)

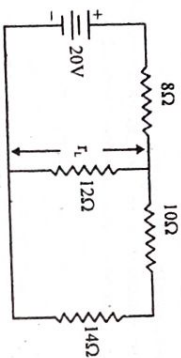


Fig.

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

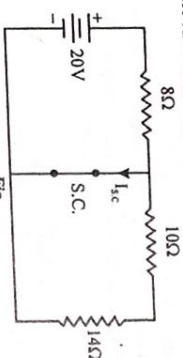


Fig.

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

$$I_{sc} = \frac{20}{8} = 2.5 \text{ Amp}$$

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

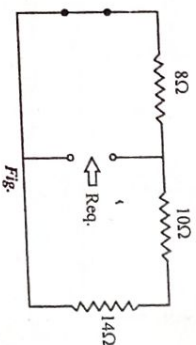


Fig.

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

$$= \frac{24 \times 8}{24 + 8} = \frac{24 \times 8}{32} = 6 \Omega$$

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

Step 3 : Equivalent ckt -

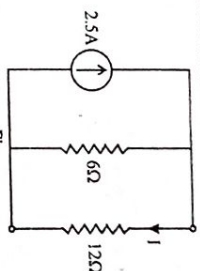


Fig.

By current division Rule -

$$I = 2.5 \times \frac{6}{12 + 6} = \frac{15}{18} = 0.83 \text{ Amp}$$

Prob.3 Calculate current in 2-ohm resistor in the network shown in figure.

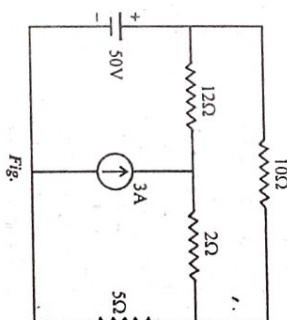


Fig.

Sol.

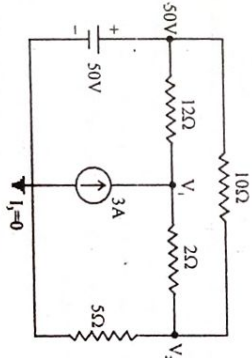


Fig.

Here we solved this circuit by Nodal analysis Apply KCL at node V_1

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

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

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

Now Apply KCL at node V_2

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

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

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

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

$$\frac{35V_1 - 30V_2}{35V_1 - 56V_2} = \frac{430}{-350}$$

$$\frac{26V_2}{780} = \frac{780}{20}$$

$$= 30V$$

Put V_2 value in eq. (1)

$$7V_1 - (30 \times 6) = 86$$

$$7V_1 = 266$$

$$V_1 = 38V$$

current across 2Ω branch

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

$$= \frac{38 - 30}{2} = 4 \text{ Amp}$$

Ans.

Prof. 4 State and explain Thevenin's 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 Thevenin's as Thevenin's]

Sol. 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_1 is removed in Fig. 1(b) and V_{oc} is calculated.

$$V_{oc} = I_1 r_1 = \frac{V_1}{r_1 + r_2}$$

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(c).

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

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

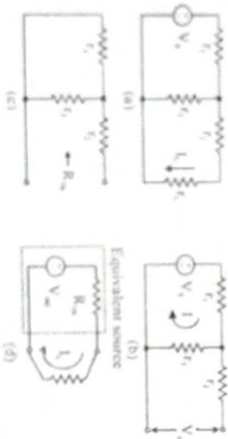


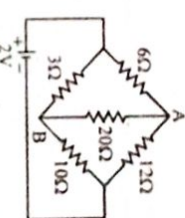
Fig. 1 : (a) A simple DC circuit, (b) Finding of V_{oc} , (c) Finding of R_{Th} (d) Finding of I_L , forming Thevenin's equivalent circuit

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

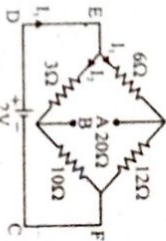
The internal resistance of the source network is then

$$\text{obtained as } R_{Th} = \frac{V_{oc}}{I_{sc}}$$

Application of Thevenin's Theorem



Step - 1 : Remove load resistance $R_L = 200\Omega$.



Applying Kirchhoff's Voltage Law (KVL) for path DEAC

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

Step - 2 : Applying Kirchhoff's Voltage Law (KVL) for path DEBFC

$$I_2 = \frac{2}{3 + 10} = \frac{2}{13} = \frac{1}{6.5} A$$

For path AEB using KVL

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

$$V_A - V_B = -6I_1 + 3I_2 = -6 \times \frac{1}{9} + 3 \times \frac{1}{6.5}$$

$$V_A - V_B = \frac{-2}{3} + \frac{10}{13} = \frac{-10 + 3}{15} = \frac{-7}{15} \text{ Volt}$$

B is at higher potential.

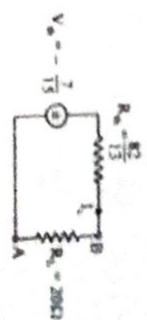
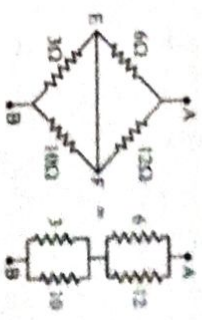
Step - 3 : Short circuit voltage sources

$$R_{Th} = \frac{6 \parallel 12 + 3 \parallel 10}{6 + 12} = \frac{6 \times 12}{6 + 12} + \frac{3 \times 10}{6 + 12}$$

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

The Thevenin's Resistance

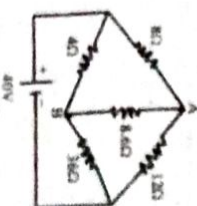
$$R_{Th} = \frac{82}{13} \Omega$$



$$\text{Load current } I_L = \frac{V_{oc}}{R_{Th} + R_L} = \frac{\frac{7}{13}}{\frac{82}{13} + 20}$$

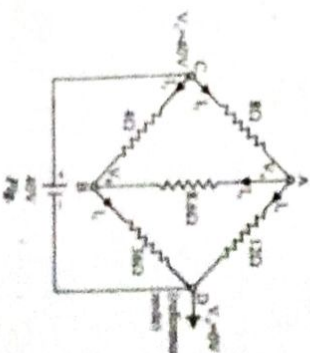
$$I_L = 0.0177 A$$

Prob. 5 Find the current in branch AB in the unbalanced bridge using Nodal analysis, as shown in Fig.



[Note : Precise nodal analysis is needed.]

Sol. As seen, the given circuit has 4 nodes:



Taking D as reference node, then $V_D = 0V$ and $V_C = 40V$
KCL equation at node A

$$I_1 - I_2 - I_3 = 0$$

$$\frac{V_C - V_A}{8} - \frac{V_A - 0}{12} - \frac{(V_A - V_B)}{8.6} = 0$$

$$\frac{V_A - V_C}{8} + \frac{V_A}{12} + \frac{10(V_A - V_B)}{8.6} = 0$$

$$\frac{129V_A - 129V_C + 86V_A + 120V_A - 120V_B}{1032} = 0$$

$$129V_A - 129V_C + 86V_A + 120V_A - 120V_B = 0$$

$$335V_A - 120V_B - 129V_C = 0$$

$$\text{here, } V_C = 40V$$

$$335V_A - 120V_B = 5160$$

KCL equation at node B

$$I_2 + I_3 = I_1$$

$$\frac{V_C - V_B}{8.6} + \frac{V_A - V_B}{3.6} = \frac{V_B - V_D}{3.6}$$

$$\frac{V_B - V_C}{8.6} - \frac{V_B - V_A}{3.6} + \frac{V_B - V_D}{3.6} = 0$$

$$\text{here } V_C = 40V, V_D = 0V$$

$$\frac{V_B - 40}{8.6} - \frac{V_B - V_A}{3.6} + \frac{V_B}{3.6} = 0$$

$$\frac{V_B - 40}{8.6} + \frac{10(V_B - V_A)}{86} + \frac{V_B}{36} = 0$$

$$\frac{387(V_B - 40) + 180(V_B - V_A) + 43V_B}{1548} = 0$$

$$387V_B - 15480 + 180V_B - 180V_A + 43V_B = 0$$

$$-180V_A + 610V_B = 15480$$

Using Cramer's rule

$$\begin{bmatrix} 335 & -120 \\ -180 & 610 \end{bmatrix} \begin{bmatrix} V_A \\ V_B \end{bmatrix} = \begin{bmatrix} 5160 \\ 15480 \end{bmatrix}$$

$$\text{So, } V_A = \frac{15480 \cdot 610 - 335 \cdot 120}{335 \cdot 610 - (-180 \cdot 120)} = \frac{3147600 + 1857600}{204350 - 21600}$$

$$= \frac{5005200}{182750} = 27.388$$

$$\text{and } V_B = \frac{335 \cdot 15480 - (-180 \cdot 5160)}{335 \cdot 610 - (-180 \cdot 120)} = \frac{5185800 + 928800}{204350 - 21600}$$

Applying KVL in this loop

$$6 = 5i' + 5V_x + i'(1)$$

$$\text{Also } V_x = 1 \times i' = i'$$

$$\text{Using (ii) in (i)} \quad 6 = 6i' + 5i' = 11i'$$

Therefore

$$i' = \frac{6}{11} A \quad \dots(iii)$$

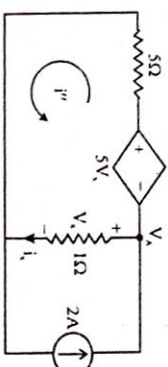


Fig. 3

At node V_A $2 = i_x + i''$

$$= \frac{V_x}{1} + i'' \quad \dots(iv)$$

But loop analysis in the left loop gives

$$-V_x - 5V_x + 5i'' = 0$$

$$\text{or } -6V_x = -5i''$$

$$\text{or } i'' = \frac{6}{5} V_x$$

Using (v) in (iv)

$$2 = \frac{5i''}{6} + i'' = \frac{11}{6} i''$$

$$\therefore i'' = \frac{12}{11} A$$

Hence, using the principle of superposition,

$$i = i' - i'' = \frac{6}{11} - \frac{12}{11} = -\frac{6}{11} A \quad \text{Ans.}$$

Sol.(b) In the given circuit apply nodal analysis. The circuit has three nodes. The bottom node is taken as reference node. The other node voltages are taken as V_1 and V_2 .

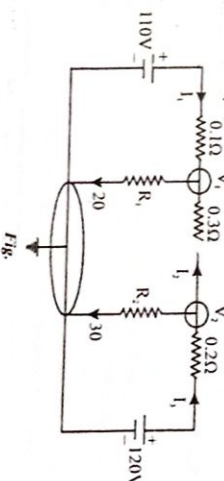


Fig. 4

Now as given in the circuit R_1 and R_2 are 20A and 30A respectively, so

$$\frac{V_1}{R_1} = 20 \quad \dots(1)$$

$$\frac{V_2}{R_2} = 30 \quad \dots(2)$$

KCL equation at node V_1

$$\frac{V_1 - 110}{0.1} + \frac{V_1 - V_2}{0.3} + 20 = 0 \quad \dots(3)$$

[Note: In these equations, do not consider the direction of current as given in the circuit]

$$\frac{10(V_1 - 110)}{1} + \frac{10(V_1 - V_2)}{3} + 20 = 0$$

$$30(V_1 - 110) + 10(V_1 - V_2) + 60 = 0$$

$$30V_1 - 3300 + 10V_1 - 10V_2 + 60 = 0;$$

$$40V_1 - 10V_2 = 3240$$

$$4V_1 - V_2 = 324$$

KCL equation at node V_2

$$\frac{V_2 - V_1}{0.3} + \frac{V_2 - 120}{0.2} + 30 = 0 \quad \dots(5)$$

$$\frac{10(V_2 - V_1)}{3} + \frac{10(V_2 - 120)}{2} + 30 = 0$$

$$20(V_2 - V_1) + 30(V_2 - 120) + 180 = 0$$

$$20V_2 - 20V_1 + 30V_2 - 3600 + 180 = 0;$$

$$-20V_1 + 50V_2 = 3420$$

$$-2V_1 + 5V_2 = 342$$

Solving equation (4) and (6)

$$\frac{4V_1 - V_2 = 324}{-4V_1 + 10V_2 = 684}$$

$$\frac{9V_2 = 1008}{V_2 = 112V}$$

Putting value of V_2 into equation (4)

$$4V_1 - 112 = 324; 4V_1 = 436$$

$$V_1 = 109V$$

From equation (1), the value of R_1

$$\frac{R_1}{V_1} = \frac{109}{20}$$

$$R_1 = 5.45 \Omega$$

From equation (2), the value of R_2

$$\frac{R_2}{V_2} = \frac{112}{30}$$

$$R_2 = 3.73 \Omega$$

Now current I_1 is

$$I_1 = \frac{110 - V_1}{0.1} = \frac{110 - 109}{0.1}$$

$$I_1 = 10 \text{ A}$$

$$\text{Current } I_2$$

$$I_2 = \frac{V_2 - V_1}{0.3} \quad (\text{As given direction is from } 110\text{V to } V_1)$$

$$= \frac{112 - 109}{0.3}$$

$$I_2 = 10 \text{ A}$$

$$\text{Current } I_3$$

$$I_3 = \frac{120 - V_2}{0.2} = \frac{120 - 112}{0.2} = \frac{8}{0.2}$$

$$I_3 = 40 \text{ A} \quad (\text{As given direction is from } 120 \text{ V to } V_2)$$

Prob. 2(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 $v = 150(1 - e^{-20t})$. After 0.05 sec, the current flow is equal to 1.14 mA. Find the capacitance and the energy stored in the capacitor.

Sol. (a) 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 it is proportional to the rate of flux cutting by the conductor.

Eddy Currents: When a conductor is kept in a constantly changing magnetic field, induced currents are produced in the body of the conductor. These are known as eddy currents. These currents were discovered by Foucault in 1965, hence they are also called Foucault's currents. Thus, eddy currents are the induced currents setting in the body of a conductor when the amount of magnetic flux linked with the conductor changes.

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

The Process of Generation of Eddy Currents on the Basis of Faraday's Law of EMI: According to Faraday's first law, whenever the magnetic flux is cut by an electrical conductor there will be an induced emf in the conductor. If the conductor circuit is closed, then the current will also circulate through the circuit and this current is called eddy current.

Sol. (b) Given:

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

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

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

$$\text{Now } i = v \frac{dv}{dt}$$

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

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

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

$$\therefore \text{Capacitance}$$

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

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

$$= 0.00114$$

$$= 1103.64$$

$$[C = 1.03 \mu\text{F}]$$

$$\text{Energy stored in capacitor} = \frac{1}{2} C v^2$$

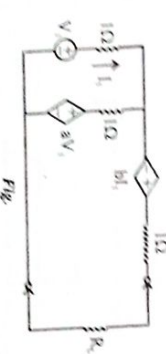
$$= \frac{1}{2} \times 1.03 \times 10^{-6} [150(1 - e^{-20 \times 0.05})]^2$$

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

$$= 4.63 \times 10^{-5} \text{ J}$$

$$= 4.63 \text{ mJ}$$

Prob. 2(b) Find the Thevenin's equivalent circuit for the network shown below:



b) Find out the energy stored in capacitor in the figure shown below under steady state conditions. Also find current I_3 .

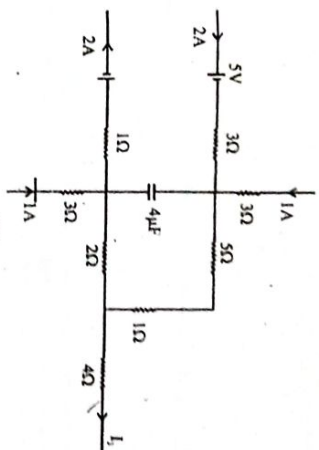


Fig. 2

3) 'N' cells, each of emf 'E' and internal resistance 'r' are connected in a closed ring so that the positive terminal of each cell is joined to the negative terminal of the next. Two points of this ring are connected through an external resistance 'R'. Find the current in 'R' using Kirchhoff's mesh equations.

1. (a) Step-1: Calculate the voltage across the terminal b which is V_b

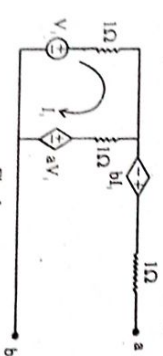


Fig. 1

Apply KVL to the loop

$$-I_1 - aV_1 + V_1 - I_1 = 0$$

$$2I_1 = V_1(1 - a)$$

$$I_1 = \frac{V_1(1 - a)}{2}$$

Hence the dependent sources and various drops are,

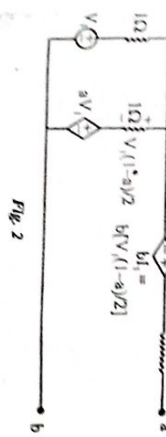


Fig. 2

$$V_{ab} \text{ or } V_b = \frac{bV_1}{2} (1 - a) + \frac{V_1}{2} (1 - a) + aV_1$$

$$= \frac{V_1}{2} [b - ab + 1 - a + 2a]$$

$$V_b = \frac{V_1}{2} (1 + a + b - ab)$$

Step-2: Calculate equivalent impedance Z_{eq} as viewed through the terminal a-b

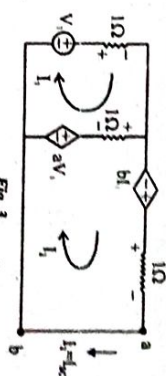


Fig. 3

Apply KVL to the loop-1

$$-I_1 + I_2 - aV_1 + V_1 - I_1 = 0$$

$$I_2 = 2I_1 + aV_1 - V_1$$

Apply KVL to the loop-2

$$bI_1 - I_2 + aV_1 - I_2 + I_1 = 0$$

$$\therefore I_1(1 + b) - 2I_2 + aV_1 = 0$$

Substituting the value of I_2 from eq. (i) into eq. (ii)

$$\therefore I_1(1 + b) - 2[2I_1 + aV_1 - V_1] + aV_1 = 0$$

$$\therefore I_1[1 + b - 4] - 2aV_1 + 2V_1 + aV_1 = 0$$

$$\therefore I_1[b - 3] = aV_1 - 2V_1$$

$$I_1 = \frac{V_1(a - 2)}{b - 3}$$

Substituting the value of I_1 in the eq. (i), we get

$$I_2 = \frac{2V_1(a - 2)}{(b - 3)} + aV_1 - V_1$$

$$= \frac{2V_1(a - 2) + aV_1(b - 3) - V_1(b - 3)}{(b - 3)}$$

$$= \frac{V_1[2a - 4 + ab - 3a - b + 3]}{(b - 3)}$$

$$= \frac{-V_1(1 + a + b - ab)}{(b - 3)}$$

$$\therefore I_2 = I_{sc} = \frac{V_1(1 + a + b - ab)}{(3 - b)}$$

$$\therefore Z_{eq} = \frac{V_b}{I_{sc}}$$

$$= \frac{V_1}{2} \times \left[\frac{1+a+b-ab}{3-b} \right]$$

$$= \frac{(3-b)}{2}$$

Step-3: Hence the thevenin's equivalent is

$$V_{th} = \frac{V_1}{2} (1+a+b-ab)$$

Sol.(b)

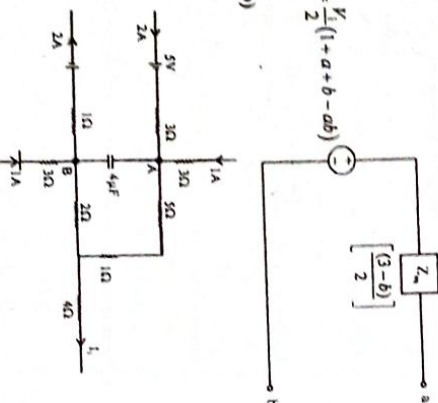


Fig. 1

Voltage across 3Ω resistance

$$V = IR$$

$$V_{3\Omega} = 2 \times 3$$

$$V_{3\Omega} = 6V$$

Voltage across 1Ω resistance

$$V_{1\Omega} = IR$$

$$V_{1\Omega} = 2 \times 1$$

$$V_{1\Omega} = 2V$$

Voltage across point A = Voltage across 3Ω resistance

$$V_A = 6V$$

Voltage across point B = Voltage across 1Ω resistance

$$V_B = 2V$$

Energy stored in capacitor = $\frac{1}{2} CV^2$

$$= \frac{1}{2} C (V_A - V_B)^2$$

$$= \frac{1}{2} \times 4 \times 10^{-4} (6-2)^2$$

At steady-state conditions, capacitor are fully charge and act as open circuit.

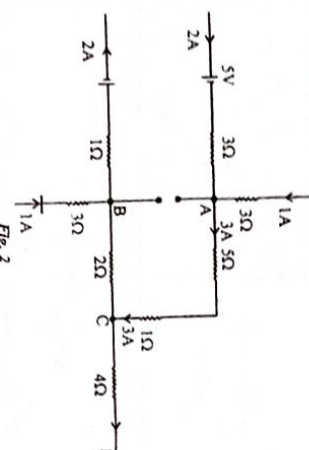


Fig. 2

At summing point A

$$I_{3\Omega} + I_{5\Omega} = I_{5\Omega}$$

$$2A + 1A = I_{5\Omega}$$

$$I_{5\Omega} = 3A$$

At summing point B

$$I_{3\Omega} + I_{2\Omega} = I_{1\Omega}$$

$$1A + I_{2\Omega} = 2A$$

$$I_{2\Omega} = 1A$$

At summing point C

$$I_{1\Omega} = I_{3\Omega} + I_3$$

$$3A = 1A + I_3$$

$$I_3 = 3A - 1A$$

$$I_3 = 2A$$

Sol.(c) If n be the number of cells connected on one side of R, then the number of cells connected on the other side of R is (N-n). Current distribution in the equivalent circuit is shown in fig. 1.

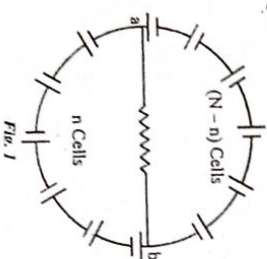


Fig. 1

Here, n cells are shown as equivalent to a single cell e.m.f. nE and internal resistance nr. Similarly (N-n) cells shown equivalent to single cell of e.m.f. (N-n)E and internal resistance (N-n)r.

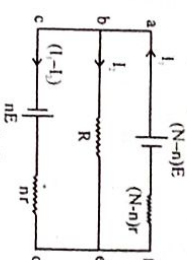


Fig. 2

Apply KVL at mesh abcda

$$I_1 (N-n)r + I_2 R = (N-n)E$$

$$I_1 = \frac{(N-n)E - I_2 R}{(N-n)r}$$

$$= \frac{E}{r} - \left[\frac{I_2}{(N-n)} \right] \frac{R}{r}$$

...(i)

Apply KVL at mesh abcda

$$I_1 (N-n)r + (I_1 - I_2)nr = (N-n)E + nE$$

$$I_1 [(N-n)r + nr] = NE - nE + nE + I_2 nr$$

$$I_1 (Nr) = NE + I_2 nr$$

$$I_1 = \frac{E}{r} + \frac{I_2 nr}{N}$$

...(ii)

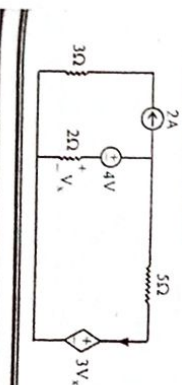
Combining eq. (i) and eq. (ii), we get

$$\frac{E}{r} - \left[\frac{I_2}{(N-n)} \right] \frac{R}{r} = \frac{E}{r} + \frac{I_2 nr}{N}$$

$$\text{or } I_2 \left[\frac{n}{N} + \frac{R}{(N-n)r} \right] = 0$$

$\therefore I_2 = 0$, i.e. current through resistance R is zero.

b.9 Find the current in 5Ω resistance using superposition theorem.



Sol. Remove Current Source

$$4 = 5I_1 + 3V_x - V_x$$

$$= 5I_1 + 2V_x$$

$$= 5I_1 + 2(2I_1) \quad [\because V_x = 2 \times I_1 = 2I_1]$$

$$= 5I_1 + 4I_1$$

$$4 = 9I_1$$

$$I_1 = \frac{4}{9}$$

Fig. 1

Now Remove 4V Source

At node 'x'

$$2 = I_x + I_2$$

$$2 = \frac{V_x}{2} + \frac{V_x - 3V_x}{5}$$

$$2 = \frac{V_x}{2} - \frac{2V_x}{5}$$

$$2 = \frac{5V_x - 4V_x}{10} = \frac{V_x}{10}$$

$$\Rightarrow V_x = 20$$

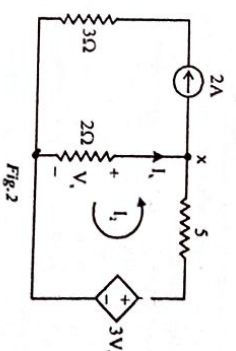


Fig. 2

$$\text{Thus } I_2 = \frac{V_x - 3V_x}{5}$$

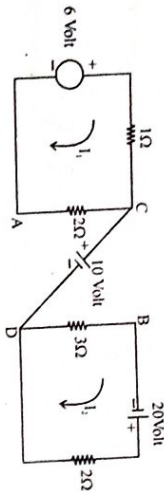
$$= \frac{20 - 3(20)}{5}$$

$$I_2 = -8$$

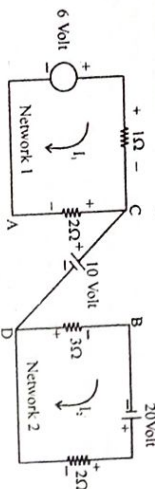
$$\therefore I = I_1 - I_2 = \frac{4}{9} - (-8) = \frac{4}{9} + 8$$

$$= 0.44 + 8 = 8.44 \text{ A}$$

Prob.10 Find the voltage drop between terminal AB, CB and AD in Fig.



Sol. 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

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

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

$$= 12 + 10 - 4$$

$$= 18 \text{ V}$$

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

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

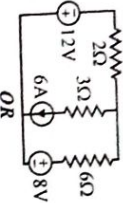
$$V_{CB} = 12 + 10 = 22 \text{ V}$$

V_{AD} is the potential of node A with respect to D.

So starting with D and moving upto A, we have

$$V_{AD} = 10 - 2I_1 = 10 - 2(2) = 10 - 4$$

Prob.11 State and explain superposition theorem. Use superposition theorem to determine the current I in the network.

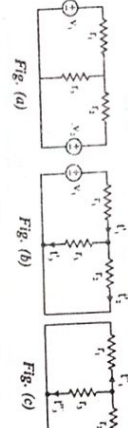


State and explain superposition theorem. Illustrate the application of this theorem with reference to appropriate electric circuit.

Sol. Superposition Theorem : This theorem finds us 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 algebraic sum of the currents that would be produced 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 short circuit [Fig. (b)].



$$\text{Here, } I_1 = \frac{V_1}{R_1 + R_2 + R_3}; \quad I_2 = \frac{V_2}{R_2 + R_3}$$

and $I_3 = I_1 - I_2$

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

$$\text{Here, } I_2' = \frac{V_2}{R_2 + R_3}$$

$$\text{and } I_1' = \frac{I_2' \cdot R_3}{R_1 + R_3}$$

Also, $I_3' = I_2' - I_1'$

As per superposition theorem,

$$I_3 = I_3' + I_3''; \quad I_2 = I_2' + I_2''; \quad I_1 = I_1' + I_1''$$

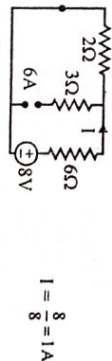
Steps for Solving a Network Using the Principle of superposition

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, delete the source keeping the respective circuit terminals open.) Obtain branch currents.

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

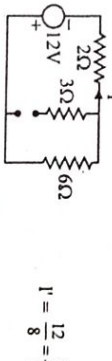
Step 3 : To determine the net branch current utilizing superposition theorem, just add the currents obtained in step-1 step-2 each branch. If the currents obtained in step-1 step-2 are in same direction, just add them; on the other hand, if the respective currents are directed opposite in each other, subtract the current obtained in the next step using the initial current. The net current in each branch is then obtained.

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



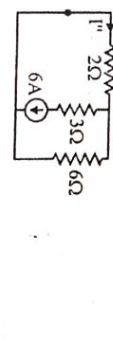
$$I = \frac{8}{8} = 1 \text{ A}$$

Remove all energy sources except 12V voltage source.



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

Remove all energy sources except 6A.



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

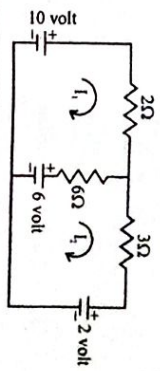
$$\text{Current through } 2\Omega = I + I' - I''$$

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

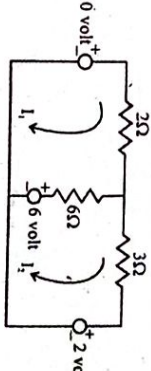
$$= -\frac{4}{2} = -2 \text{ A}$$

Now current flowing through the 2Ω (resistance) is

Prob.12 Using loop current method find the current I_1 and I_2 in Fig.



Sol. The circuit contains two loops. The loop currents are assumed as I_1 and I_2 .



For loop I_1 , current I_2 is assumed to be highest and writing KVL equation in I_1 loop.

$$+10 - 2I_1 - 6(I_1 - I_2) - 6 = 0$$

$$8I_1 - 6I_2 = 4 \quad \dots (1)$$

In loop I_2 , the KVL equation is (I_2 is highest)

$$+6 - 6(I_2 - I_1) - 3I_2 - 2 = 0$$

$$-6I_1 + 9I_2 = 4 \quad \dots (2)$$

Now solving the equation (1) and (2)

$$72I_1 - 54I_2 = 36$$

$$-36I_1 + 54I_2 = 24$$

$$36I_1 = 60$$

$$I_1 = \frac{5}{3} \text{ A}$$

From equation (2)

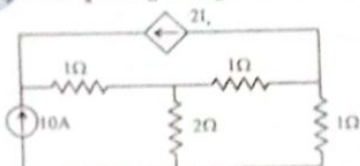
$$-6 \times \frac{5}{3} + 9I_2 = 4$$

$$9I_2 = 14$$

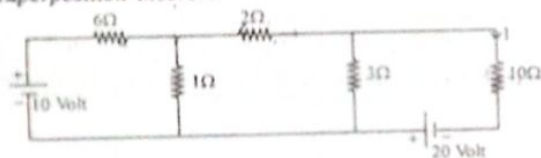
$$I_2 = \frac{14}{9} \text{ A}$$

Prob.13 (a) Find the current in the ammeter of the 2Ω resistance branch as shown in figure using theorem's

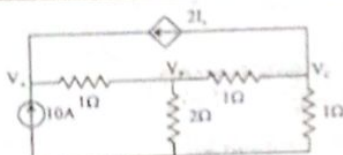
Prob.15 (a) Find I_x in Fig. using Nodal Analysis.



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



Sol.(a)



Nodal eq. at A

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

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

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

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

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 found out by applying matrix method -

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

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

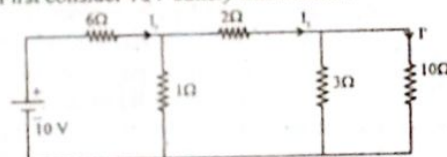
$$V_C = \frac{\Delta_3}{\Delta} = \frac{\begin{vmatrix} 1 & 1 & 10 \\ -2 & 5 & 0 \\ 0 & -3 & 0 \end{vmatrix}}{\begin{vmatrix} 1 & 1 & -2 \\ -2 & 5 & -2 \\ 0 & -3 & 4 \end{vmatrix}} = \frac{60}{10} = 6V$$

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

It implies current flows in opposite direction given questions.

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

First consider 10V battery into account.



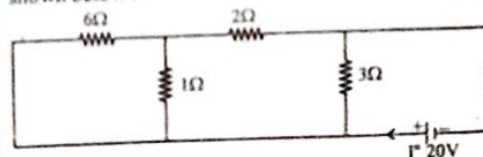
$$I_1 = \frac{10}{\left(\frac{10 \times 3}{10 + 3} + 2 \right) \times 1 + 6} = \frac{690}{470} = \frac{69}{47}$$

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

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

$$I' = 0.0636A$$

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



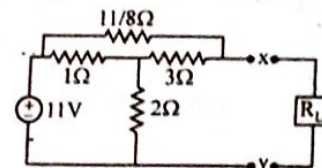
$$I'' = \frac{20}{\left(\frac{6 \times 1}{6 + 1} + 2 \right) \times 3 + 10} = -1.744A$$

$$I'' = -1.744A$$

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

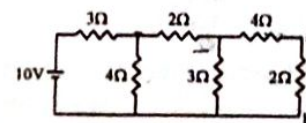
$$I = 0.064 - 1.74 = -1.68A$$

Prob.16 (a) Find the Thevenin's equivalent of the circuit as shown in Fig. at terminals x and y.

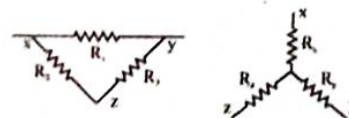


Find the load current if R_L is 9Ω

(b) Determine V_{ab} using Mesh Analysis in Fig. given below.



Sol.(a) **Thevenin's Theorem**: This theorem states that "Any two terminal bilateral linear DC circuits can be replaced by an equivalent circuit consisting of a voltage source and a series resistor". Now to solve the above network first we have to convert the "delta" network to its equivalent "star" network.

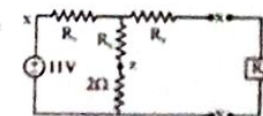


$$\text{Here } R_x = \frac{R_1 R_2}{R_1 + R_2 + R_3}$$

$$R_y = \frac{R_1 R_3}{R_1 + R_2 + R_3}$$

$$R_z = \frac{R_2 R_3}{R_1 + R_2 + R_3}$$

Hence, the Fig. will become:



$$R_x = \frac{11}{8} \times 1 = \frac{11}{8} \Omega$$

$$R_y = \frac{11}{8} \times 3 = \frac{33}{8} \Omega$$

$$R_z = \frac{11}{8} \times 2 = \frac{11}{4} \Omega$$

I. SHORT ANSWER TYPE QUESTIONS

Prob.1 (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. 2018]

Sol.(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 which 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 complete cycle would become zero.

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

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

Average value of a sine wave 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,
$$V_{av} = \frac{2}{T} \int_0^{\frac{T}{2}} v dt$$

Sol.(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 expressed as,

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

Prob.2 Write the advantages of AC over DC.

Sol. 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.

Prob. 5 Differentiate between AC and DC.**Sol. 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).

Prob. 6 What is peak factor?

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

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

Prob. 7 How to convert polar form to Rectangular form Explain with example.

Sol. Let the phasor is given into polar form as $P = |P| \angle \phi$

To find rectangular form simply convert this as

$$P = |P| \angle \phi = |P| [\cos \phi + j \sin \phi]$$

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

where

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

$$B = |P| \sin \phi$$

Example

$$I = 10 \angle -60^\circ \quad (\text{Polar form})$$

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

$$= 10 [0.5 - j(0.866)]$$

$$= 5 - j8.66$$

(Rectangular form)

Prob. 8 Define power factor.

Sol. Power Factor : 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 :

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

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

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

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

II. LONG ANSWER TYPE QUESTIONS**Prob. 1 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]

Sol. 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

$$H \propto I^2 R t = K I^2 R \text{ calories} \quad \dots (1)$$

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

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

$$\propto \frac{(i_1^2 + i_2^2 + i_3^2 + \dots + i_n^2)}{n} R t$$

$$= K \frac{(i_1^2 + i_2^2 + i_3^2 + \dots + i_n^2)}{n} R t \quad \dots (2)$$

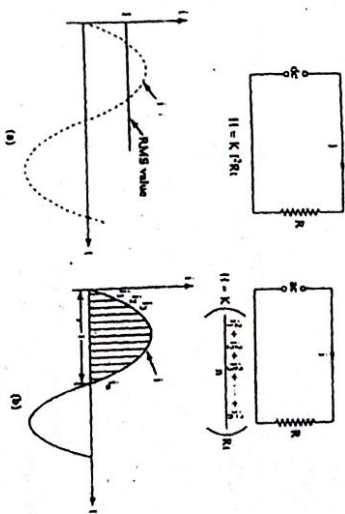


Fig. : RMS value of an alternating current illustrated
Equating expressions (1) and (2),

$$I^2 R t = \frac{(i_1^2 + i_2^2 + i_3^2 + \dots + i_n^2)}{n} R t$$

$$\text{or } I = \sqrt{\frac{(i_1^2 + i_2^2 + i_3^2 + \dots + i_n^2)}{n}}$$

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,

$$P = I^2 R \text{ watts} \quad \dots (3)$$

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,

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

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

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

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

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

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

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

Prob.2 (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.

Sol.(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,

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

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.

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

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

$$\text{Sol.(b)} \quad E = E_m \sin(2\pi f t)$$

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

$$E = 325.26 \sin 100 \pi t$$

Above equation is the required equation

Prob.3 (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.

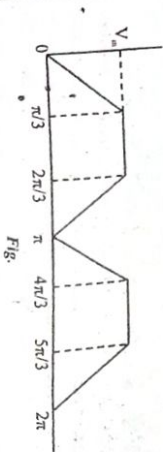


Fig.

Sol.(a) Peak value : Peak value is the maximum value obtained 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.)

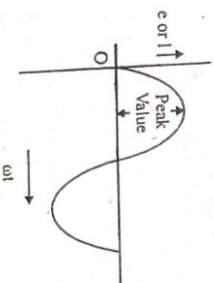


Fig. : Peak Value of Sinusoidal Current

Average Value : Refer to Short Answer Prob.1.(a).

Effective or RMS Value : Refer to Long Answer Prob.

Sol.(b) Average value

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

• Area of alternation

$$\begin{aligned} &= \frac{1}{2} V_m \times \frac{\pi}{3} + V_m \left(\frac{2\pi}{3} - \frac{\pi}{3} \right) + \frac{1}{2} V_m \times \frac{\pi}{3} \\ &= \frac{\pi V_m}{6} + \frac{\pi V_m}{3} + \frac{\pi V_m}{6} \\ &= \frac{2\pi V_m}{3} \end{aligned}$$

$$\text{Base} = \pi$$

$\therefore$ Average value,

$$V_{av} = \frac{2\pi V_m / 3}{\pi} = \frac{2\pi V_m}{3\pi} = 0.667 V_m$$

Prob.4 (a) Define the following with suitable diagram :

(i) RMS values

(ii) Form factor

(iii) Peak factor

(iv) Phase angle

(b) In the circuit 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.

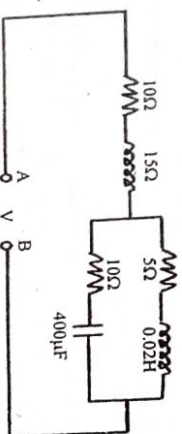


Fig.

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

Sol.(a)(i) Effective or RMS value : Refer to Long Answer Prob.1.

(ii) 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,

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

(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 quantity is at a phase angle of $\pi/2$ radians or 90° .

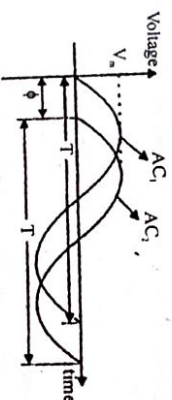


Fig. : Two AC Waveform having Different Phase Angles

Sol.(b) The circuit contains three impedances

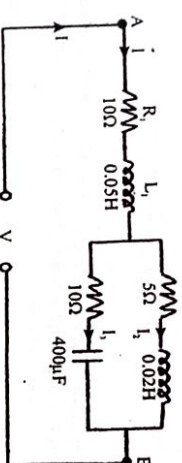


Fig.

$$Z_1 = 10 + j2\pi \times 50 \times 0.05$$

$$= 10 + j15.71 \Omega$$

$$= 18.6 \angle 57^\circ.33' \Omega$$

$$Z_2 = 5 + j2\pi \times 50 \times 0.02$$

$$= 5 + j6.28$$

$$= 8.027 \angle 51^\circ.47' \Omega$$

$$Z_3 = 10 - \frac{j}{2\pi} \times 50 \times 400 \times 10^{-6}$$

$$= 10 - j7.957$$

$$= 12.77 \angle -38^\circ.50' \Omega.$$

Here Z_2 and Z_3 are in parallel.

Hence

$$Z_p = \frac{Z_2 Z_3}{Z_2 + Z_3} = \frac{8.027 \angle 51.47^\circ \times 12.77 \angle -38.50^\circ}{5 + j6.28 + 10 - j7.957} = \frac{102.50 \angle 12.97^\circ}{15 - j1.677} = \frac{102.50 \angle 12.97^\circ}{15.093 \angle -6.379^\circ} = 6.79 \angle 19.34^\circ \approx 6.8 \angle 19.34^\circ = 6.406 + j 2.24 \Omega$$

Equivalent impedance

$$Z_{eq} = Z_p + Z_1 = 6.406 + j 2.24 + 10 + j 15.71 = 16.42 + j 17.96 = 24.36 \angle 47.36^\circ$$

$$\text{Given } I = 10 \angle 0^\circ \\ V = IZ = 10 \angle 0^\circ \times 24.36 \angle 47.36^\circ = 243.6 \angle 47.36^\circ$$

$$\therefore V_p = IZ_p = 10 \angle 0^\circ \times 6.8 \angle 19.34^\circ = 68 \angle 19.34^\circ$$

$$I_2 = \frac{V_o}{Z_2} = \frac{68 \angle 19.34^\circ}{8.027 \angle 51.47^\circ} = 8.47 \angle -32.13^\circ$$

$$I_3 = \frac{V_p}{Z_3} = \frac{68 \angle 19.34^\circ}{12.77 \angle -38.50^\circ} = 5.32 \angle 57.84^\circ$$

$$V_{AC} = IZ_1 = 10 \angle 0^\circ \times 18.6 \angle 57.93^\circ = 186 \angle 57.93^\circ$$

The phasor diagram is shown in fig.

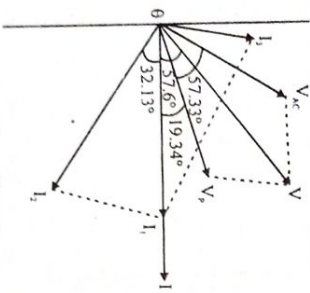


Fig. : Phasor Diagram

Prob.5 Three sinusoidal voltages acting in series are given by :

$$V_1 = 10 \sin 440 t \\ V_2 = 10\sqrt{2} \sin(440 t - 45^\circ) \\ V_3 = 20 \cos 440 t$$

find :

- (a) The expression for resultant voltage
(b) The frequency and RMS value of resultant voltage

Sol. Here,

$$V_1 = 10 \sin 440 t \\ V_2 = 10\sqrt{2} \sin(440 t - 45^\circ) \\ V_3 = 20 \cos 440 t$$

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

All the three voltages are shown vectorially in fig.

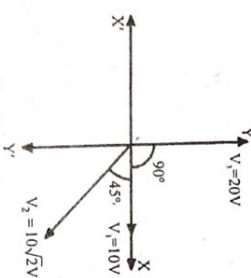


Fig. : Phasor diagram

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,

$$V_{\max} = \sqrt{(V_{xx})^2 + (V_{yy})^2} = \sqrt{20^2 + 10^2} = 22.36 V$$

Phase angle,

$$\phi_r = \tan^{-1} \frac{V_{yy}}{V_{xx}} = \tan^{-1} \frac{10}{20} = 26.56^\circ \text{ or } 0.476 \pi \text{ radian}$$

- (a) Expression for resultant voltage,

$$V_r = 22.36 \sin(440 t + 0.476 \pi)$$

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

RMS value of resultant voltage,

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

Prob.6 How power can be measured using two wattmeter method for balance load? Derive an expression

$$- \tan \phi = \frac{\sqrt{3}(W_1 - W_2)}{(W_1 + W_2)}$$

OR

Explain the method of power measurement in a 3-phase system using two wattmeters.

OR

Explain two wattmeter method of measuring power and power factor.

OR

Write short note on measurement of power in 3-phase balance circuits.

Sol. Two Wattmeter Method (Delta Connected Load)

Two wattmeter method used to measure the power when load is delta connected, either than load is balanced/unbalanced. The circuit arrangement for measuring the power by two wattmeter method (Delta Connected Load) is shown in Fig.1.

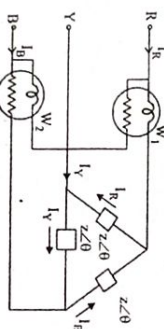


Fig. 1 : Circuit arrangement for measurement of power using two wattmeter method (Delta connected load)

The current carried by current coil of wattmeter W_1 is I_R and voltage across its potential coil is V_{RY} .

So reading of wattmeter $W_1 = P_1 = |V_{RY}| |I_R| \cos(\text{angle between } V_{RY} \text{ and } I_R)$

Similarly the current carries by current coil of wattmeter W_2 is I_B and voltage across its potential coil is V_{BY} .

So reading of wattmeters $W_2 = P_2 = |V_{BY}| |I_B| \cos(\text{angle between } V_{BY} \text{ and } I_B)$

The angle between V_{RY} and I_R , V_{BY} and I_B can be found out by phasor diagram, shown in Fig.2.

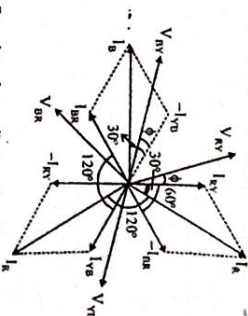


Fig. 2 : Complete phasor diagram for voltage and current in delta connection

So from phasor diagram, it is clear that

Angle between V_{RY} and $I_R = 30^\circ - \phi$ and Angle between V_{BY} and $I_B = 30^\circ - \phi$ Therefore $P_1 = |V_{RY}| |I_R| \cos(30^\circ - \phi)$

$$P_2 = |V_{BY}| |I_B| \cos(30^\circ - \phi)$$

Now $V_{RY} = |V_{BY}| = V_L$ and $|I_R| = |I_B| = I_L$ So total power $P = W_1 + W_2$

$$\Rightarrow P = V_L I_L \cos(30^\circ + \phi) + V_L I_L \cos(30^\circ - \phi)$$

$$\Rightarrow P = V_L I_L [\cos(30^\circ + \phi) + \cos(30^\circ - \phi)]$$

$$\Rightarrow P = V_L I_L [2 \cos 30^\circ \cos \phi]$$

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

This shows that the two wattmeter method gives the total power consumed by three phase load.

Determination of Power Factor

As we know that

$$P_1 = V_L I_L \cos(30^\circ - \phi) \text{ and } P_2 = V_L I_L \cos(30^\circ + \phi)$$

$$P_2 = V_L I_L \cos(30^\circ + \phi)$$

$$\text{Subtract } P_1 \text{ from } P_2$$

$$\therefore P_1 - P_2 = V_L I_L [\cos(30^\circ - \phi) - \cos(30^\circ + \phi)]$$

$$P_1 - P_2 = V_L I_L [2 \sin 30^\circ \sin \phi]$$

$$P_1 - P_2 = V_L I_L \sin \phi$$

It is seen that

$$P_1 + P_2 = \sqrt{3} V_L I_L \cos \phi$$

$$\frac{P_1 - P_2}{P_1 + P_2} = \frac{V_L I_L \sin \phi}{\sqrt{3} V_L I_L \cos \phi} = \frac{\tan \phi}{\sqrt{3}}$$

$$\therefore \tan \phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)}$$

$$\therefore \phi = \tan^{-1} \left[\frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)} \right]$$

$$i_2 = 8 \sin(100\pi t + 110^\circ + 180^\circ)$$

$$= 8 \sin(100\pi t + 290^\circ) = 8 \sin(100\pi t - 70^\circ)$$

Now for angle by which i_2 lags i_1

angle = phase angle of i_1 - phase angle of i_2

$$= 60^\circ - (-70^\circ) = 130^\circ$$

So i_2 lags i_1 by 130°

$$(ii) i_2 = 5 \sin(100\pi t + 50^\circ)$$

So the angle by which i_2 lags i_1 is $= 60^\circ - 50^\circ = 10^\circ$

i.e. i_2 lags i_1 by 10°

$$(iii) i_2 = -6 \sin(100\pi t - 30^\circ)$$

First the negative sign must be removed, so

$$i_2 = 6 \sin(100\pi t - 30^\circ + 180^\circ)$$

$$= 6 \sin(100\pi t + 150^\circ)$$

The angle of which i_2 lags i_1 is $= 60^\circ - 150^\circ = -90^\circ$

So i_2 lags i_1 by -90° or i_2 leads i_1 by 90°

$$(iv) i_2 = 2 \sin(100\pi t - 20^\circ) + 2 \cos(100\pi t - 20^\circ)$$

$$= 2 \sin(100\pi t - 20^\circ) + 2 \sin(90^\circ + 100\pi t - 20^\circ)$$

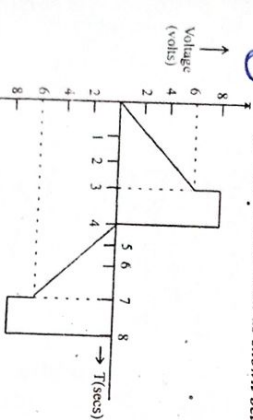
$$= 2 \sin(100\pi t - 20^\circ) + 2 \sin(100\pi t + 70^\circ)$$

The angle by which i_2 lags i_1 is

$$= 60^\circ - (20^\circ + 60^\circ - 70^\circ) = 80^\circ - 10^\circ = 70^\circ$$

So i_2 lags i_1 by 70°

Prob. 8(a) A voltage wave has variation as shown below:



Find the average and RMS value (effective value) of voltage as shown in figure. [R.T.U. 2015, K.J. Som, 2005]

17

BEE-30

of $(1/\pi)$ Henry is connected in series with a capacitor of $(100/\pi)$ microfarad. A $200V$, $50Hz$ alternating voltage source (sinusoidal) is applied across the circuit.

- Find the total impedance of the circuit.
- Find the current flowing through the voltage source.
- Find the voltage across R , L and C components.
- Draw the phasor diagram.

Sol. (a) 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 i.e. the integration will be with respect to t .

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

$$T = 8 \text{ sec.}$$

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)

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

$$\text{So } v = 2t + c$$

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

$$v = 2t \quad 0 \leq t \leq 3$$

The equation for second section BC is

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

The equation of wave is

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

Average Value

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

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

17

Basic Electrical Engineering

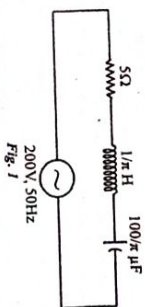
RMS Value or Effective Value

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

$$= \sqrt{\frac{1}{8} \left[\int_0^3 4t^2 dt + 64 \int_3^4 dt \right]} = \sqrt{\frac{1}{8} [4 \times 9 + 64]}$$

$$= \sqrt{\frac{1}{8} [36 + 64]} = \sqrt{\frac{1}{8} [100]} = \sqrt{25} = 5V$$

Sol.(b)



$$\omega = 2\pi f$$

$$= 2\pi(50) = 100\pi \text{ rad/sec}$$

$$X_L = \omega L$$

$$= (100\pi) \left(\frac{1}{\pi} \right) = 100\Omega$$

$$X_C = \frac{1}{\omega C} = \frac{1}{100\pi \left(\frac{100}{\pi} \times 10^{-6} \right)} = 100\Omega$$

(i) Total impedance of the circuit

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

$$\therefore X_L = X_C$$

$$\therefore Z = R$$

$$\boxed{Z = 5\Omega}$$

(ii) Current flowing through the voltage source

$$I = \frac{V}{Z}$$

$$= \frac{200}{5}$$

$$V_R = IR = 40 \times 5 = 200V$$

$$V_L = IX_L = 40 \times 100 = 4000V$$

$$V_C = IX_C = 40 \times 100 = 4000V$$

Basic Electrical Engineering

(iv) Phasor diagram

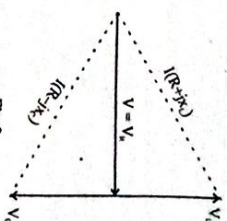


Fig. 2

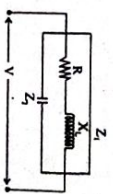
Prob.9 A series RL circuit has resistance and reactance of 15 ohm and 10 ohm respectively. Calculate the value of capacitor which when connected across the series combination in parallel, the system attain unity power factor.

Sol. Given:

$$R = 15\Omega$$

$$X_L = 10\Omega$$

$$\therefore \text{So } Z_1 = 15 + j10 = 18.03 \angle 33.69^\circ \Omega$$



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

Total impedance of circuit is:

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

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

$$\Rightarrow Y = 0.05546 \angle -33.69^\circ + j \frac{1}{X_C}$$

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

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

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

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

$$\Rightarrow X_C = 32.506$$

period.

known

effective

hence in

capacitor

This is

known

change a

steady c

average

Determ



BEE.32

Hence for sinusoidal voltage waves,

$$\begin{aligned}
 V_{rms} &= \sqrt{\frac{1}{2\pi} \int_0^{2\pi} (V_m \sin \omega t)^2 d(\omega t)} \\
 &= \sqrt{\frac{1}{2\pi} \int_0^{2\pi} V_m^2 \left[\frac{1 - \cos 2\omega t}{2} \right] d(\omega t)} \\
 &= \sqrt{\frac{V_m^2}{2}} = \frac{V_m}{\sqrt{2}} = 0.707 V_m
 \end{aligned}$$

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

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

Form Factor : Refer to Long Answer Prob.2(a).

Prob.11 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.

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

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

$$\text{In VA} = 3606 \text{ Volt-Ampere}$$

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

Resistance of B

$$\therefore I^2 R_{\text{net}} = P$$

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

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

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

Now, impedance of the whole circuit is given by

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

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

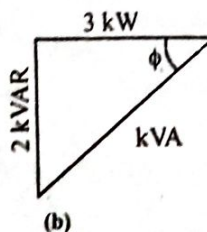
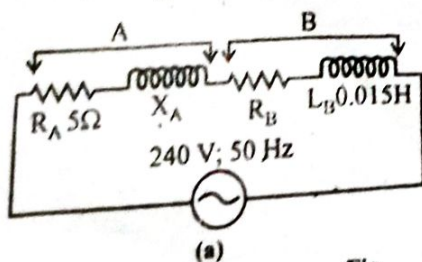


Fig.

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

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

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

Inductance of A

$$\therefore L_A = 0.0132 \text{ H (approx.)}$$

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

Potential drop across coil

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

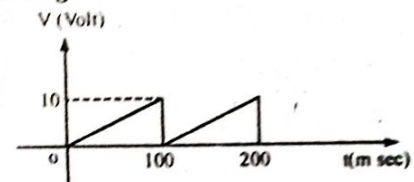
$$Z_B = \sqrt{8.3^2 + 4.713^2} = 9.545 \Omega$$

Potential drop across coil

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

Prob.12 (a) A periodic voltage wave form has been shown in figure. Determine :

- Frequency of wave form
- Wave equation for $0 < t < 100 \text{ m sec}$.
- RMS value
- Average value.



(b) Explain the generation of single phase AC voltage & derive its EMF equation.

Sol. (a) Time period

$$T = 100 \text{ ms} = 100 \times 10^{-3} \text{ sec} = 10^{-1} \text{ sec}$$

$$(i) \text{ Frequency } f = \frac{1}{T} = \frac{1}{10^{-1}} \text{ Hz} = 10 \text{ Hz}$$

(ii) Equation of wave for $0 < t < 100$ is straight line passing through origin. The straight line equation is $y = mx + c$

$$50 \text{ at } (0, 0) \Rightarrow 0 = 0 + C \Rightarrow C = 0$$

$$\text{Thus, } y = mx$$

$$\text{or } v = mt$$

$$m = \frac{v}{t} = \frac{10}{0.1} = 100$$

Hence wave equation is $v = 100 t$

(iii) Root mean square value

$$\begin{aligned}
 &= \sqrt{\frac{1}{T} \int_0^T v^2 dt} = \sqrt{\frac{1}{10^{-1}} \int_0^{100} (100t)^2 dt} \\
 &= \sqrt{\frac{10^4}{10^{-1}} \int_0^{100} t^2 dt} \\
 &= \sqrt{\frac{1}{3} \times 10^5 \times 10^{-3}} = \sqrt{\frac{100}{3}} = 5.77 \text{ A}
 \end{aligned}$$

PREVIOUS YEARS QUESTIONS

I. SHORT ANSWER TYPE QUESTIONS

Prob.1 Explain Statically and Dynamically induced emf with examples. [R.T.U. 2018]

Sol. 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.

Prob.2 What is Transformer?

Sol. 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.

Prob.3 Write the advantages of auto-transformer.

Sol. Advantage of Auto-Transformer

1. The efficiency of auto-transformers are more.
2. The size of auto-transformers 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.

Prob.4 Define voltage regulation of a transformer.

Sol. 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 =

$$\frac{\text{Terminal voltage at no load} - \text{Terminal voltage on load}}{\text{Terminal voltage at no load}} \times 100$$

$$= \frac{\text{Voltage drop in transformer at load}}{\text{No load rated voltage (secondary)}} \times 100$$

$$= \frac{I_2 R_{02} \cos \phi + I_2 X_{02} \sin \phi}{\text{No load rated voltage (secondary)}} \times 100 \quad \dots(i)$$

When the power factor is leading, the percentage regulation is expressed as :

$$\% \text{ regulation} = \frac{I_2 R_{02} \cos \phi - I_2 X_{02} \sin \phi}{\text{No load rated voltage (secondary)}} \times 100 \quad \dots(ii)$$

Prob.5 Define an auto-transformer.

$$\sqrt{(E_1 + I_1 R_1 \cos \phi + I_1 X_1 \sin \phi)^2 + (I_1 X_1 \cos \phi - I_1 R_1 \sin \phi)^2}$$

$$= E_1 + I_1 R_1 \cos \phi + I_1 X_1 \sin \phi \quad \dots(7)$$

(iii) For resistive - capacitive load [Fig.2(c)]

$$E_2 = \sqrt{(V_2 + I_2 R_2 \cos \phi - I_2 X_2 \sin \phi)^2 + (I_2 X_2 \cos \phi + I_2 R_2 \sin \phi)^2}$$

$$= V_2 + I_2 R_2 \cos \phi - I_2 X_2 \sin \phi \quad \dots(8)$$

$$E_1 = \frac{E_2}{K}$$

$$\text{and } V_1 = \sqrt{(E_1 + I_1 R_1 \cos \phi - I_1 X_1 \sin \phi)^2 + (I_1 X_1 \cos \phi + I_1 R_1 \sin \phi)^2}$$

$$= E_1 + I_1 R_1 \cos \phi - I_1 X_1 \sin \phi \quad \dots(9)$$

Prob.2 (a) Describe the no-load vector diagram of an ideal transformer. Derive the equation of emf induced in the windings of transformer.

- (b) A 25 KVA transformer has 250 turns on primary and 40 turns on secondary winding. The primary is connected to 1500 Volts, 50 Hz mains. Calculate :
- Primary and Secondary currents on full load
 - Secondary emf
 - Maximum flux in the core.

Sol. (a) Phasor diagrams of an ideal transformer : For the phasor diagram of an ideal transformer at no load conditions i.e. secondary current is zero ($I_2 = 0$) and then draw the phasor diagram of ideal transformer under load conditions (load may be purely Resistive/Inductive/Capacitive).

Ideal transformer at no load

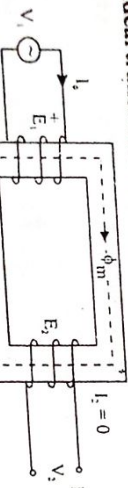


Fig. 1 : Ideal transformer at no load

Let us consider the ideal transformer at no load conditions (switch S open) as shown in Fig.1. When an alternating voltage V_1 is applied across the primary winding of an ideal transformer at no load conditions (i.e. $I_2 = 0$ or of an ideal transformer) then transformer draws no load or secondary open circuit I_0 .

The no load current I_0 is in phase with flux ϕ and magnetizing current I_0 . From equation $I_0 \cos 90^\circ$ with respect to applied voltage V_1 . From equation ($\phi = \phi_m \sin \omega t$) and equation ($e = N \omega \phi_m \sin(\omega t - \frac{\pi}{2})$), it is

clear that induced emf in primary winding lags 90° with respect to flux ϕ . As this is the case of ideal transformer, so primary and secondary induced emf are of same magnitude and in same phase (because there are no losses in ideal transformer, so $|E_1| = |E_2|$).

As at no load conditions, secondary current $I_2 = 0$, so that $|E_2| = |V_2|$. The phasor diagram for ideal transformer at no load conditions is shown in Fig.2 below.

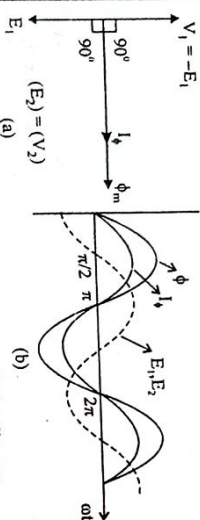


Fig. 2 : Ideal transformer at no load

(a) Phasor diagram

(b) Timing diagram

Equation of Induced emf
Let the transformer is energised at no load (secondary winding open) by alternating voltage source V_1 , which causes a current I_0 to flow through its primary winding, no current would flow through the secondary winding, as secondary is open circuited. This is shown in Fig.3.

$$V_1 = I_0 r_1 + i_1 X_1 + e_1 \quad \dots(1)$$

where r_1 and X_1 denotes resistance and reactance of primary winding. As discussed earlier r_1 and X_1 are of low values, so these may be ignored. Therefore the resistive and reactive voltage drops $i_1 r_1$ and $i_1 X_1$ may be neglected, then

$$V_1 \approx e_1 = -N_1 \frac{d\phi}{dt} \quad (\text{By Faraday's law})$$

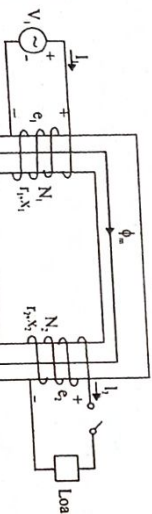


Fig. 3 : Transformer at no load

Let us consider the ideal transformer at no load conditions (switch S open) as shown in Fig.1. When an alternating voltage V_1 is applied across the primary winding of an ideal transformer at no load conditions (i.e. $I_2 = 0$ or of an ideal transformer) then transformer draws no load or secondary open circuit I_0 .

The no load current I_0 is in phase with flux ϕ and magnetizing current I_0 . From equation $I_0 \cos 90^\circ$ with respect to applied voltage V_1 . From equation ($\phi = \phi_m \sin \omega t$) and equation ($e = N \omega \phi_m \sin(\omega t - \frac{\pi}{2})$), it is

Let the flux at any instant $\phi = \phi_m \sin \omega t$

Then the instantaneous induced emf in a coil of N turns linked by this flux, is given by Faraday's law as

$$e = -N \frac{d\phi}{dt} \quad \dots(1)$$

$$e = -N \frac{d}{dt} (\phi_m \sin \omega t) = -N \omega \phi_m \cos \omega t$$

$$e = N \omega \phi_m \sin \left(\omega t - \frac{\pi}{2} \right) \quad \dots(2)$$

Equation (3) may be written as

$$e = E_m \sin \left(\omega t - \frac{\pi}{2} \right)$$

where E_m = maximum value of induced emf $= N \omega \phi_m$
For a sine wave, the rms value of emf is given as

$$E_{rms} = \frac{E_m}{\sqrt{2}}$$

$$E_{rms} = \frac{N \omega \phi_m}{\sqrt{2}} = \frac{N (2\pi f) \phi_m}{\sqrt{2}} \quad \dots(3)$$

Equation (4) is called the emf equation of a transformer.

The emf induced in each winding of the transformer can be calculated from its emf equation. Let the subscripts 1 and 2 be used for primary and secondary windings respectively. The primary rms voltage is :

$$E_1 = 4.44 \phi_m f N_1 \quad \dots(4)$$

The secondary rms voltage is

$$E_2 = 4.44 \phi_m f N_2 \quad \dots(5)$$

where ϕ_m is the maximum value of flux in webers (wb), f is frequency in Hertz (Hz), N_1 and N_2 are numbers of turns in primary and secondary windings, E_1 and E_2 are induced emf in primary and secondary windings.

ϕ_m can also be expressed in terms of maximum flux density B_m as:

$$\phi_m = B_m A \quad \dots(6)$$

Therefore equation (5) and (6) gets modified as follows:

$$E_1 = 4.44 B_m A f N_1 \quad \dots(7)$$

$$\text{and } E_2 = 4.44 B_m A f N_2 \quad \dots(8)$$

where A is the cross sectional area of the core in square meters (m^2).

Equation (8) and (9) are called equations of induced emfs in terms of maximum flux density.

Sol.(b) (i) Given $N_1 = 250$, $N_2 = 40$, $V_1 = 1500$ volts, KVA rating = 25

$$\Rightarrow 25 \times 1000 = 1500 \times I_1 \quad [\because \text{KVA} \times 1000 = V_1 I_1]$$

$$\Rightarrow I_1 = \frac{25 \times 1000}{1500} = 16.66 \text{ Amp} \quad \text{Ans.}$$

$$\text{Now } \frac{I_2}{I_1} = \frac{N_1}{N_2}$$

$$\Rightarrow I_2 = \frac{N_1}{N_2} \times I_1$$

$$\Rightarrow I_2 = \frac{250}{40} \times 16.66 = 104.125 \text{ A} \quad \text{Ans.}$$

$$(ii) \text{ Now } \frac{V_1}{V_2} = \frac{N_1}{N_2}$$

$$\Rightarrow \frac{V_1}{V_2} = \frac{250}{40}$$

$$\Rightarrow V_2 = \frac{1500 \times 40}{250} \quad [\because V_1 = 1500 \text{ V}]$$

$$(iii) \text{ Secondary induced emf } E_2 = 4.44 f N_2 \phi$$

$$\Rightarrow \text{Given } E_2 = 240 \text{ V, } f = 50 \text{ Hz, } N_2 = 40$$

$$\Rightarrow \phi = \frac{E_2}{4.44 f N_2} = \frac{240}{4.44 \times 50 \times 40} = 0.027 \text{ wb} \quad \text{Ans.}$$

Prob.3 (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.

Sol. (a) 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

Assuming I/P kVA to be equal to the O/P kVA, we have

Secondary Current

$$I_2 = \frac{200,000}{6600} = 30.4 \text{ A}$$

$$(ii) \quad K = \frac{N_2}{N_1} = \frac{E_2}{E_1}$$

$$\therefore \frac{80}{N_1} = \frac{400}{6600}$$

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,

$$\phi_m = 22.25 \text{ mWb.}$$

Prob.8 A 250 kVA, 11000 V/415 V, 50 Hz, single phase transformer has 80 turns on the secondary. Calculate:

- The approximate values of full load primary and secondary currents.
- The approximate no. of primary turns.
- The maximum value of the flux.

Sol. (i) $I_2 = \frac{250,000}{415} = 6024 \text{ Amp}$

(ii) $K = \frac{415}{11000} = \frac{83}{2200}$; $\frac{N_1}{N_2} = \frac{80}{2200}$

$$N_1 = 2121$$

$$I_1 = K I_2 = \left(\frac{83}{2200} \right) 6024 = 227.27 \text{ Amp}$$

(iii) $11000 = 4.44 \times 50 \times 212 \phi_m$

$$[E_1 = 4.44 f N_1 \phi_m]$$

$$\phi_m = 11000/470862 = 0.0235 \text{ Wb}$$

Prob.9 What losses are present in a transformer? Discuss a method to determine the efficiency of a transformer.

Sol. 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 remains 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 $W_h = \eta B_{\max}^{1.6} f V_{\text{core}}$; Eddy current loss

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

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.

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 losses, 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.

$$\text{Efficiency} = \frac{\text{Output}}{\text{Output} + \text{losses}}$$

$$= \frac{\text{Output}}{\text{Output} + \text{Cu losses} + \text{Iron loss}}$$

$$\text{or } \eta = \frac{\text{input} - \text{losses}}{\text{input}} = 1 - \frac{\text{losses}}{\text{input}}$$

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.

Prob.10 Write short notes on equivalent circuit of a single phase transformer.

Sol. 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.

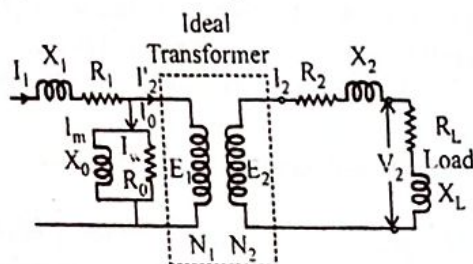


Fig. 1 : Equivalent circuit of a transformer

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 X_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

$$(I'_2)^2 R'_2 = I_2^2 R_2 \text{ or } R'_2 = R_2 \left(\frac{I_2}{I_1} \right)^2$$

But $\frac{I_2}{I_1} = \frac{N_1}{N_2}$; Therefore $R'_2 = R_2 \left(\frac{N_1}{N_2} \right)^2$

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.

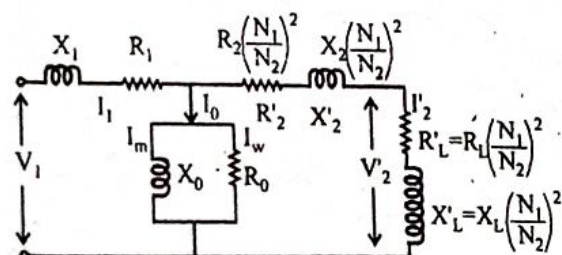


Fig. 2 : Equivalent circuit of a transformer with all impedances

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

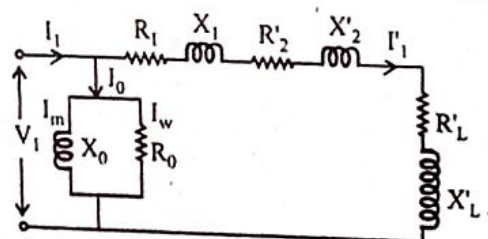


Fig. 3 : Approximate Equivalent Circuit of a Transformer

$$R_{e1} = R'_2 + R_1 + R_2 \left(\frac{N_1}{N_2} \right)^2$$

$$X_{e1} = X_1 + X'_2 = X_1 + X_2 \left(\frac{N_1}{N_2} \right)^2$$

Likewise we can also find the equivalent resistance and reactance as referred to secondary winding (i.e. winding 2). Thus

$$R_{e2} = R_2 + R'_1 = R_2 + R_1 \left(\frac{N_2}{N_1} \right)^2$$

$$X_{e2} = X_2 + X'_1 = X_2 + X_1 \left(\frac{N_2}{N_1} \right)^2$$

Prob.11 Derive the condition under which a transformer operates at maximum efficiency.

3. DC Compound Motor: These motors are used where large load is connected and large momentary torque is required like rolling mills, cutting tools in steel industries etc.

Prob. 7 A 8 pole wave wound armature has 720 conductors which rotate at 1500 RPM. If flux per pole is 20 mwb, calculate generated voltage.

Sol. For wave winding $A = 2$.

$$E = \frac{N \Phi Z}{60 A} = \frac{1500 \times 8 \times 20 \times 10^{-3} \times 720}{60 \times 2}$$

$$= 1440 \text{ Volt} \quad \text{Ans.}$$

II. LONG ANSWER TYPE QUESTIONS

Prob. 8 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.C. 2018]

Sol. (a) 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 as windings and it feels a magnetic force, which is called magnetic 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 windings 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.

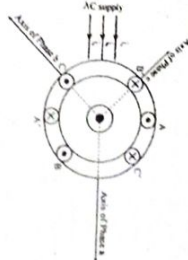


Fig. 1: Three Phase motor

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.

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.

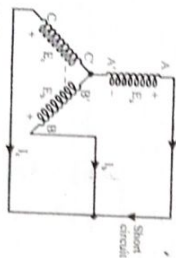


Fig. 2: Current in rotor winding of induction machine

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 ($N_s < N_r$). 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 (s) is expressed as:

$$\text{Slip } (s) = \frac{N_s - N_r}{N_s}$$

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, $N_r = 0$

$$s = \frac{N_s - N_r}{N_s} = 1$$

At synchronous speed,

$$N_s = N_r \Rightarrow s = \frac{N_s - N_r}{N_s} = 0$$

Generally at full speed, slip lies between 0.04 to 0.06.

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.

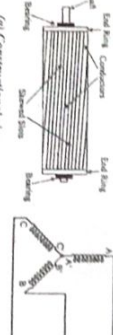


Fig. 3: Squirrel cage induction machine

Induction machine employs squirrel cage rotor, is called squirrel cage induction machine

BEE-54

(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.

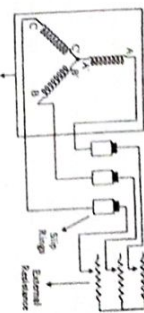


Fig. 4: Rotor winding of wound rotor induction machine

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.

Sol. (b) Principle of D.C. Generator: "Whenever a conductor cut 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 $\frac{d\phi}{dt}$ 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.

$$e = \frac{d\phi}{dt}$$

$$\phi = \text{Flux per pole (webers)}$$

$$P = \text{Number of Poles}$$

$$Z = \text{Total number of armature conductors}$$

$$A = \text{Number of parallel paths in armature between brushes of opposite polarity}$$

$$C = \text{Number of series path of coils}$$

$$N = \text{Armature rotation speed in revolutions per minute (RPM)}$$

E_g = Emf induced across armature

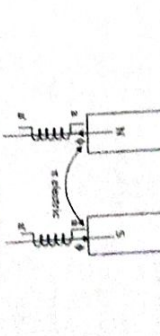


Fig. 5: Flux linkage through magnetic field

From N pole to S pole, flux linking with coil changes from $+\Phi$ to $-\Phi$

Rate of change of flux is given by

$$\frac{d\Phi}{dt} = \frac{-\Phi - (+\Phi)}{\Delta t} = \frac{-2\Phi}{\Delta t}$$

Φ = Flux/pole in time Δt

Coil moves from N to S pole i.e. travel a distance of π electrical

So, $\Delta t = \frac{\pi}{\omega_r}$

where, ω_r is speed of rotor in electrical radians/sec.

If number of turns per coil is N_c , induced emf across a single coil can be expressed as:

$$E_c = -N_c \frac{d\Phi}{dt}$$

$$E_c = \frac{2N_c \Phi}{\Delta t}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

$$E_c = \frac{2N_c \Phi \omega_r}{\pi}$$

olation and maintenance. SFU is a combination of fuse and vitch for providing an economical unit with best performance f fuse and switch. The symbols of switch, fuse and SFU nit shown in figure.

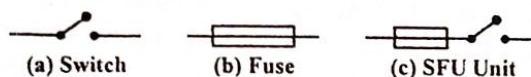


Fig. : Switch Fuse Unit

rob.3 Gives Comparision between MCB and MCCB.

ol. Comparision of MCB and MCCB

1. An MCB has less than 100 amps, while an MCCB goes as high as 2,500 amps.
2. The interrupting rating for an MCB is 18,000 amps, and up to 200,000 amps for an MCCB.
3. MCBs are mostly installed for home use, while an MCCB is generally utilized for commercial or industrial purposes.
4. Both are low-voltage circuit breakers created to meet IEC 947 standards.
5. Some MCCB units are specially made to respond to remote control signals, usually as standby power.

II. LONG ANSWER TYPE QUESTIONS

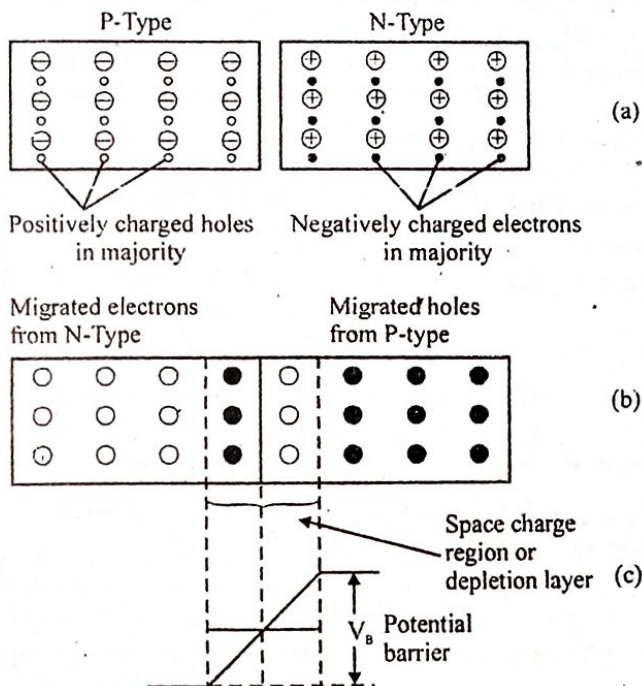
rob.1(a) Explain Principle of operation and characteristics of P-N junction diode.

(b) Explain Principle of operation and characteristics of BJT. [R.T.U. 2018]

ol.(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, -N junction cannot be formed due to surface films and other regularities, which produce major discontinuities in the crystal structure. Thus P-N junction is formed from a piece of emiconductor 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. 'type material has a high concentration of holes and N-type material has high concentration of free electrons, so there is tendency of holes to diffuse over to N-side and electrons o P-side. This process is known as diffusion. Due to diffusion, ome 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.

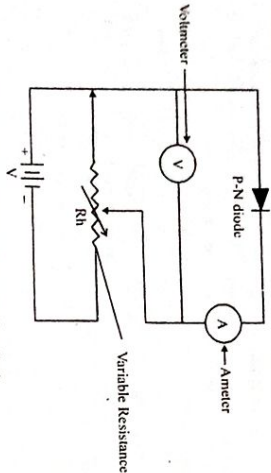


Fig. 2 : Forward Biased PN junction diode

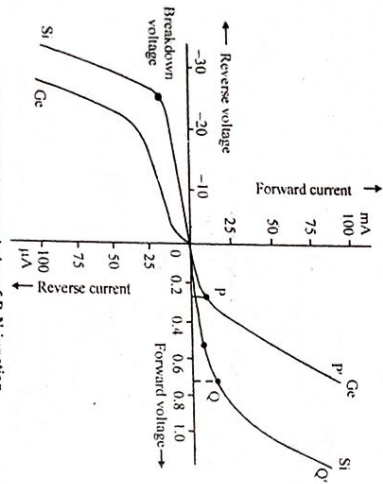


Fig. 3 : V-I characteristics of P-N junction

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.

Sol.(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 conduct 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.

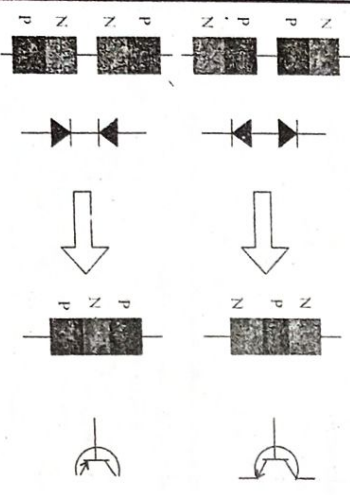


Fig. 1 : Bipolar junction transistors

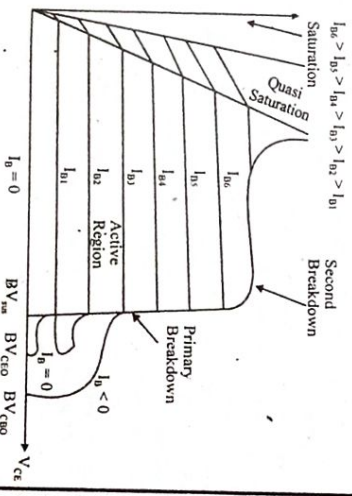
- The size and doping level of three layers are as follows
 - Emitter - Heavy doping and medium size
 - Collector - Medium doping and large size
 - Base - Light doping and small size
- The emitter is heavily doped because it supplies majority charge carriers and it must be maximum. The dop

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).

The size of the collector is made larger because it collects charge carriers (about 90%) holes or electrons and due to 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 highest 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 the 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 emitter and the base and there will be no emitter collector current.

Characteristics of Power BJT



capacitance of junction base-emitter. The time t_1 is the time taken by collector current to rise from 10% to 90% of its final value. During time t_1 , the collector-emitter voltage V_{CE} falls from 90% to 10% of its off state value. The time t_2 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_1 and t_2 . The time t_1 is called storage time and is the time required to neutralize the carriers stored in the collector and the base. During the t_1 , 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.

Prob 2 Draw the I-V Characteristics of IGBT.

Sol. I-V Characteristics

Fig. shows the drain characteristics of IGBT.

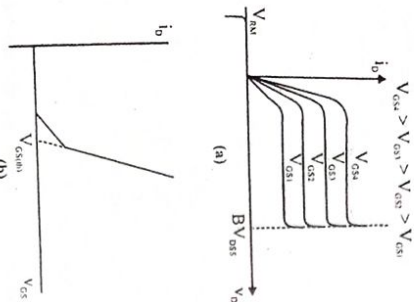


Fig. 2: Characteristics of IGBT (a) Drain characteristics (b) Transfer characteristics

It shows the relation between drain current i_D and drain source voltage V_{DS} for different values of gate source voltage V_{GS} .

The junction J_1 blocks reverse voltage. An IGBT without n^+ buffer has higher reverse blocking capability. Therefore an IGBT required for blocking high reverse blocking voltage does not have n^+ buffer layer. The reverse blocking voltage is shown as V_{RM} on I-V characteristics. The junction J_2 blocks forward voltage when IGBT is off. BV_{DSS} represents the

breakdown voltage in forward direction. The applied voltage between drain and source must be less than BV_{DSS} .

Fig. (b) shows the transfer characteristics of IGBT. Here when V_{GS} is less than $V_{GS(th)}$, device is in off state. This curve is almost linear except when drain current is very low.

Prob 3 Write basic structure of DC to DC converter.

Sol. 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.

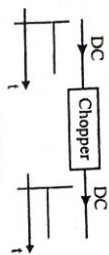


Fig. 1: Representation of DC-DC converter or chopper

A chopper may be thought as of DC equivalent of an ac transformer since they behave in an identical manner. A 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.

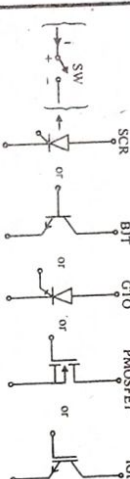


Fig. 2: Representation of a power semiconductor device

When the switch is on, no current can flow. When the switch is off, current flows in the direction of arrow on the power semiconductor devices have on state voltage drop 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.

Prob 4 Explain construction and working principle of ϕ half bridge inverter.

Sol. Operating Principle of Single Phase Voltage Source Inverters

In this section, operating principle of single phase voltage source inverter is discussed.

Single Phase Bridge Inverter: These are basically of two types i.e. (i) Single phase half bridge inverter (ii) Single phase full bridge inverters.

Power circuit diagram for single phase half bridge inverter is shown in Fig. (a). In this diagram, the circuitary for turning on or turning off the thyristor is not shown for simplicity. The gating signals for the thyristors and the resulting output voltage waveforms are shown in Fig. (b). These voltage waveforms are drawn an assumption that each thyristor conducts for the duration when its gate pulse is present and is commutated (turn off) as soon as this gate pulse is removed.

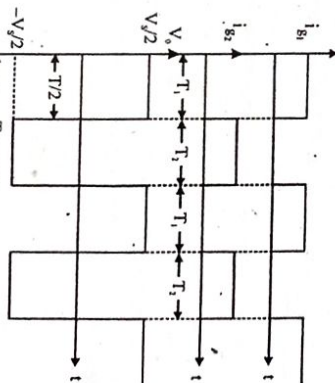
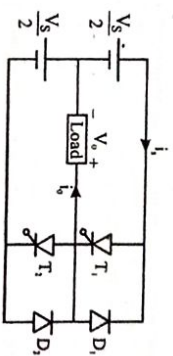


Fig. 1: Single Phase Half Bridge Inverter

Single phase half bridge inverter, as shown in Fig. (a), consists of two SCR's, two diodes and three wire supply. It is clearly seen from Fig. (b), that for $0 < t \leq T/2$, thyristor T_1 conducts and a load is subjected to voltage $V_s/2$. At half cycle i.e. at $t = T/2$, thyristor T_2 commutates (turn off) and T_2 is gated on. During its period, $T/2 < t \leq T$, thyristor T_2 conducts and the load is subjected to voltage $(-V_s/2)$ due to lower voltage source $V_s/2$. It is seen from Fig. (b) that load voltage is an alternating voltage waveform of amplitude $V_s/2$ and of frequency $1/T$ Hz.

The waveform of amplitude $V_s/2$ and of frequency $1/T$ Hz. The frequency of the inverter output voltage can be changed by controlling time period T .

The main drawback of half bridge inverter is that it requires 3 wire d.c. supply. This difficulty can be overcome by use of full bridge inverter.

Prob 5 What do you know about ELCB? Explain.

Sol. 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 an 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.

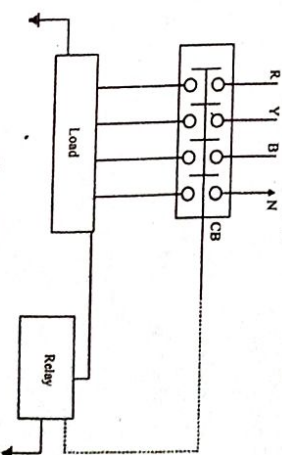


Fig. 1: Voltage ELCB

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.

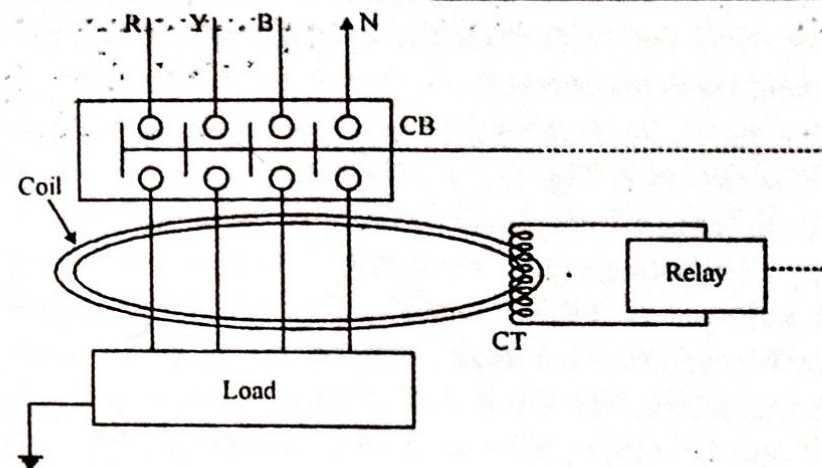


Fig. 2 : Current ELCB or RCCB

Prob.6 How power can be measured using two wattmeter method for balance load? Derive an expression

$$-\tan \phi = \sqrt{3} \frac{(w_1 - w_2)}{(w_1 + w_2)}$$

OR

Explain the method of power measurement in a 3-phase system using two wattmeters.

OR

Explain two wattmeter method of measuring power and power factor.

OR

Write short note on measurement of power in 3-phase balance circuits.

Sol. Refer to Long Answer Prob.6, Unit-2.