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B.Tech. - I Semester Regular Examinations, December / January – 2025

Network Theory and Machines –(24EE11RC02)

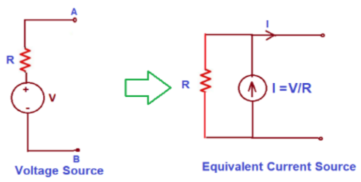
Solutions

Q)1.a

Answer

Source transformation technique

Source transformation is a fundamental technique employed in circuit analysis, offering a valuable tool for simplifying complex electrical circuits. This technique involves the replacement of either a voltage source in series with a resistor by a current source in parallel with a resistor, or vice versa.



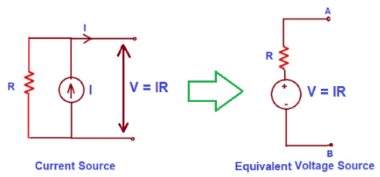
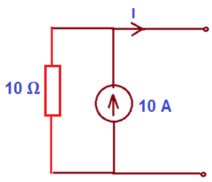


Figure 1 voltage source to current source transformation   Figure 2 current source to voltage source transformation   ***------ (2M)***

Example: conversion of current source to a voltage source



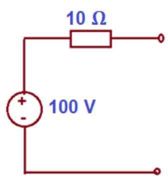
First of all, find the voltage across the terminals of the source while keeping the source terminal open. This voltage (V) is given as

V = IR

= 10×10

= 100 Volt

Thus, the strength of voltage source will be 100 V. The internal series resistance of this source will be equal to the resistance of current source i.e. 10 Ω. Therefore, equivalent voltage source is shown as below.

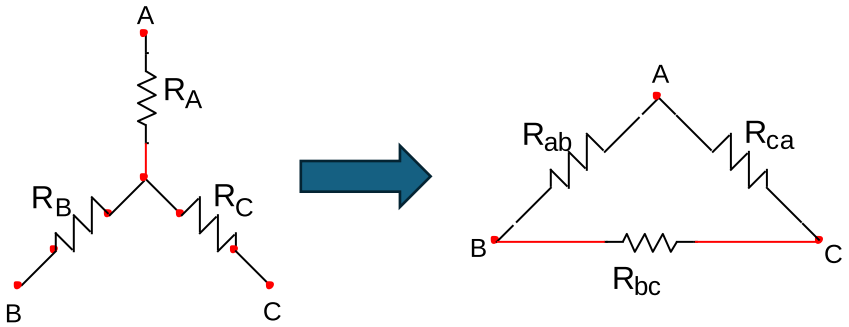


------ (1M)

Star to Delta transformation:

Both **Star to Delta Transformation** and **Delta to Star Transformation** allows us to convert one type of circuit connection into another type in order for us to easily analyse the circuit. These transformation techniques can be used to good effect for either star or delta circuits containing resistances or impedances.

Let us consider three resistors are connected in star between the points A, B, C. So, these resistors considered as R_A, R_B, R_C. R_{AB}, R_{BC}, R_{CA} be the resistances in Delta.



$$R_{ab} = R_A + R_B + \frac{R_A R_B}{R_C}$$

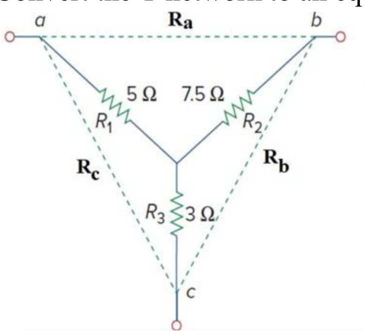
$$R_{bc} = R_B + R_C + \frac{R_B R_C}{R_A}$$

$$R_{ac} = R_A + R_C + \frac{R_A R_C}{R_B}$$

---------(2M)

Example:

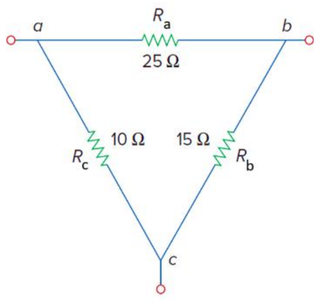
Convert the Y network to an equivalent Δ network.



$$R_a = 7.5 + 5 + \frac{7.5 \times 5}{3} = 25 \text{ ohms}$$

$$R_b = 7.5 + 3 + \frac{7.5 \times 3}{5} = 15 \text{ ohms}$$

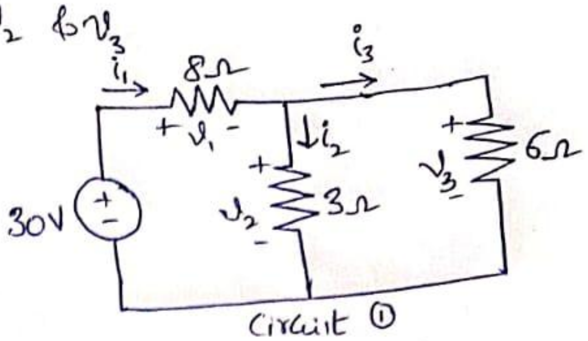
$$R_c = 5 + 3 + \frac{5 \times 3}{7.5} = 10 \text{ ohms}$$



---------(2M)

Q)1.b

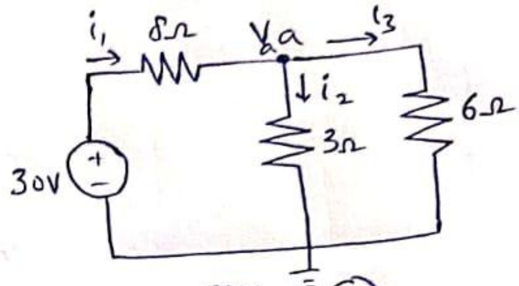
Answer:- To find i_1, i_2, i_3, v_1, v_2 & v_3



Circuit ①

From circuit ②

→ Applying KCL at node 'a'



Circuit ②

$$i_1 = i_2 + i_3$$

$$\frac{-V_a + 30}{8} = \frac{V_a}{3} + \frac{V_a}{6}$$

$$V_a\left[\frac{1}{8} + \frac{1}{3} + \frac{1}{6}\right] = \frac{30}{8}$$

$$V_a\left[\frac{\cancel{5}}{\cancel{8}}\right] = \frac{\cancel{30}\,6}{\cancel{8}}$$

$$\boxed{V_a = 6V}$$ — (2M)

→ $i_1 = \frac{-V_a + 30}{8} = \frac{-6+30}{8} = \underline{3A}$ — (1M)

→ $i_2 = \frac{V_a}{3} = \frac{6}{3} = \underline{2A}$ — (1M)

→ $i_3 = \frac{V_a}{6} = \frac{6}{6} = \underline{1A}$ — (1M)

→ $v_1 = 8 i_1 = 8 \times 3 = \underline{24V}$ — (1M)

→ $v_2 = 3 i_2 = V_a = \underline{6V}$

→ $v_3 = 6 i_3 = V_a = \underline{6V}$

— (1M)

Q)2.a

Answer

Nodal Analysis (KCL + ohm's Law)

In Nodal analysis, we will apply Kirchhoff's current law to determine the potential (voltage) at any node with respect to some arbitrary reference point in a network. Once the potentials of all nodes are known, it is a simple matter to determine other quantities such as current and power within the network.

Simple steps:

1. Identify the Number of nodes when current is dividing and assign voltage to nodes.
2. Write KCL equation at each node and except as reference node.
3. Write ohm's law form for current in nodal equation & solve the equation. ***---------(3M)***

In other way the steps used in solving a circuit using Nodal analysis are explained elaborately as follows:

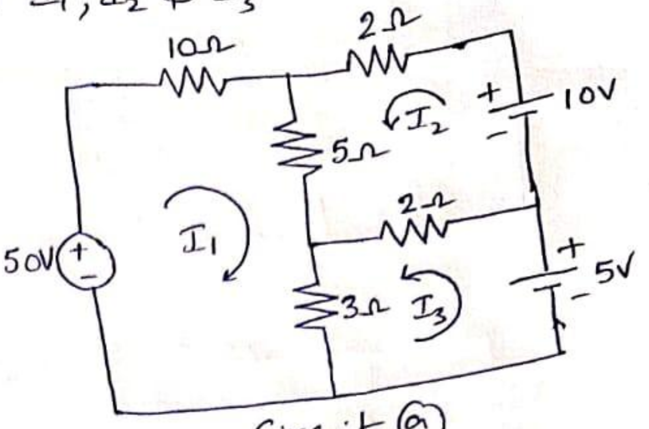
i. Arbitrarily assign a reference node within the circuit and indicate this node as ground. The reference node is usually located at the bottom of the circuit, although it may be located anywhere.
ii. Convert each voltage source in the network to its equivalent current source. This step, although not absolutely necessary, makes further calculations easier to understand.
iii. Arbitrarily assign voltages $(V_1, V_2, \ldots V_n)$ to the remaining nodes in the circuit. (Remember that you have already assigned a reference node, so these voltages will all be with respect to the chosen reference.)
iv. Arbitrarily assign a current direction to each branch in which there is no current source. Using the assigned current directions, indicate the corresponding polarities of the voltage drops on all resistors.
v. With the exception of the reference node (ground), apply Kirchhoff's current law at each of the nodes. If a circuit has a total of n+1 nodes (including the reference node), there will be n simultaneous linear equations.
vi. Rewrite each of the arbitrarily assigned currents in terms of the potential difference across a known resistance.
vii. Solve the resulting simultaneous linear equations for the voltages $(V_1, V_2, \ldots V_n)$.

Explanation with suitable example

---------(4M)

Q)2.b

Answer:- To find mesh currents I_1, I_2 & I_3



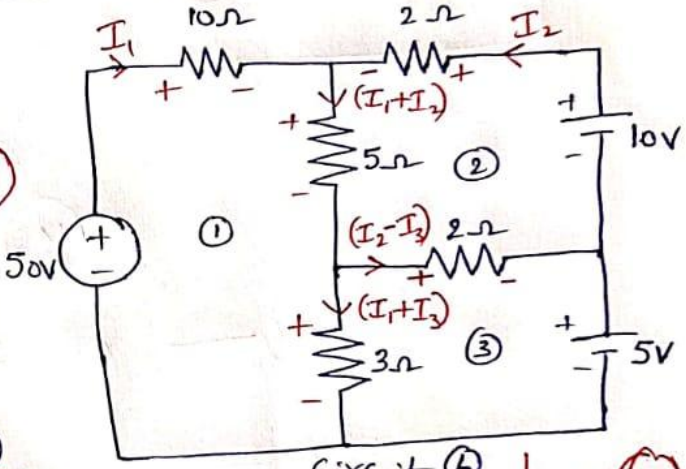
Circuit (a)

→ Apply KVL to mesh ①

$$-50+10I_1+5(I_1+I_2)+3(I_1+I_3)=0$$

$$\boxed{18I_1+5I_2+3I_3=50} \quad \text{—— (1)}$$

—— (1M)



Circuit (b) → (1M)

→ Apply KVL to mesh ②

$$-10+2I_2+5(I_1+I_2)+2(I_2-I_3)=0$$

$$\boxed{5I_1+9I_2-2I_3=10} \quad \text{—— (2)}$$

—— (1M)

→ Apply KVL to mesh ③

$$-5+3(I_1+I_3)-2(I_2-I_3)=0$$

$$\boxed{3I_1-2I_2+5I_3=5} \quad \text{—— (3)}$$

—— (1M)

→ Solving eq ①, ② & ③ by Cramer's rule (method)

$$\begin{bmatrix} 18 & 5 & 3 \\ 5 & 9 & -2 \\ 3 & -2 & 5 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 50 \\ 10 \\ 5 \end{bmatrix}$$

$$A \qquad X \quad = \quad B$$

$$I_1 = \frac{\Delta_1}{\Delta}, \quad I_2 = \frac{\Delta_2}{\Delta}, \quad I_3 = \frac{\Delta_3}{\Delta}$$

$$I_1 = \frac{\begin{vmatrix} 50 & 5 & 3 \\ 10 & 9 & -2 \\ 5 & -2 & 5 \end{vmatrix}}{\begin{vmatrix} 18 & 5 & 3 \\ 5 & 9 & -2 \\ 3 & -2 & 5 \end{vmatrix}} = \underline{3.29\,A} \text{ — (1M)}$$

$$I_2 = \frac{\begin{vmatrix} 18 & 50 & 3 \\ 5 & 10 & -2 \\ 3 & 5 & 5 \end{vmatrix}}{\begin{vmatrix} 18 & 5 & 3 \\ 5 & 9 & -2 \\ 3 & -2 & 5 \end{vmatrix}} = \underline{-1.03A} \text{ — (1M)}$$

$$I_3 = \frac{\begin{vmatrix} 18 & 5 & 50 \\ 5 & 9 & 10 \\ 3 & -2 & 5 \end{vmatrix}}{\begin{vmatrix} 18 & 5 & 3 \\ 5 & 9 & -2 \\ 3 & -2 & 5 \end{vmatrix}} = \underline{-1.39A} \text{ — (1M)}$$

Q)3.a

Answer

Reciprocity Theorem Statement

According to the Reciprocity theorem statement the value of current obtained in any branch of an electrical circuit or network due to a single voltage source (V) in the circuit or network is the same as the value of current flowing through that branch when the source was originally connected and when the source was again connected to the branch where the value of current was originally determined.

Steps to solve a Reciprocity Theorem

The steps to solve a Reciprocity Theorem are as follows:

- First, choose the branches in the circuit where reciprocity must be generated.
- Any normal network analysis approach may be used to determine the current flow within the branch.
- The voltage source can be switched between the branches that have been chosen.
- Determine current flow inside the branch, wherever the voltage source previously existed
- It is then noticed that the current obtained during the previous connection (i.e., the second step) and the flow of current after the source is exchanged (i.e., the fourth step) are equal.

---------(3M)

Explanation of Reciprocity Theorem:

Reciprocity theorem can be explained with the help of the following circuit:

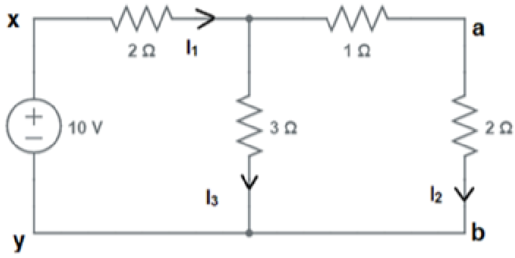


Figure 1a

Assume we wish to test the validity of the reciprocity theorem in branches x-y and a-b.
To do so, we first calculate the current via the branch a-b as follows:
Equivalent resistance between x-y = (3×3)/6 + 2 = 3.5Ω
As a result,
current I_1 =10/3.5 A =2.86 A.
The current via branches a-b may now be estimated using the current division formula as follows:
I_2= (3x I_1) / (3+3)
=2.86/2
=1.43A
Change the location of the voltage source and place it in branch a-b, as illustrated below:

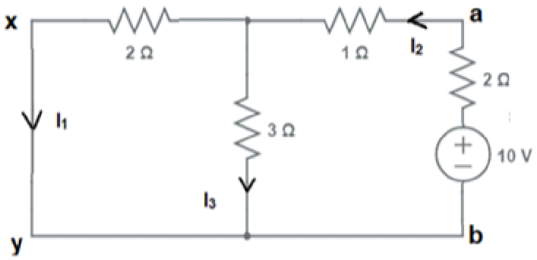


Figure 1b

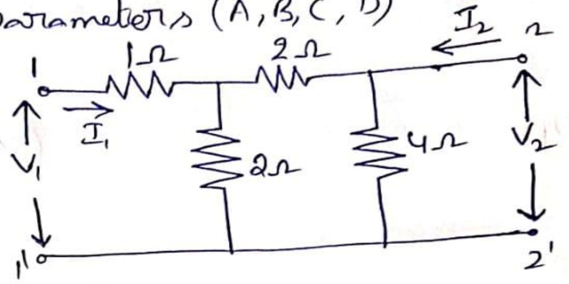
We want to determine the current value in branch x-y, which is the branch where the source was initially stored before being transferred to branch a-b, where we calculated the current.
The following calculations are used to determine the equivalent resistance between source terminals:
=2+1+6/5
=4.2Ω
Current I_2 =10/4.2 =2.38A
Using the current division rule, the current in branch x-y may be calculated as follows:
I_1 = (2.38 x 3)/5 =1.43A
As a result, I_1 in Figure 1b and I_2 in Figure 1a have the same value. (hence proved)

---------(4M)

Q)3.b

Answer To find transmission parameters (A, B, C, D)

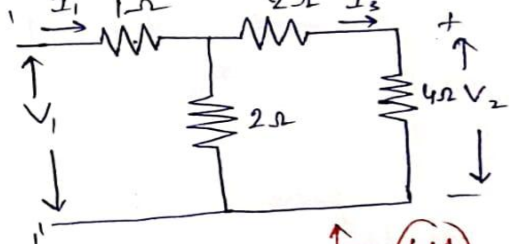
Two-port N/w equations represented by T-parameters



$V_1 = AV_2 - BI_2$ — (1)

$I_1 = CV_2 - DI_2$ — (2) — (1M)

→ To find A & C, let us consider $I_2 = 0$ (2nd port open circuit)



(1M)

* $\frac{V_1}{I_1} = \left(1 + \frac{6 \times 2}{6+2}\right) = \left(\frac{5}{2}\right) = 2.5\Omega$

⇒ $\boxed{V_1 = 2.5 I_1}$ — (3)

* $I_3 = \frac{2}{2+6} \times I_1 = \frac{1}{4} I_1$

⇒ $\boxed{I_1 = 4 I_3}$ — (4)

* $V_2 = 4I_3 = 4 \times \left(\frac{I_1}{4}\right) = I_1$

$$\Rightarrow \boxed{\frac{I_1}{V_2} = 1 \mho = C} \quad \text{— (5)} \quad \text{— (1M)}$$

From eq (5) & (3), we get

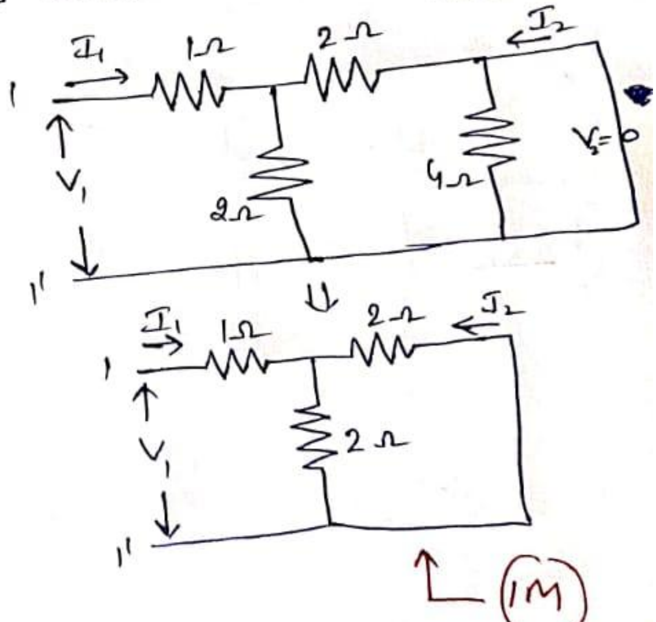
* $V_1 = 2.5 I_1$

$V_1 = 2.5 V_2 \quad [\because I_1 = V_2]$

$$\boxed{\frac{V_1}{V_2} = 2.5 = A} \quad \text{— (6)} \quad \text{— (1M)}$$

$\therefore A = 2.5 \; , \; C = 1 \mho$

→ To find B & D, let us consider $V_2 = 0$ (ie, 2^{nd} port short circuited)



— (1M)

* $I_2 = -I_1 \frac{2}{2+2}$

$I_2 = -\frac{1}{2} I_1$

$$\boxed{\frac{I_1}{I_2} = -2 = -D} \quad \text{— (7)}$$

$$\boxed{\therefore D = 2} \quad \text{— (1M)}$$

* $\frac{V_1}{I_1} = 2$

$\Rightarrow V_1 = 2(-2I_2) = -4I_2$

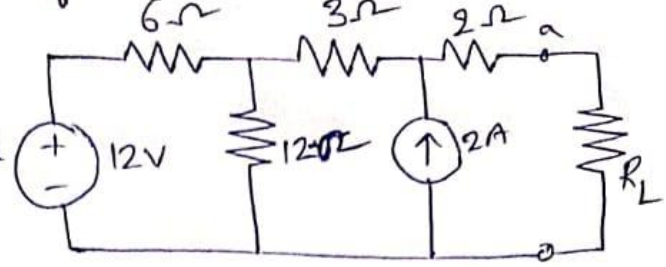
$$\boxed{\frac{V_1}{I_2} = -4 = -B}$$

$$\boxed{\therefore B = 4\Omega} \quad \text{— (1M)}$$

Q)4.a

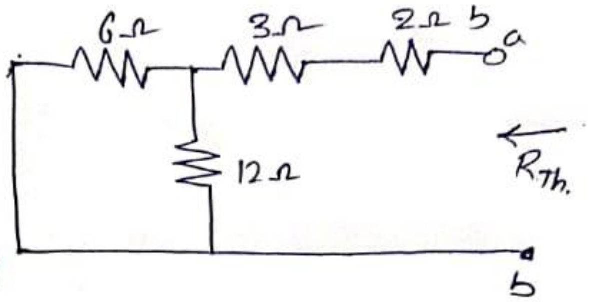
Answer: To find value of R_L for maximum power transfer & maximum power transferred

→ To find $R_L = ?$



$R_L = R_{Th}$ = Thevenin resistance

$$R_{eq} = R_{th} = \left(\frac{6 \times 12}{6+12}\right) + 3 + 2$$



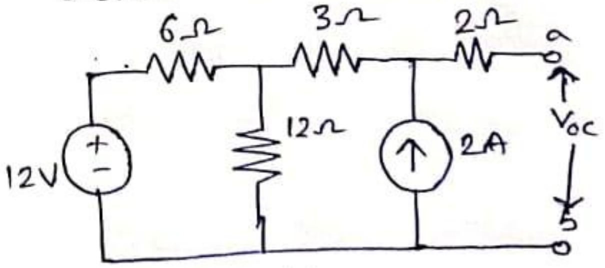
$$R_{th} = 9\,\Omega$$

$\therefore \boxed{R_L = R_{th} = 9\,\Omega}$ for maximum power transfer. — 2M

→ To find maximum power $(P_{max}) = \frac{V_{th}^2}{4R_{th}}$

* V_{th} = Thevenin voltage = open circuit voltage across 'a-b' terminals

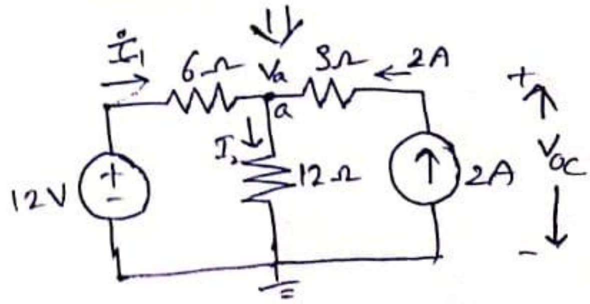
$V_{th} = V_{oc} = ?$



* Apply KCL at node 'a'

$$2 + I_1 = I_2$$

$$2 + \frac{-V_a + 12}{6} = \frac{V_a}{12}$$



$$V_a\left[\frac{1}{6} + \frac{1}{12}\right] = 4$$

$$\boxed{V_a = 16\,V}$$

$\therefore V_{th} = V_{oc} = 3 \times 2 + V_a = 6 + 16 = 22\,V$

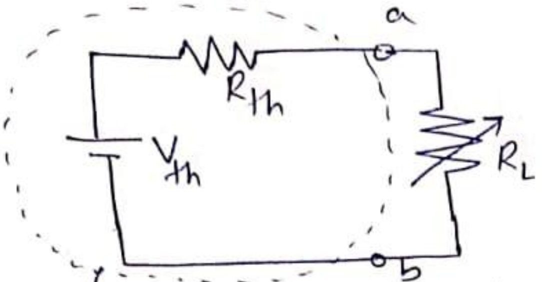
$\boxed{V_{th} = 22\,V}$ — 3M $\quad P_{max} = \frac{V_{th}^2}{4R_{th}} = \frac{22^2}{4(9)} = 13.44\,W$ — 2M

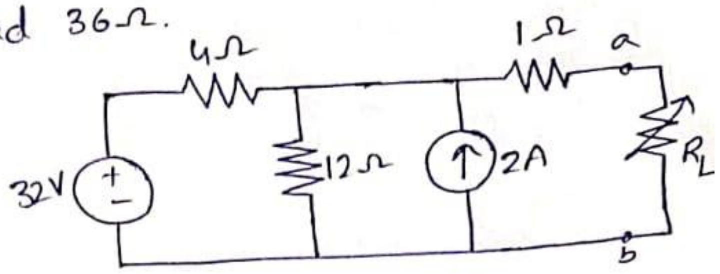
Q)4.b

4b

Answer

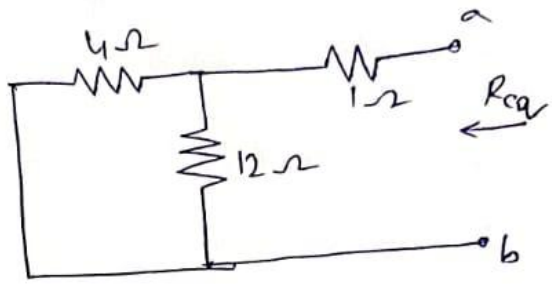
To find Thevenin equivalent circuit & current through $R_L = 6\Omega$ and 36Ω.





↳ Thevenin equivalent circuit

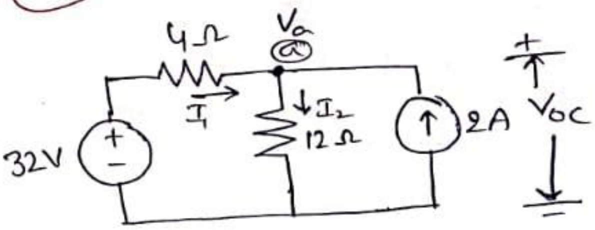
→ To find $R_{th} = ?$



$$R_{th} = R_{eq} = \frac{4 \times 12}{4+12} + 1$$

$$\boxed{R_{th} = 4\Omega} \text{ — (1M)}$$

→ To find $V_{th} = ?$



$$\boxed{V_{th} = V_{oc}}$$

Apply KCL at node 'a'.

$$I_1 + 2 = I_2$$

$$\frac{-V_a + 32}{4} + 2 = \frac{V_a}{12}$$

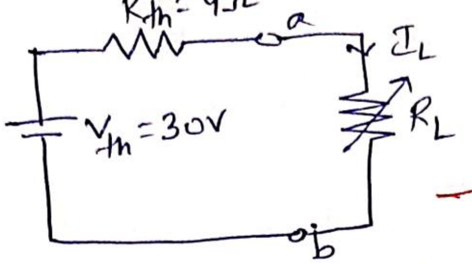
$$V_a \left[\frac{1}{4} + \frac{1}{12}\right] = 8 + 2$$

$$\boxed{V_a = 30V}$$

Here $V_{oc} = V_a = 30V$

$$\boxed{\therefore V_{th} = V_{oc} = 30V} \text{ — (2M)}$$

$\therefore$ Thevenin's Equivalent circuit is



— 2M

→ Current through $R_L = 6\Omega$ is

$$I_L = \frac{V_{th}}{R_{th}+R_L} = \frac{30}{4+6} = 3A$$

$$\boxed{I_L\Big|_{R_L=6\Omega} = 3A}$$ ✓ — 1M

→ Current through $R_L = 36\Omega$

$$I_L = \frac{V_{th}}{R_{th}+R_L} = \frac{30}{4+36} = \frac{30}{40} = 3/4\,A$$

$$\boxed{\therefore I_L = 3/4\,A \text{ (for } R_L = 36\Omega)}$$ ✓ — 1M

Q)5.a

Answer:

Power factor:

Power factor (PF) is defined as the ratio of real power to apparent power. Real power is measured in kW and apparent power is measured in kVA.

Power Factor Formula

The mathematical expression of a power factor is,

Cosθ = active power/apparent power

Where,

cosθ is the Power factor.

Active power is measured in watts.

Apparent power is measured in Volts-ampere.

There is no power factor involved in DC circuits due to zero frequency. But, in AC circuits, the value of power factor always lies between 0 and 1.

---------(2M)

Power Factor Importance:

Power factor is very crucial for economic operation and quality transmission of the power system. The current required to deliver the same power increases with a decrease in power factor. Hence losses increases, therefore efficiency decreases.

Poor power factor indicates the inefficient usage of available power

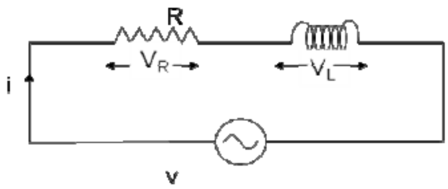
- Low power factor results in increased cross-section and thus the equipment size.
- Reduction in the amount of available useful power.
- Lower power factor causes heat damage to insulation and other equipment.

Hence greater the power factor, the higher the efficiency, the lower the losses, and the lower the operating cost. Every utility aims for a higher power factor since higher efficiency indicates better utilization of generating and transmission systems.

---------(2M)

R-L Series circuit:

Consider an AC circuit with a resistance R and an inductance L connected in series as shown in the figure.

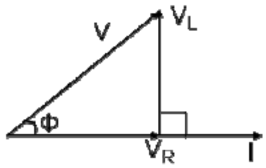


The alternating voltage v is given by V=Vm Sinωt. The current flowing in the circuit is i. The voltage across the resistor is V_R and that across the inductor is V_L.

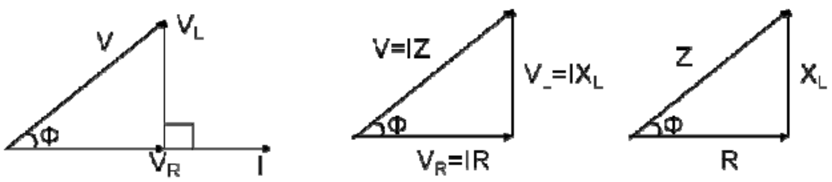
V_R=IR is in phase with I

V_L=IX_L leads current by 90 degrees

With the above information, the phasor diagram can be drawn as shown.



We can derive a triangle called the impedance triangle from the phasor diagram of an RL series circuit as shown



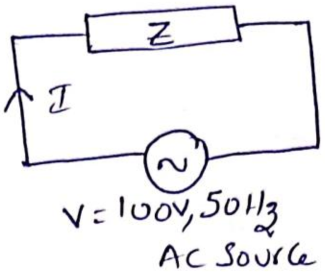
We know that, power factor $= \frac{Active\ power}{apparent\ power} = \frac{VIcos\phi}{VI} = cos\phi = \frac{R}{Z} = \frac{R}{\sqrt{R^2+X_L^2}}$

---------(3M)

Q (5b)

Answer:- Given,

$$Z = 20 + j30\,\Omega$$



— (1M)

→ Admittance (Y) :-

$$Y = \frac{1}{Z}$$

$$Y = \frac{1}{20 + j30}$$

$$Y = (0.015 - 0.023j)\ ℧ \text{ or } S$$

$$\boxed{Y = 0.028 \angle -56.31\ ℧}$$ — (3M)

→ $V = IZ$

$$I = \frac{V}{Z} = \frac{100}{(20 + j30)} = (1.54 - 2.31j)\,A$$

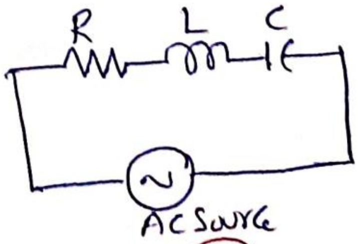
$$I = \underline{\underline{2.77 \angle -56.31^\circ}}\ A$$ — (3M)

Q) 6.a

Answer :- Given,

$R = 5\Omega$, $L = 0.05\,H$ & $C = 200\mu F$

$C = 200 \times 10^{-6}\,F$



— (1M)

a) resonant frequency $(f_0) = \dfrac{1}{2\pi\sqrt{LC}}$

$$f_0 = \frac{1}{2\pi\sqrt{(0.05)\times(200\times10^{-6})}}$$

$$f_0 = \underline{50.33\ Hz}$$

(or)

$$\omega_0 = 2\pi f_0 = 2\pi \times 50.33 = \underline{316.23}\ rad/sec \quad \text{—— 2M}$$

b) <u>Quality factor (Q)</u>

$$Q = \frac{X_L}{R} = \frac{2\pi f_0 L}{R} = 3.16$$

$$Q = 3.16 \quad \text{—— 2M}$$

c) <u>Band-width (BW)</u>

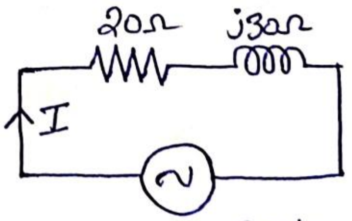
$$B.W. = \frac{\omega_0}{Q} = \frac{316.23}{3.16} = 100.07\ rad/sec$$

(or)

$$B.W. = \frac{f_0}{Q} = \frac{50.33}{3.16} = 15.93\ Hz \quad \text{—— 2M}$$

Q) 6. b.

a) <u>Phasor diagram</u> :-



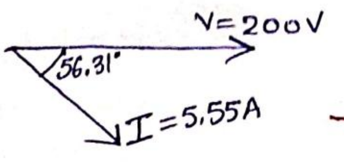
V = 200V, 50Hz AC Source.

1M

$$\text{Current, } I = \frac{200}{20+j30}$$

$$= (3.08 - j4.62)\ A$$

$$\boxed{I = 5.55 \angle -56.31^\circ\ A}$$



—— 2M

b) Power factor :-

$V = 200\angle 0^\circ$

$I = 5.55\angle -56.31$

$$P.f. = \cos\theta = \cos(\theta_v - \theta_i)$$
$$= \cos(0-(-56.31))$$
$$= \cos(56.31)$$
$$\boxed{\cos\theta = 0.55} \text{ — } 2M$$

c) Apparent power $(S) = |V||I|$

$$= 200 \times 5.55$$
$$S = 1110 \text{ VA} \text{ — } 1M$$

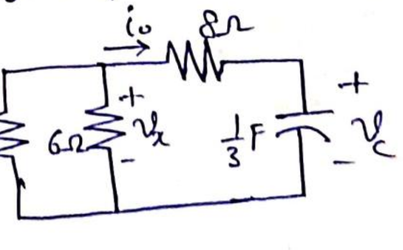
d) Active power $(P) = |V||I| \cos\theta$

$$= 200 \times 5.55 \times 0.55$$
$$= 610.5 \text{ W} \text{ — } 1M$$

Q) 7. a

Answer :- To find $v_c(t)$, $v_x(t)$ & $i_o(t)$ for $t \geq 0$.

given $V_c(0) = 60V$

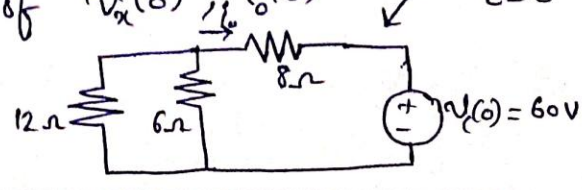


→ Time Constant of the Circuit :-

$$\tau = R_{eq}C = \underbrace{\left(\frac{12\times 6}{12+6} + 8\right)}_{R_{eq}} \times \frac{1}{3} = 4 \text{ sec} \text{ — } 2M$$

→ To find initial values of $v_x(0)$, $i_o(0)$

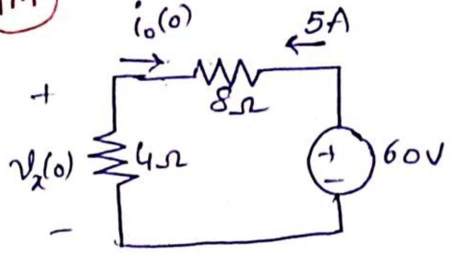
Circuit at $t = 0^+$



$$\longrightarrow i_o(0^+) = \frac{-60}{Z_T} = \frac{-60}{\left[\frac{12\times 6}{12+6} + 8\right]}$$

$$i_0(0^+) = \frac{-60}{12} = -5A$$

$$\boxed{\therefore\ i_0(0) = i_0(0^+) = -5A}$$ — (1M)



$\rightarrow v_x(0^+) = 5 \times 4$

$$\boxed{v_x(0^+) = 20V}$$ — (1M)

→ To find response of any element in a first order

Source-free circuit:

$$f(t) = f(0)\, e^{-t/\tau}$$

where $f(0) \rightarrow$ initial value

$\tau \rightarrow$ Time Constant

$$\boxed{\begin{aligned} f(t) &= f(\infty) + (f(0) - f(\infty))\, e^{-t/\tau} \\ \because f(\infty) &= 0 \\ f(t) &= f(0)\, e^{-t/\tau} \end{aligned}}$$

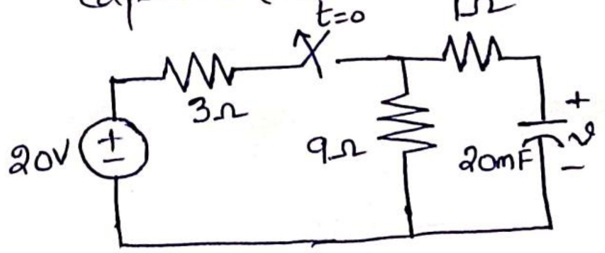
a) $v_c(t) = v_c(0)\, e^{-t/\tau} = 60\, e^{-t/4} = \underline{60\, e^{-0.25t}}$ V — (1M)

b) $v_x(t) = v_x(0)\, e^{-t/\tau} = 20\, e^{-t/4} = \underline{20\, e^{-0.25t}}$ V — (1M)

c) $i_0(t) = i_0(0)\, e^{-t/\tau} = -5\, e^{-t/4} = \underline{-5\, e^{-0.25t}}$ A — (1M)

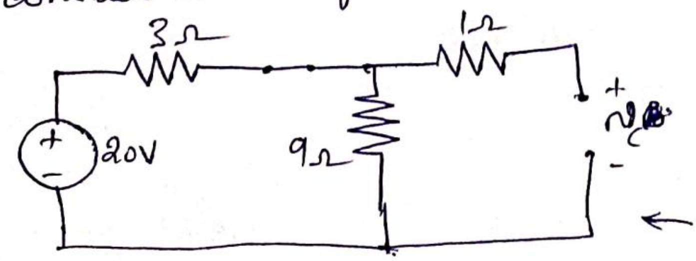
Q7. b

Answer :- To find $v(t)$ for $t \geq 0$ & initial energy stored in capacitor (W_0)



→ To find Initial Value of $v_c(0) = ?$

* Consider circuit for $t<0$:



← capacitor acts as open circuit at steady state.

So $v_c = v_{9\Omega}$ for $t<0$

$$v_c = 20\times\frac{9}{3+9} = 20\times\frac{9^{3}}{12_4} = 15V$$

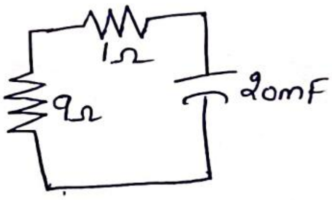
$v_c = 15V$ for $t<0$ [Before switch is opened & is closed for long time during this time]

$\because$ for Capacitor Voltage

$$v_c(0^+) = v_c(0^-) = 15V$$

So, $\boxed{v_c(0) = 15V}$ — 2M

for $t>0$

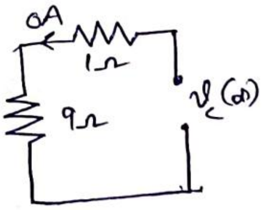


→ Time Constant :- $(\tau) = R_{eq}C$

$$\tau = (9+1)(20\times10^{-3})$$

$$\boxed{\tau = 0.2\ sec}$$ — 2M

at $t=\infty$



→ final value of $v_c(\infty)$:-

$$v_c(\infty) = 0V$$

Therefore,

$$v_c(t) = v_c(\infty) + (v_c(0) - v_c(\infty))\,e^{-t/\tau}$$

$$= 0 + (15-0)\,e^{-t/0.2}$$

$$\boxed{v_c(t) = 15e^{-5t}}$$ — 2M

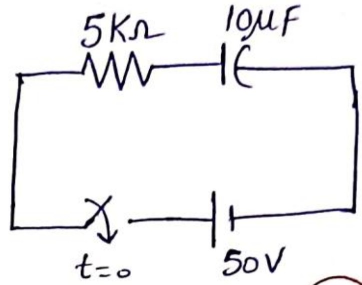
→ Initial Energy Stored :- $W_0 = \frac{1}{2}C\,v_c^2(0)$

$$= \frac{1}{2}(20\times10^{-3})(15)^2$$

$$\boxed{W_0 = 2.25\ \text{Joules}}$$ — 1M

Q)8. a

Answer:- To find Voltage across the capacitor at $t=0$ & $t=\infty$, & Time Constant of the Circuit.



(1M)

→ For $t<0$:

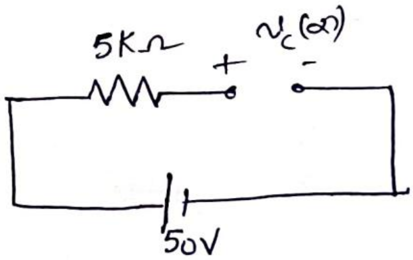
Switch is in open position, so responses in the circuit are zero.

$\Rightarrow v_c = 0$

$\because$ for capacitor $\boxed{v_c(0^+) = v_c(0^-) = 0V}$ — (2M)

→ For $t=\infty$: (Circuit is at Steady State)

At steady state for DC Excitation, capacitor acts as open circuit.



$\Rightarrow \boxed{v_c(\infty) = 50V}$ — (2M)

→ Time Constant $(\tau) = RC$

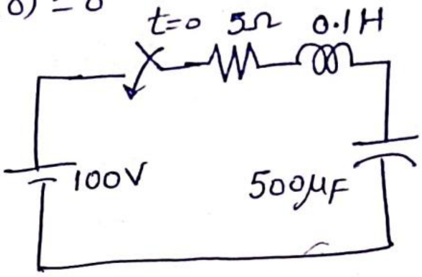
$= 5\times10^3 \times 10\times10^{-6}$

$= 0.05$ Sec — (2M)

Q) 8. b

Answer :- Given, the initial conditions as zero.

$\Rightarrow i(0) = 0$ & $v_c(0) = 0$



To find $i(t) = ?$

→ Since the given circuit is second order circuit, response

$$i(t) = i_{ss}(t) + i_t(t)$$

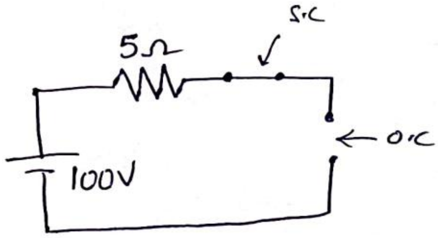
i_{ss} ↓ Steady state response

i_t ↳ transient response.

— 1M

→ At $t = \infty$: (Steady state)

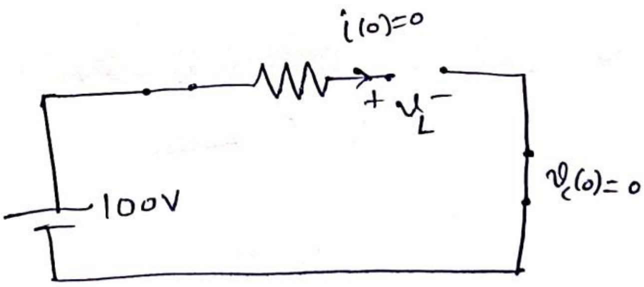
$$\boxed{i_{ss} = i(\infty) = 0\,A}$$



→ Initial Conditions :-

↳ At $t = 0^+$

$v_L(0) = 100V$



WKT $v_L = L\dfrac{di}{dt}$

at $t=0$

$$v_L(0) = L\frac{di(0)}{dt}$$

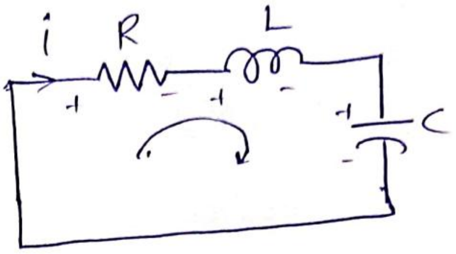
$$\frac{di(0)}{dt} = \frac{v_L(0)}{L} = \frac{100}{0.1} = 1000\ A/s$$

$$\boxed{\therefore \frac{di(0)}{dt} = 1000\ A/s}$$

— 2M

→ For $t>0$:-

↳ To find $i_t(t)$, we consider source free circuit



$$iR + L\frac{di}{dt} + \frac{1}{C}\int i\,dt = 0$$

$$R\frac{di}{dt} + L\frac{d^2i}{dt^2} + \frac{1}{C}i = 0$$

$$\frac{d^2i}{dt^2} + \frac{R}{L}\frac{di}{dt} + \frac{1}{LC}i = 0$$

$$\frac{d^2i}{dt^2} + \frac{5}{0.1}\frac{di}{dt} + \frac{1}{0.1 \times 500 \times 10^{-6}}i = 0$$

$$\frac{d^2i}{dt^2} + 50\frac{di}{dt} + 20000\,i = 0$$

The characteristic equation is

$$(s^2 + 50s + 20000) = 0$$

The roots are $S_{1,2} = (-25 \pm 139.19j)$ ⇒ Complex Conjugate roots

$$= -\alpha \pm j\omega_d \quad \text{— (1M)}$$

So, the solution is

$$i_t(t) = e^{-25t}\left(A_1 \cos(139.19t) + A_2 \sin(139.19t)\right)$$

→ The total response is

$$i(t) = i_{ss} + i_t$$

$$i(t) = 0 + e^{-25t}\left(A_1 \cos 139.19t + A_2 \sin 139.19t\right)$$

$$\boxed{i(t) = e^{-25t}\left(A_1 \cos 139.19t + A_2 \sin 139.19t\right)} \quad \text{— (1)}$$

→ To find A_1 & A_2; let us use initial conditions

$i(0) = 0\,A$, $\frac{di(0)}{dt} = 1000\ A/s$

* Consider, $i(0) = 0$

$$0 = e^{0}\left(A_1 \cos(0) + A_2 \sin(0)\right)$$

$$\Rightarrow \boxed{A_1 = 0}$$

* Now, $\frac{di(0)}{dt} = 1000$

Let us differentiate eq ① with respect to 't' on both sides.

$$\frac{di}{dt} = -25e^{-25t}\left(A_1 \cos 139.19t + A_2 \sin 139.19t\right) + e^{-25t}\left(-139.19A_1 \sin 139.19t + 139.19A_2 \cos 139.19t\right)$$

at $t=0$

$$1000 = -25e^{0}\left(\cancel{A_1}^{0} \times 1 + 0\right) + e^{0}\left(0 + 139.19A_2 \times 1\right)$$

$$\Rightarrow A_2 = \frac{1000}{139.19} = 7.18$$

Therefore, $i(t) = e^{-25t}\left(0 + 7.18 \sin 139.19t\right)$

$$\boxed{i(t) = 7.18\, e^{-25t} \sin 139.19t}$$ — SM

Q)9.a

Answer

Speed control of Shunt motor

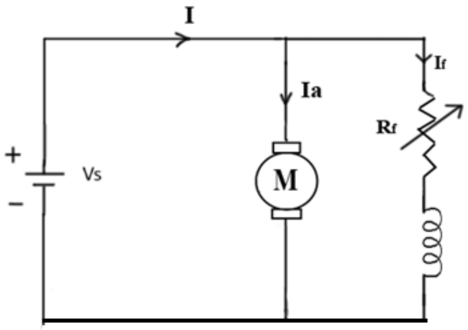
Speed of DC motors can be controlled by varying the flux per pole, armature resistance, and applied voltage.

$N \, \alpha \, \frac{V_t - I_a r_a}{\phi}$ ---------*(1M)*

1. Flux control method

It is already explained above that the **speed of a dc motor** is inversely proportional to the flux per pole. Thus by decreasing the flux, speed can be increased and vice versa.

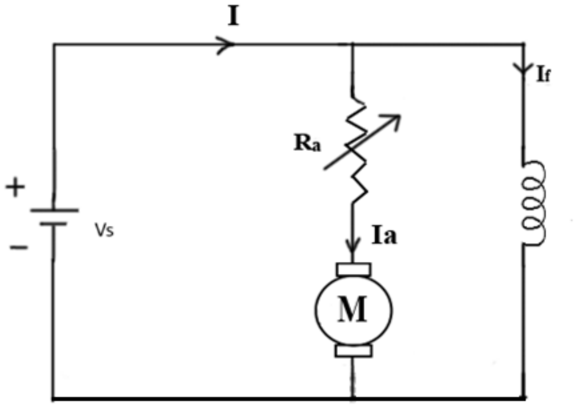
To control the flux, a rheostat is added in series with the field winding, as shown in the circuit diagram. Adding more resistance in series with the field winding will increase the speed as it decreases the flux. In shunt motors, as field current is relatively very small, I_{sh}^2R loss is small. Therefore, this method is quite efficient. Though speed can be increased above the rated value by reducing flux with this method, it puts a limit to maximum speed as weakening of field flux beyond a limit will adversely affect the commutation.



---------*(2M)*

2. Armature resistance control method

Speed of a dc motor is directly proportional to the back emf E_b and $E_b = V - I_aR_a$. That means, when supply voltage V and the armature resistance R_a are kept constant, then the speed is directly proportional to armature current I_a. Thus, if we add resistance in series with the armature, I_a decreases and, hence, the speed also decreases. Greater the resistance in series with the armature, greater the decrease in speed.



---------*(2M)*

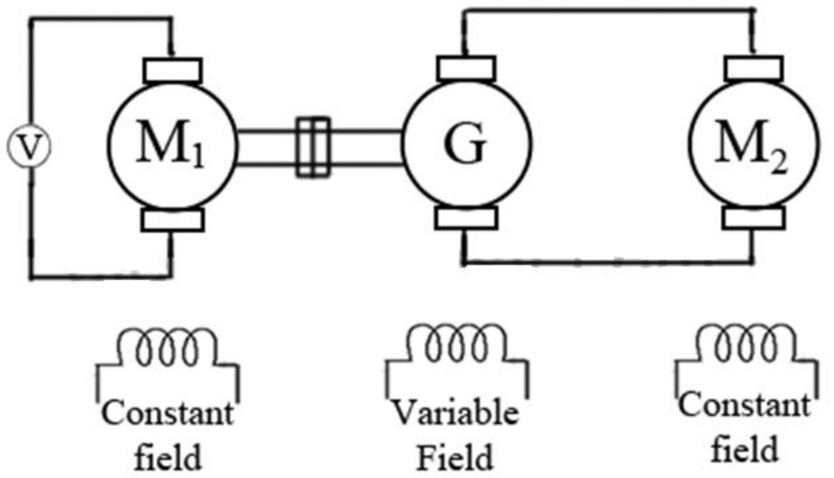
3. Armature Voltage Control Method

a) **Multiple voltage control**:

In this method, the shunt field is connected to a fixed exciting voltage and armature is supplied with different voltages. Voltage across armature is changed with the help of suitable switchgear. The speed is approximately proportional to the voltage across the armature.

b) **Ward-Leonard System**:

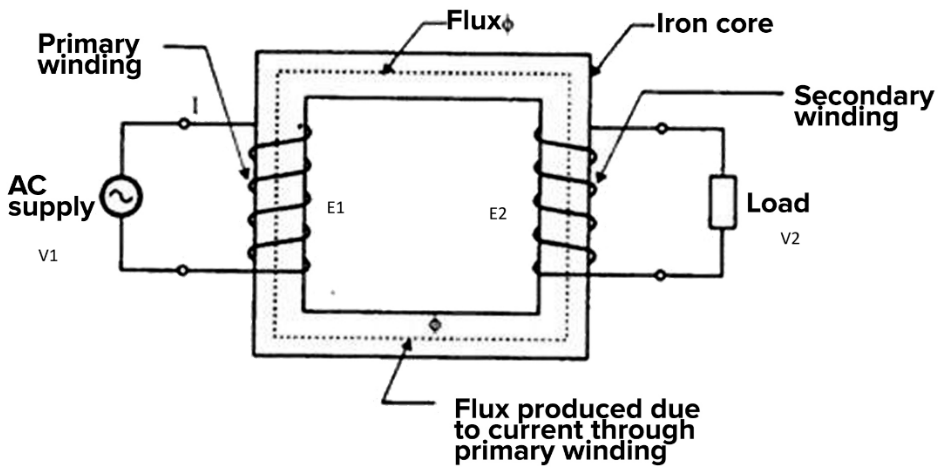
This system is used where very sensitive **speed control of motor** is required (e.g electric excavators, elevators etc.). The arrangement of this system is as shown in the figure at right. M_2 is the motor to which speed control is required.
M1 may be any AC motor or DC motor with constant speed.
G is a generator directly coupled to M1.
In this method, the output from generator G is fed to the armature of the motor M2 whose speed is to be controlled. The output voltage of generator G can be varied from zero to its maximum value by means of its field regulator and, hence, the armature voltage of the motor M2 is varied very smoothly. Hence, very smooth speed control of the dc motor can be obtained by this method.



---------(2M)

Q)9.b
Answer

Transformer Principle of Operation:
A transformer works on the principle of mutual inductance, which states that when an alternating voltage is applied to the primary winding, an alternating flux is produced in the core. This flux links both the windings magnetically and induces an electromotive force (emf) in the secondary coil.



---------(2M)

E.M.F. Equation of a Transformer

Consider that an alternating voltage V_1 of frequency f is applied to the primary. The sinusoidal flux φ produced by the primary can be represented as:

$\varphi = \varphi m \sin\omega t$

The instantaneous e.m.f. e_1 induced in the primary is

$$e_1 = -N_1 \frac{d\phi}{dt} = -N_1 \frac{d}{dt}(\phi_m \sin \omega t)$$
$$= -\omega N_1 \phi_m \cos \omega t = -2\pi f N_1 \phi_m \cos \omega t$$
$$= 2\pi f N_1 \phi_m \sin(\omega t - 90°) \qquad \text{(i)}$$

It is clear from the above equation that maximum value of induced e.m.f. in the primary is

$$E_{m1} = 2\pi f N_1 \phi_m$$

The r.m.s. value E^ of the primary e.m.f. is

$$E_1 = \frac{E_{m1}}{\sqrt{2}} = \frac{2\pi f N_1 \phi_m}{\sqrt{2}}$$

or $\qquad E_1 = 4.44 f N_1 \phi_m$

Similarly $\qquad E_2 = 4.44 f N_2 \phi_m$

In an ideal transformer, $E_1 = V_1$ and $E_2 = V_2$.

Note. It is clear from exp. (i) above that e.m.f. E_1 induced in the primary lags behind the flux ϕ by 90°. Likewise, e.m.f. E_2 induced in the secondary lags behind flux ϕ by 90°.

---------(5M)

Q)10.a

Answer

Construction of D.C. Machine

A D.C. machine consists of two main parts

1. Stationary part (Stator): It is designed mainly for producing a magnetic flux.
2. Rotating part (Rotor): It is called the armature, where mechanical energy is converted into electrical (electrical generate) or conversely electrical energy into mechanical energy (electric motor)

The d.c. generators and d.c. motors have the same general construction. In fact, when the machine is being assembled, the workmen usually do not know whether it is a d.c. generator or motor. Any d.c. generator can be run as a d.c. motor and vice-versa.

Parts of a DC Machine:

1) Yoke

2) Magnetic Poles

a) Pole core b) Pole Shoe

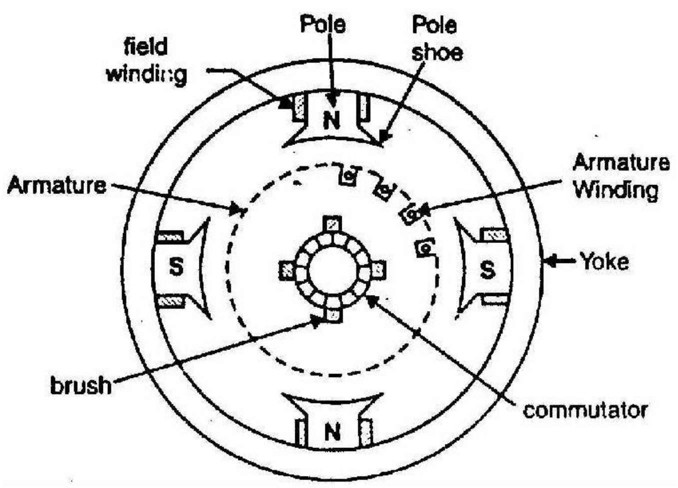
3) Field Winding

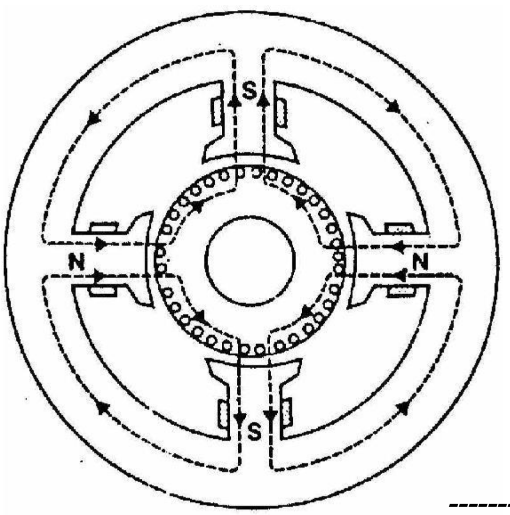
4) Armature Core

5) Armature winding

6) Commutator

7) Brushes and Bearings





---------*(2M)*

The stationary parts and rotating parts are separated from each other by an air gap. The stationary part of a D. C. machine consists of main poles, designed to create the magnetic flux, commutating poles interposed between the main poles and designed to ensure spark less operation of the brushes at the commutator and a frame / yoke. The armature is a cylindrical body rotating in the space between the poles and comprising a slotted armature core, a winding inserted in the armature core slots, a commutator and brush.

Yoke:

1. It saves the purpose of outermost cover of the dc machine so that the insulating materials get protected from harmful atmospheric elements like moisture, dust and various gases like SO2, acidic fumes etc.

2. It provides mechanical support to the poles.

3. It forms a part of the magnetic circuit. It provides a path of low reluctance for magnetic flux.

Choice of material: To provide low reluctance path, it must be made up of some magnetic material. It is prepared by using cast iron because it is the cheapest. For large machines rolled steel or cast steel, is used which provides high permeability i.e., low reluctance and gives good mechanical strength.

Poles:

Each pole is divided into two parts

a) pole core b) pole shoe

Functions:

1. Pole core basically carries a field winding which is necessary to produce the flux.

2. It directs the flux produced through air gap to armature core to the next pole.

3. Pole shoe enlarges the area of armature core to come across the flux, which is necessary to produce larger induced emf. To achieve this, pole core has been given a particular shape.

Choice of material: It is made up of magnetic material like cast iron or cast steel. As it requires a definite shape and size, laminated construction is used. The laminations of required size and shape are stamped together to get a pole which is then bolted to yoke.

Armature: It is further divided into two parts namely,

(1) Armature core (2) Armature winding.

1. **Armature core** is cylindrical in shape mounted on the shaft. It consists of slots on its periphery and the air ducts to permit the air flow through armature which serves cooling purpose.

Functions:
1. Armature core provides house for armature winding i.e., armature conductors.
2. To provide a path of low reluctance path to the flux it is made up of magnetic material like cast iron or cast steel.

Choice of material: As it has to provide a low reluctance path to the flux, it is made up of magnetic material like cast iron or cast steel.
It is made up of laminated construction to keep eddy current loss as low as possible.

2. **Armature winding:** Armature winding is nothing but the inter connection of the armature conductors, placed in the slots provided on the armature core. When the armature is rotated, in case of generator magnetic flux gets cut by armature conductors and emf gets induced in them.
Function:
1. Generation of emf takes place in the armature winding in case of generators.
2. To carry the current supplied in case of dc motors.
3. To do the useful work it the external circuit.

Choice of material: As armature winding carries entire current which depends on external load, it has to be made up of conducting material, which is copper.

Field winding: The field winding is wound on the pole core with a definite direction.
Functions: To carry current due to which pole core on which the winding is placed behaves as an electromagnet, producing necessary flux. As it helps in producing the magnetic field i.e. exciting the pole as electromagnet it is called '**Field winding'** or '**Exciting winding'.**
Choice of material: As it has to carry current it should be made up of some conducting material like the aluminium or copper.

But field coils should take any type of shape should bend easily, so copper is the proper choice. Field winding is divided into various coils called as field coils. These are connected in series with each other and wound in such a direction around pole cores such that alternate N and S poles are formed.

Commutator: The rectification in case of dc generator is done by device called as commutator.

Functions: 1. To facilitate the collection of current from the armature conductors.
2. To convert internally developed alternating emf to in directional (dc) emf
3. To produce unidirectional torque in case of motor.
Choice of material: As it collects current from armature, it is also made up of copper segments. It is cylindrical in shape and is made up of wedge shaped segments which are insulated from each other by thin layer of mica.

Brushes and brush gear: Brushes are stationary and rest on the surface of the Commutator. Brushes are rectangular in shape. They are housed in brush holders, which are usually of box type. The brushes are made to press on the commutator surface by means of a spring, whose tension can be adjusted with the help of lever. A flexible copper conductor called pigtail is used to connect the brush to the external circuit.
Functions: To collect current from commutator and make it available to the stationary external circuit.
Choice of material: Brushes are normally made up of soft material like carbon.

Bearings: Ball-bearings are usually used as they are more reliable. For heavy duty machines, roller bearings are preferred.

---------(5M)

Q)10.b
Answer

Double revolving field theory
According to double field revolving theory, any alternating quantity can be resolved into two components, each component have magnitude equal to the half of the maximum magnitude of the alternating quantity and both these component rotates in opposite direction to each other. For example - a flux, φ can be resolved into two components

$\frac{\phi_m}{2}\ and\ -\frac{\phi_m}{2}$

Each of these components rotates in opposite direction i. e if one φm / 2 is rotating in clockwise direction then the other φm / 2 rotates in anticlockwise direction. When a single phase ac supply is given to the stator winding of single phase induction motor, it produces its flux of magnitude, φm. According to the double field revolving theory, this alternating flux, φm is divided into two components of magnitude φm /2. Each of these components will rotate in opposite direction, with the synchronous speed, Ns. Let us call these two components of flux as forward component of flux, φf and backward component of flux, φb. The resultant of these two component of flux at any instant of time, gives the value of instantaneous stator flux at that particular instant.

$$i.e.\phi_r = \frac{\phi_m}{2} + \frac{\phi_m}{2}\ or\ \phi_r = \phi_f + \phi_b$$

Now at starting, both the forward and backward components of flux are exactly opposite to each other. Also both of these components of flux are equal in magnitude. So, they cancel each other and hence the net torque experienced by the rotor at starting is zero. So, the single phase induction motors are not self starting motors.

---------(5M)

In a single-phase induction motor, the forward and backward rotating fields are important because they create opposing torques that determine the net torque acting on the rotor:

- **Explanation**

A single-phase AC current produces a pulsating magnetic field that can be mathematically divided into two rotating fields, one forward and one backward. Each field cuts the rotor, inducing an electromotive force (EMF) and producing its own torque. The two torques are oppositely directed, so the net torque is the difference between the two.

- **Significance**

At zero speed, the forward and backward torques are equal and opposite, resulting in zero net torque. This means that a single-phase induction motor is not self-starting. To start the motor, an external torque must move it in any direction.

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