

USN

16 R 24 PE 072

BESCK2

Second Semester B.E./B.Tech. Degree Examination, June/July 2025

Introduction to Electrical Engineering

Time: 3 hrs.

Max. Marks: 100

Note: 1. Answer any FIVE full questions, choosing ONE full question from each module.

2. VTU Formula Hand Book is permitted.

3. M : Marks, L: Bloom's level, C: Course outcomes.

Module - 1			M	L	C
Q.1.	a.	Enumerate and explain briefly the essential elements of hydro power plant.	06	L2	CO1
	b.	State and explain Kirchhoff's laws.	06	L2	CO1
	c.	A resistance of $5\ \Omega$ is connected in series with a parallel combination of $4\ \Omega$ and $12\ \Omega$. If the current through $5\ \Omega$ resistor is 10 A , find the (i) Currents in $4\ \Omega$ and $12\ \Omega$ resistors, (ii) Supply voltage and (iii) Power dissipated by each resistor.	08	L3	CO2
OR					
Q.2	a.	List the advantages and disadvantages of nuclear power plant.	06	L1	CO1
	b.	List the characteristics of parallel circuit. Obtain the expression for current through any resistor in a parallel circuit.	06	L1	CO2
	c.	Two batteries having emfs of 10 V and 7 V , and internal resistances of $2\ \Omega$ and $3\ \Omega$ respectively, are connected in parallel across a load of resistance $1\ \Omega$. Calculate (i) the current supplied by each battery, (ii) the current through the load, and (iii) the voltage across the load.	08	L3	CO2
Module - 2					
Q.3	a.	Show that the pure inductance does not dissipate any power. Draw the phasor diagram and the waveforms of voltage and current.	06	L2	CO2
	b.	What are the advantages of three phase system over a single phase system?	06	L1	CO2
	c.	A coil has a resistance of $10\ \Omega$ and draws a current of 5 A when connected across a 100 V , 60 Hz source. Determine (i) the inductance of the coil (ii) the power factor of the circuit (iii) the voltage across inductance and (iv) the reactive power.	08	L3	CO2
OR					
Q.4	a.	Derive an expression for the average power consumed by a R-L series circuit. Draw the phasor diagram and the waveforms of voltage and current.	06	L2	CO2
	b.	A three-phase, delta connected load consumes a power of 120 KW , drawing a lagging line current of 200 A from a three-phase, 400 V , 50 Hz supply. (i) Find the parameters of each phase, (ii) What would be the power consumed if the loads were connected in star?	06	L3	CO2
	c.	A coil of resistance $10\ \Omega$ and inductance 0.1 H is connected in series with a $150\ \mu\text{F}$ capacitor across a 200 V , 50 Hz supply. Calculate (i) the impedance, (ii) the current, (iii) the power factor, (iv) the voltage across the coil and the capacitor.	08	L3	CO2

Module - 3

Q.5	a.	Explain the function of main parts of a dc machine.	06	L2	
	b.	Sketch and explain speed-load characteristics of (i) series motor (ii) shunt motor. Mention two applications of each motor.	06	L2	
	c.	A 4-pole, shunt generator with Lap-connected armature has field and armature resistances of 50Ω and 0.1Ω respectively. It supplies power to sixty 100 V , 40 W lamps. Calculate (i) the armature current (ii) the current per armature path, and (iii) the generated emf. Allow a contact drop of 1 V per brush.	08	L3	

OR

Q.6	a.	Derive the emf equation for a dc generator.	06	L2	C
	b.	Explain the different methods used to control the speed of dc series motor.	08	L2	C
	c.	A 6 pole, Lap-connected dc series motor, with 864 conductors, takes a current of 110 A at 480 V . The armature and series-field resistance are 0.18Ω and 0.02Ω respectively. The flux per pole is 50 mwb . Calculate (i) the speed, and (ii) the gross torque developed by the armature.	06	L3	C

Module - 4

Q.7	a.	Derive the emf equations of a transformer and hence find the transformation ratio.	06	L2	C
	b.	Explain the principle of operation of a 3-phase induction motor and give reason for an induction motor cannot run at synchronous speed.	06	L2	C
	c.	A 600 KVA , single phase transformer has an efficiency of 92% both at full load and half full load, upf. Determine its efficiency at 75% full load, 0.9 pf .	08	L3	C

OR

Q.8	a.	Define slip. Derive an expression for frequency of rotor current. In what way, an induction motor is similar to a transformer?	06	L2	CO
	b.	Explain the various losses that occur in a transformer. Also derive the condition for maximum efficiency of a transformer.	08	L2	CO4
	c.	A 4-pole, 3-phase, 50 Hz induction motor runs at a speed of 1470 rpm . Find (i) the synchronous speed (ii) the slip and (iii) the frequency of the induced emf in the rotor.	06	L3	CO4

Module - 5

Q.9	a.	With relevant circuit diagrams and switching tables, explain two-way and three-way control of a lamp. Mention its applications.	08	L2	CO5
	b.	Write a short note on Fuse and MCB.	06	L2	CO5
	c.	Explain the necessity of earthing. Explain pipe earthing with a neat diagram.	06	L2	CO5

OR

Q.10	a.	Explain different types of wiring systems.	06	L2	CO5
	b.	What is electric shock? What are the precautions to be taken to prevent electric shock?	06	L1	CO5
	c.	Define "unit" used for consumption of electrical energy and explain two-part tariff. Mention its advantages and disadvantages.	08	L2	CO5

1a)

POWER GENERATION HYDEL POWER PLANT

1. Water Source: Hydropower plants are built near a water source such as a dam, river or reservoir.
2. Dam: A dam is built to create a reservoir, which stores the water. The dam controls the flow of water to the power plant.
3. Penstock: The water from the reservoir flows through a penstock, which is a large pipe or conduit. The penstock carries the water to the turbine.
4. Turbine: The water turns a turbine, which is connected to a generator.
5. Generator: The generator converts the mechanical energy from the turbine into electrical energy.
6. Transformer: The electrical energy from the generator is then sent to a transformer, which increases the voltage to the level needed for transmission.
7. Transmission Lines: The electricity is then transmitted through high-voltage transmission lines to the end-users.
8. End-Users: The electricity generated is distributed to the end-users such as homes, businesses, and industries.

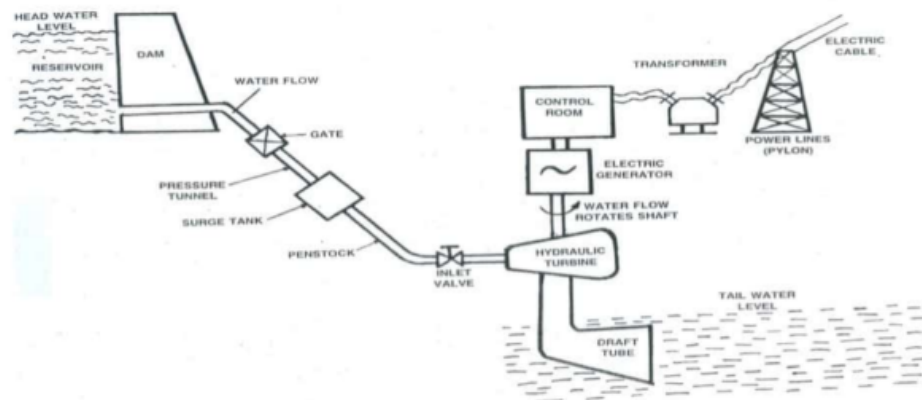


Fig. Layout of Hydro electric Power plant

1b)

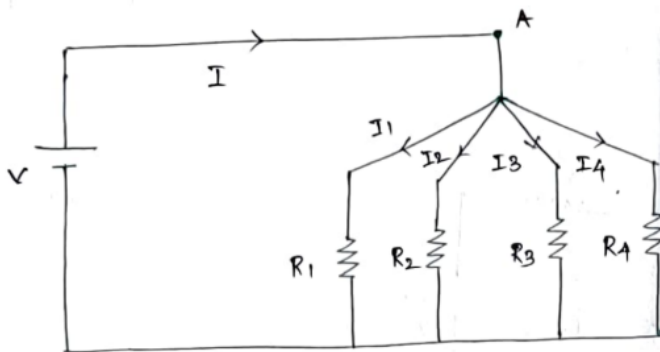
KIRCHHOFF'S LAW:-

- Kirchhoff's law is useful in
- determining the equivalent resistance of a complicated n/w of conductors
 - for calculating the currents flowing in various conductors.

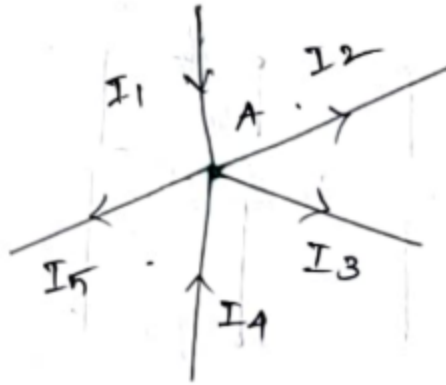
KIRCHHOFF'S CURRENT / POINT LAW: [KCL]

In any electrical network, the algebraic sum of the currents meeting at a point or junction is zero. i.e. $\sum I = 0$.

i.e. total current leaving a junction is equal to the total current entering that junction.



$$I = I_1 + I_2 + I_3 + I_4$$



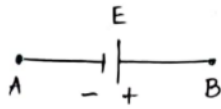
$$I_1 + I_4 = I_2 + I_3 + I_5$$

KIRCHHOFF'S VOLTAGE / MESH LAW: [KVL]

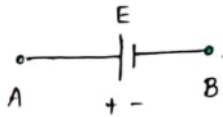
The algebraic sum of voltages [voltage drop + e.m.f.] around a closed loop or circuit is zero.

$$\sum IR + \sum \text{e.m.f} = 0$$

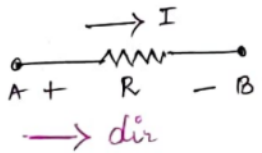
Determination of voltage sign:-



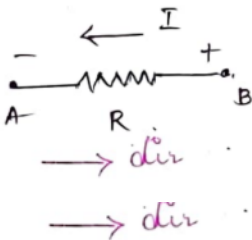
Rise in voltage +ve sign.



Fall in voltage -ve sign.



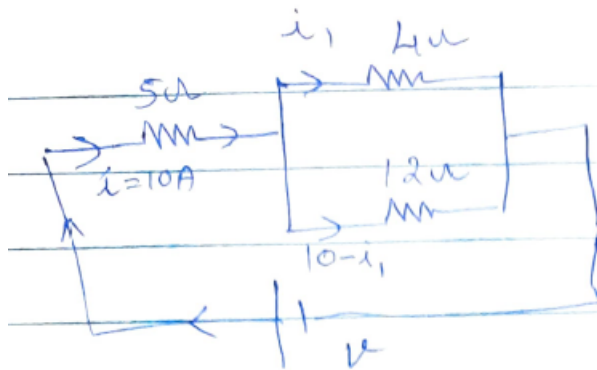
Fall in voltage -ve sign.



Rise in voltage +ve sign.

It should be noted that sign of voltage drop depends on the direction of current and is independent of the polarity of the emf of source in the circuit under consideration.

1c)



$$i_1 = \frac{10 \times 12}{16} = 7.5A = \text{current through } 4\Omega$$

$$10 - 7.5 = 2.5A = \text{current through } 12\Omega$$

$$\text{Supply voltage} = V = I \cdot R_{eq} ; \underline{I = 10A}$$

$$R_{eq} = 5 + \frac{4 \times 12}{4 + 12} = \underline{8\Omega}$$

$$V = 10 \times 8 = \underline{80V}$$

Power dissipated

$$P_{5\Omega} = I^2 R_{5\Omega} = 10^2 \times 5 = \underline{500W}$$

$$P_{4\Omega} = i_1^2 R_{4\Omega} = (7.5)^2 \times 4 = \underline{225W}$$

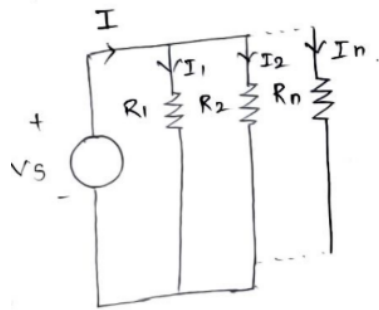
$$P_{12\Omega} = (10 - i_1)^2 R_{12\Omega} = \underline{75W}$$

2A)

One of the main advantages of nuclear power plants is that they produce large amounts of electricity without emitting greenhouse gases, such as carbon dioxide. However, they also produce nuclear waste, which can remain radioactive for thousands of years and require careful handling and storage. Safety concerns, such as the risk of accidents or nuclear proliferation, are also important considerations for nuclear power plant operation.

2b)

PARALLEL COMBINATION:



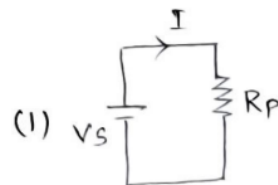
$$V_S = I_1 R_1 = I_2 R_2 = I_n R_n$$

$$I = I_1 + I_2 + \dots + I_n$$

$$= \frac{V_S}{R_1} + \frac{V_S}{R_2} + \dots + \frac{V_S}{R_n}$$

$$= V_S \left[\frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n} \right]$$

$$= V_S \left[\sum_{k=1}^n \frac{1}{R_k} \right]$$



$$\therefore V_S = I R_P \quad (2)$$

using (1) & (2),

$$R_P = \left[\sum_{k=1}^n \frac{1}{R_k} \right]^{-1}$$

∴ resistance.

∴ Equivalent parallel resistance,

$$R_p = \left[\frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n} \right]^{-1}$$

Eg:- If 2 resistors are connected in parallel,

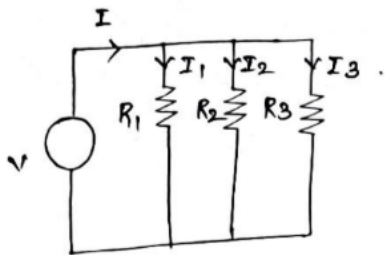
$$R_p = \left[\frac{1}{R_1} + \frac{1}{R_2} \right]^{-1}$$

$$= \left[\frac{R_2 + R_1}{R_1 R_2} \right]^{-1}$$

$$R_p = \frac{R_1 R_2}{R_1 + R_2}$$

parallel,

CURRENT DIVISION RULE:



$$V = I_1 R_1 = I_2 R_2 = I_3 R_3$$

$$I = I_1 + I_2 + I_3$$

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

$$I = V \left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right]$$

$$V = \frac{I}{\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right]} \quad \text{--- (1)}$$

$$I_1 = \frac{V}{R_1} \Rightarrow I \left[\frac{\frac{1}{R_1}}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \right]$$

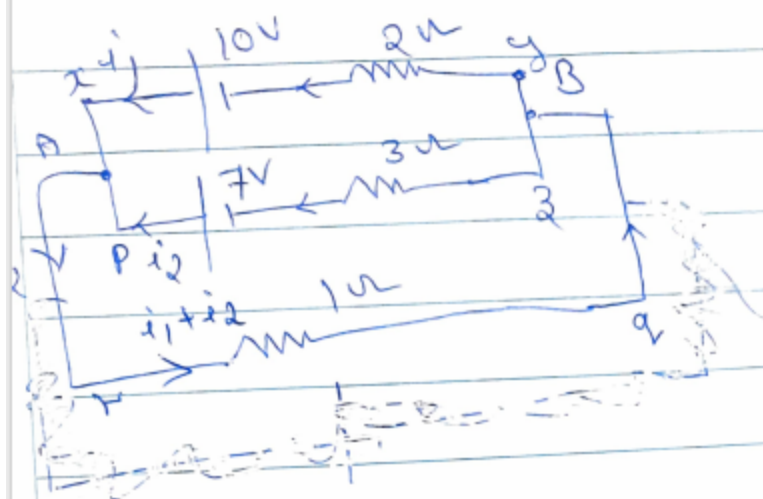
$$I_2 = \frac{V}{R_2} \Rightarrow I \frac{[V/R_2]}{\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]}$$

$$I_3 = \frac{V}{R_3} \Rightarrow I \frac{[V/R_3]}{\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]}$$

$$\text{Let } G_1 = 1/R_1 ; G_2 = 1/R_2 ; G_3 = 1/R_3$$

$$I_1 = \frac{I G_1}{G_1 + G_2 + G_3} , I_2 = \frac{I G_2}{G_1 + G_2 + G_3} , I_3 = \frac{I G_3}{G_1 + G_2 + G_3} .$$

2c)



$$\text{Loop } A \rightarrow x \rightarrow y \rightarrow B \rightarrow z \rightarrow P \rightarrow A \rightarrow -10 + 2i_1 - 3i_2 + 7 = 0$$

$$2i_1 - 3i_2 = 3 \quad \text{--- (1)}$$

$$\text{Loop } A \rightarrow x \rightarrow y \rightarrow B \rightarrow q \rightarrow M \rightarrow A \rightarrow -10 + 2i_1 + 1(i_1 + i_2) = 0$$

$$3i_1 + i_2 = 10 \quad \text{--- (2)}$$

$$\begin{bmatrix} 2 & -3 \\ 3 & 1 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} 3 \\ 10 \end{bmatrix}$$

$$i_1 = 3A$$

$$i_2 = 1A$$

current from 10V battery = 3A

current from 7V battery = 1A

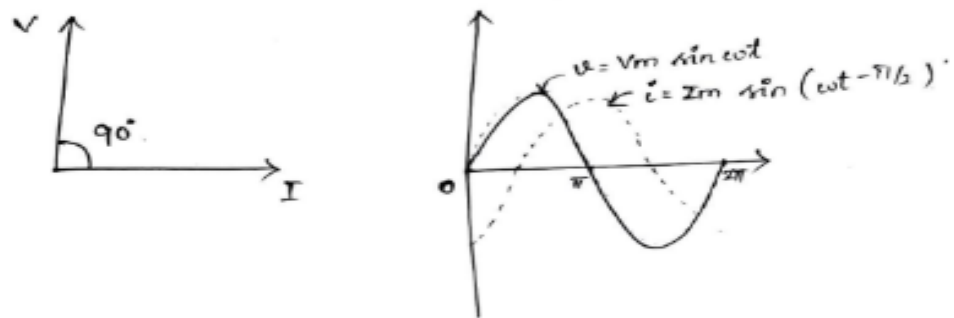
current through load = 4A

Voltage across load = $4 \times 1 = \underline{\underline{4V}}$

3a)

The value of i will be max, when $\sin(\omega t - 90^\circ) = 1$
 $\therefore I_m = \frac{V_m}{\omega L} \quad \text{--- (3)}$
 (3) in (2), $i = I_m \sin(\omega t - 90^\circ) \quad \text{--- (4)}$

Comparing (1) and (4),
 $\Rightarrow$ current lags voltage by 90° .



Inductive reactance: $I_m = \frac{V_m}{\omega L}$

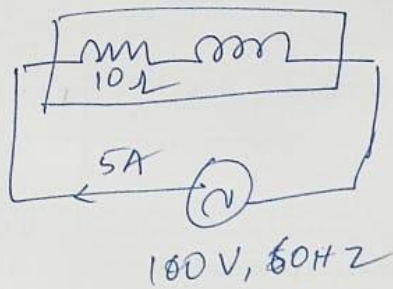
$\frac{V_m}{I_m} = \omega L$
 The opposition offered by the inductance to the current flow is $\omega L = X_L$
 X_L - Inductive reactance of the coil. (Ω)
 $X_L = \omega L = 2\pi f L$

3.b. To transmit a specific **power** over a specific distance at a given rated **voltage**, a three phase system needs less conductor material as compared to the single phase system.

1. The size of a three phase system operated machine is less than the machine operated at single phase voltage having the same output rating.
2. In a three phase power supply system, the less voltage drop occurs from source to the load points,

3. A three phase supply produces uniform rotating magnetic field therefore, three phase motors are simpler in construction, small in size and can be started automatically with smooth operation.
4. A polyphase system produces power at a constant rate in the load.
5. A three phase system can transmit more power as compared to a single phase system.
6. The efficiency of three phase operated devices and appliances is higher than the single phase operated machines.
7. Three phase machines are less costly and more efficient.
8. A three phase system provides constant power while a single phase system provides pulsating power which leads to a smooth and vibration free operation of a 3- Φ machine as compared to the 1- Φ machines with noise and vibration.
9. The output rating of machines can be increased by increasing the number of phases in a system.
10. A three phase machine having the same rating occupies less space as compared to the single phase machine.
11. A single phase supply can be obtained from three phase supply to run the 1-phase machines. A three phase machine can't be operated on single phase supply voltage.

(30)



$$Z = ? \quad L = ? \quad P.f = ?$$

$$V_L = ? \quad Q = ?$$

$$V = IZ$$

$$Z = \frac{100}{5} = 20 \Omega$$

$$Z = \sqrt{R^2 + X_L^2}$$

$$20 = \sqrt{10^2 + X_L^2} \Rightarrow X_L^2 = 20^2 - 10^2$$

$$X_L = \sqrt{300}$$

$$= 17.32 \Omega$$

$$X_L = 2\pi fL$$

$$L = \frac{17.32}{2\pi \times 50}$$

$$= 0.05513$$

$$= \underline{\underline{5.5 \text{ mH}}}$$

$$\cos \phi = \frac{R}{Z}$$

$$= \frac{10}{20} = 0.5$$

$$\phi = \cos^{-1}(0.5)$$

$$= 30^\circ$$

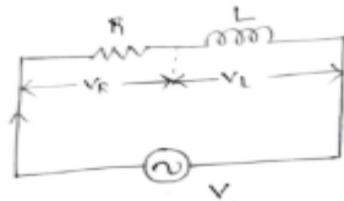
$$V_L = I \cdot X_L$$

$$= 5 \times 17.32$$

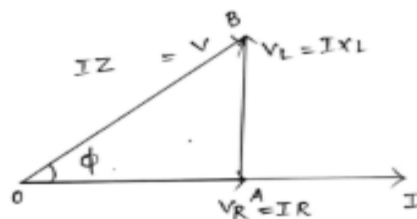
$$= \underline{\underline{86.6 \text{ Volts}}}$$

$$Q = VI \sin \phi$$

$$= 100 \times 5 \times \left(\frac{1}{2}\right) = \underline{\underline{250 \text{ VAR}}}$$



Let V - rms value of the applied voltage
 I - rms value of the applied current
 $V_R = IR$ (V_R in phase with I)
 $V_L = IX_L$ (V_L leads I by 90°).



Take that quantity as reference which is common in the ckt

$$\begin{aligned}\vec{V} &= \vec{V_R} + \vec{V_L} \Rightarrow \sqrt{V_R^2 + V_L^2} \\ &= \sqrt{(IR)^2 + (IX_L)^2} \\ &= I \sqrt{R^2 + X_L^2} \\ I &= \frac{V}{\sqrt{R^2 + X_L^2}} \Rightarrow \frac{V}{Z}\end{aligned}$$

where $Z = \sqrt{R^2 + X_L^2}$ is the impedance of the ckt which offers opposition to current flow.

4b)

1- Field (magnetic poles)

2- Armature

3- Commutator

4- Yoke and Bearings

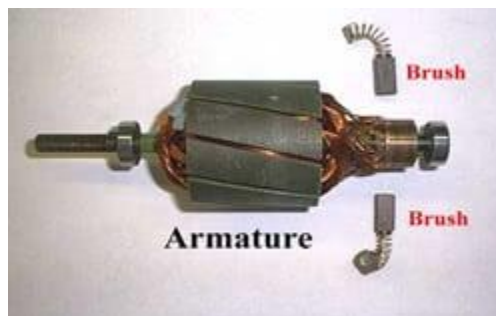
5- Carbon Brushes of a DC Machine

1. Field Winding of a DC Machine

- The field is the stationary part of a DC motor. A field is usually constructed out of magnetic poles. In the example above of the copper coil spinning on its own axis between two magnets, the two magnets produce a magnetic field in which a conductor, the armature, must move to produce an electric charge.
- The function of the field system is to produce uniform magnetic field within which the armature rotates.

2. Armature Winding

The armature is the moving part of a DC motor. It moves in the field to complete the DC machine's electro-mechanical energy conversion. In the above example, the copper coil is the armature, spinning in the magnetic field.



Armature Winding of a DC Machine

3. Commutator

- The spinning armature and its brushes produce an alternating electromagnetic field (EMF) that can disrupt the operation of a DC machine. A commutator in conjunction with commutating poles resolves the alternating EMF and prevents the brushes from sparking.
- It is a mechanical rectifier which converts the alternating voltage generated in armature winding into direct voltages across the brushes. It

is made of copper segment insulated from each other by suitable insulating material and mounted on the shaft of machine.

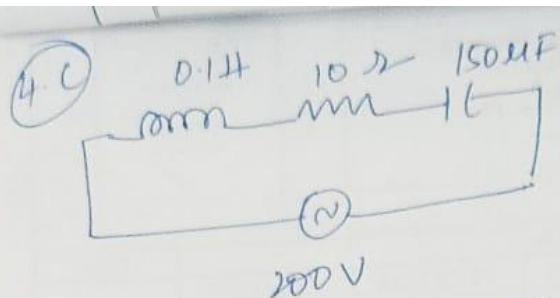
4. Yoke and Bearings

Every part of dc motor have its own working. As commutator, is made of to semi circular rings. Which convert ac current to the pulsating dc. And carbon brushes, which made contact of the circuits to external source or battery. And here we also provide magnet that rotate the rotor in magnetic field to use the electrical energy or store the electrical energy. It just happen when when electric machine is used as an electric generator.

5. Carbon Brushes in a DC machine

- Brushes are used to collect the electric charge from the armature. They must be supported by brush holders. The yoke and bearings provide mechanical support to the DC machine's spinning armature, allowing smooth, steady motion while mitigating friction.
- And purpose of carbon brushes to made the connection b/w the rotating commutator and stationary external load circuit.
- It is used to reduced sparking and provide the better connection.

The purpose of brushes is to ensure electrical connections between the rotating commutator and stationary external load circuit. The brushes are made of carbon and rest on the commutator. The brush pressure is adjusted by means of adjustable springs.



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

$$= \sqrt{10^2 + (31.41 - 21.22)^2}$$

$$= \underline{\underline{14.277 \Omega}}$$

$$X_L = 2\pi fL = 2\pi \times 50 \times 0.1$$

$$= 31.41 \Omega$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 50 \times 150 \times 10^{-6}}$$

$$= 21.22 \Omega$$

$$V = I \cdot Z$$

$$I = \frac{200}{14.27} = \underline{\underline{13.54 A}}$$

$$\cos \phi = \frac{R}{Z} \Rightarrow \frac{10}{14.27} = \underline{\underline{0.7}}$$

$$V_C = I \cdot X_C = 13.54 \times 21.22 = 287.3$$

$$V_{\text{coil}} = I \cdot Z_{\text{coil}} = 13.54 \times 32.9$$

$$= \underline{\underline{446.23}}$$

$$V_R = I \cdot R = 425.29 V$$

$$V_{CL} = I \cdot R_L = 135.4 V$$

5a)

Given: $P = 60 \text{ kW}$; $V_L = V_p = 400 \text{ V}$; $I_L = 200 \text{ A}$;

$$I_p = I_L / \sqrt{3} = 115.47 \text{ A}$$

$$Z = R + jX_L = Z \angle \phi$$

$$|Z| = \frac{V_p}{I_p} = \frac{400}{115.47} = 3.46 \Omega$$

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

$$\cos \phi = \frac{P}{\sqrt{3} V_L I_L} = \frac{60 \times 1000}{\sqrt{3} \times 400 \times 200} = 0.433$$

$$\phi = 64.34^\circ$$

$$\therefore Z = 3.46 \angle 64.34^\circ \quad (\text{use calculator})$$

$$= 1.49 + j 3.119$$

5.b

Shunt Motor :-

$$I_{sh} = \frac{V}{R_{sh}}$$

I_{sh} is constant with constant supply voltage and flux decreases slightly due to armature reaction. Thus flux is constant, (neglecting effect of armature reaction)

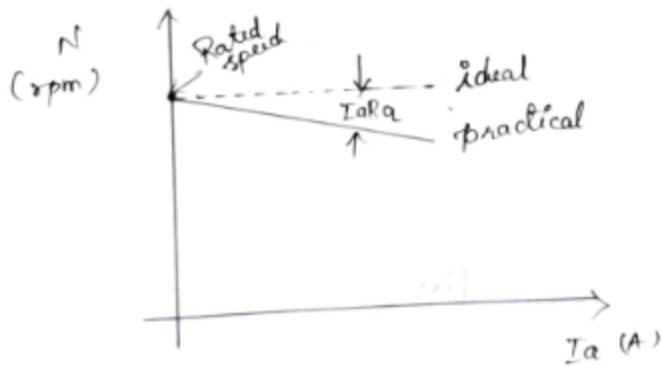
$$\text{Speed} = \frac{E_b}{K\phi}$$

$$N = \frac{V - I_a R_a}{K\phi}$$

$$N \propto \frac{V - I_a R_a}{\phi}$$

$N \propto V - I_a R_a$ (flux constant)
L> eqn of straight line with -ve slope.
... in armature

i.e. N decreases linearly with current.



* The decrease in speed from no load to full load is very small $\therefore$ the shunt motor may be taken as a constant speed motor.

Series Motor:

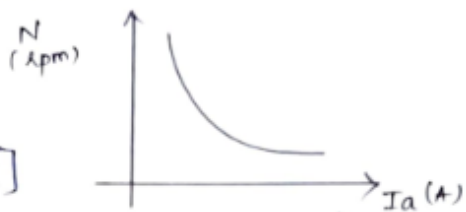
$$N \propto \frac{V - I_a(R_a + R_{se})}{\phi}$$

at low values of I_a , $I_a(R_a + R_{se})$ drop $\ll 1$

$$\therefore N \propto \frac{V}{\phi}$$

$$\propto \frac{1}{\phi} [\because V - \text{constant}]$$

$$N \propto \frac{1}{I_a} \quad (\phi \propto I_a \text{ in series motor})$$



For series motor, the speed is inversely proportional to the armature current.

DC series motors are used for applications where high starting torque is required like in electric locomotives, hoists & cranes, electric bikes and cars, etc.

DC shunt motors are used in applications where constant speed is required like in fans, blowers, elevators, centrifugal pumps, lath machines, etc.

$P = 4$, $R_g = 50 \Omega$, $R_{sh} = 0.1 \Omega$, 100V, 40W lamps.
 (S.C) $I_a = ?$, I/p , $E = ?$ contact brush drop $\sim 1V/p$.

$$E_{ng} = \frac{P \phi N Z}{60 A}$$

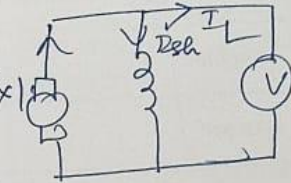
$$= 4 \times$$

$$V = E_g - I_a \cdot R_a - 2 \times 1$$

$$E_g = 400 + I_a \cdot 0.1 + 2$$

$$= 400 + 6 \times 0.1 + 2$$

$$= \underline{\underline{406V}} + 2 = \underline{\underline{408V}}$$



$$V_{sh} = I_{sh} \cdot R_{sh}$$

$$I_{sh} = \frac{100}{50} = 2A$$

$$I_{a \text{ parallel}} = \frac{6}{4} = \underline{\underline{1.5A}}$$

$$P = V \cdot I_L$$

$$400 = 100 \cdot I_L$$

$$I_L = \frac{400}{100} = 4A$$

$$I_a = I_{sh} + I_L$$

$$= \underline{\underline{6A}}$$

1.20 E.M.F. EQUATION OF A D.C. GENERATOR

We shall now derive an expression for the e.m.f. generated in a d.c. generator.

Let ϕ = flux/pole in Wb
 Z = total number of armature conductors
 P = number of poles
 A = number of parallel paths = 2 for wave winding
 $= P$ for lap winding
 N = speed of armature in r.p.m.
 E_g = e.m.f. of the generator = e.m.f./parallel path

Flux cut by one conductor in one revolution of the armature,

$$d\phi = P \phi \text{ webers}$$

Time taken to complete one revolution,

$$dt = 60/N \text{ second}$$

$$\text{e.m.f. generated/conductor} = \frac{d\phi}{dt} = \frac{P \phi}{60/N} = \frac{P \phi N}{60} \text{ volts}$$

$$\begin{aligned} \text{e.m.f. of generator, } E_g &= \text{e.m.f. per parallel path} \\ &= (\text{e.m.f./conductor}) \times \text{No. of conductors in series per parallel path} \\ &= \frac{P \phi N}{60} \times \frac{Z}{A} \end{aligned}$$

$$\therefore E_g = \frac{P \phi Z N}{60 A}$$

where

$$\begin{aligned} A &= 2 \\ &= P \end{aligned}$$

... for wave winding

... for lap winding

6.b speed can be varied by changing:

1. The terminal voltage of the armature, V .
2. The external resistance in armature circuit, R_a .
3. The flux per pole, ϕ .

Terminal voltage and external resistance involve a change that affects the armature circuit, while flux involves a change in the magnetic field. Therefore speed control of DC motor can be classified into:

1. Armature Control Methods
2. Field Control Methods

We will discuss how both of these methods control the speed of **DC series motors** and **DC shunt motors**.

Speed Control of DC Series Motor

Speed control methods for a DC series motor can be classified as:

1. Armature Control Methods
2. Field Control Methods

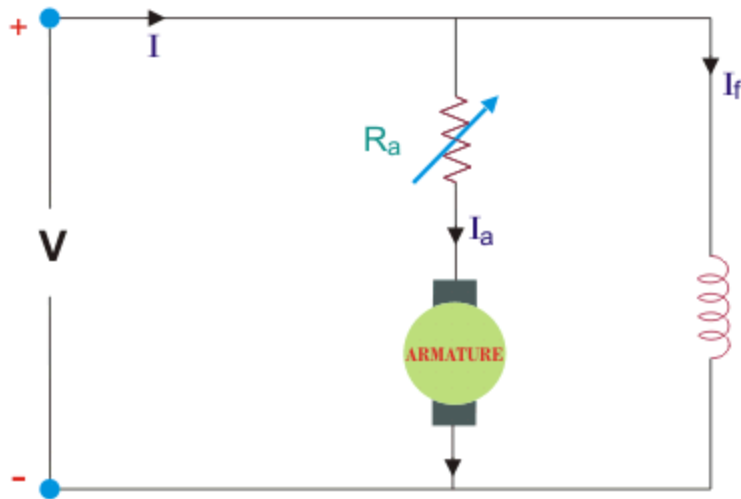
Armature Controlled DC Series Motor

Speed adjustment of a DC series motor by **armature control** may be done by:

1. Armature Resistance Control Method
2. Shunted Armature Control Method
3. Armature Terminal Voltage Control

Armature Resistance Control Method

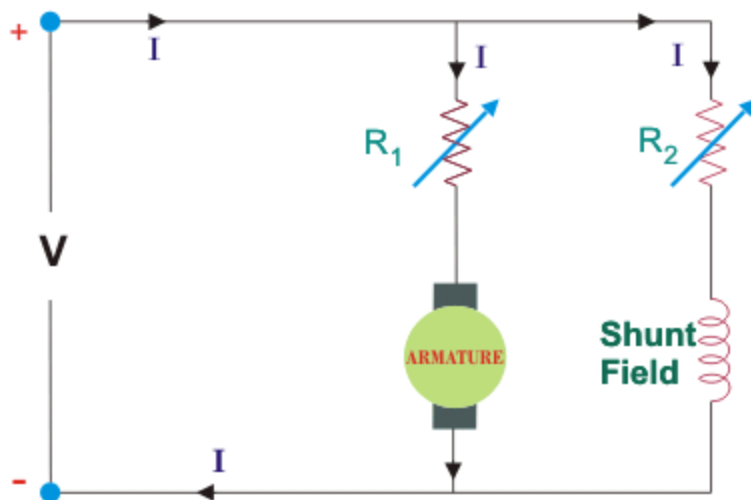
This common method involves connecting a controlling resistance directly in series with the motor's supply, as illustrated in the figure.



The power loss in the control resistance of DC series motor can be neglected because this control method is utilized for a large portion of time for reducing the speed under light load condition. This method of speed control is most economical for constant torque. This method of speed control is employed for **DC series motor** driving cranes, hoists, trains etc.

Shunted Armature Control

The combination of a rheostat shunting the armature and a rheostat in series with the armature is involved in this method of speed control. The voltage applied to the armature is varies by varying series rheostat R_1 . The exciting current can be varied by varying the armature shunting resistance R_2 . This method of speed control is not economical due to considerable power losses in speed controlling resistances. Here speed control is obtained over wide range but below normal speed.



Armature Terminal Voltage Control

Speed control of DC series motors can be achieved by using a separate variable voltage supply, although this method is costly and thus rarely used.

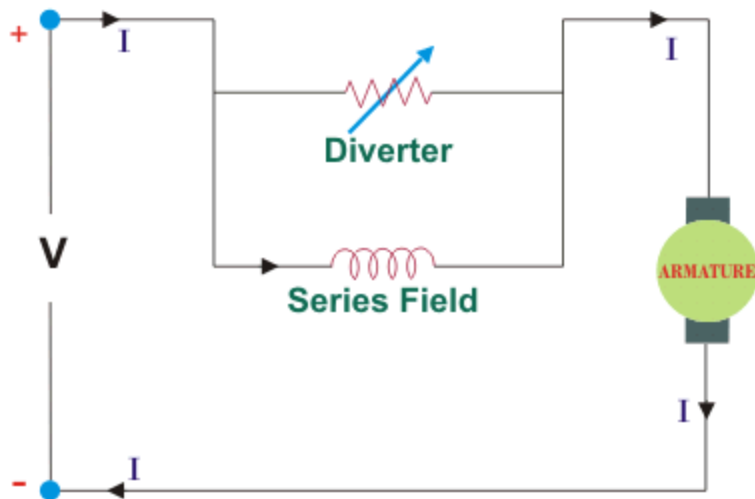
Field Controlled DC Series Motor

Speed adjustment of a DC series motor by **field control** may be done by:

1. Field Diverter Method
2. Tapped Field Control

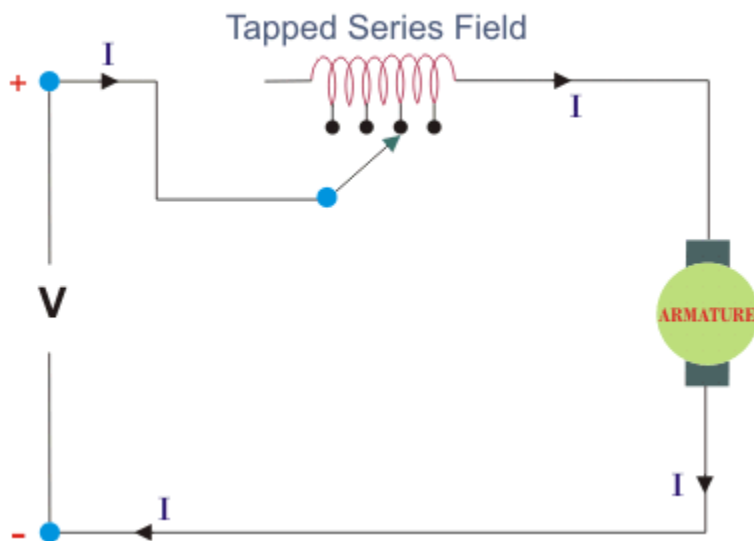
Field Diverter Method

This method uses a diverter. Here the field flux can be reduced by shunting a portion of motor **current** around the series field. Lesser the diverter resistance less is the field current, less flux therefore more speed. This method gives speed above normal and the method is used in **electric drives** in which speed should rise sharply as soon as load is decreased.



Tapped Field Control

This is another method of increasing the speed by reducing the **flux** and it is done by lowering number of turns of field winding through which current flows. In this method a number of tapping from field winding are brought outside. This method is employed in electric traction.



Speed Control of DC Shunt Motor

The classification of **speed control methods for a DC shunt motor** are similar to those of a DC series motor. These two methods are:

1. Armature Control Methods
2. Field Control Methods

Armature Controlled DC Shunt Motor

Armature controlled DC shunt motor can be performed in two ways:

1. Armature Resistance Control
2. Armature Voltage Control

Armature Resistance Control

In armature resistance control a variable resistance is added to the armature circuit. Field is directly connected across the supply so **flux** is not changed due to variation of series resistance. This is applied for DC shunt motor. This method is used in printing press, cranes, hoists where speeds lower than rated is used for a short period only.

Armature Voltage Control

This method of speed control needs a variable source of voltage separated from the source supplying the field current. This method avoids disadvantages of poor speed regulation and low efficiency of armature-resistance control methods.

Field Controlled DC Shunt Motor

By this method a DC Shunt motor's speed is controlled through a field rheostat.

Field Rheostat Controlled DC Shunt Motor

This method controls speed by inserting a variable resistance in series with the shunt field, which decreases the field current and flux but increases speed. It operates independently of motor load and wastes minimal power due to the low field current. This method of speed control is also used in **DC compound motor**.

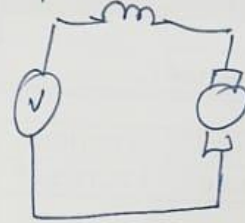
6.c) $Z = 864$, $I = 110A$, $V = 480V$ $R_a = 0.18\Omega$ $R_g = 0.02\Omega$

$\phi/p = 50mwb.$ $N = ?$, $T = ?$

$$E_b = \frac{P\phi NZ}{60A}$$

$$N = \frac{458 \times 60 \times 6}{6 \times 50 \times 10^{-3} \times 864}$$

$$= 636.111 \text{ rpm.}$$



$$V = I_a(R_{se} + R_a)$$

$$E_b = V - I_a(R_s)$$

$$= 480 - 110(0)$$

$$= \underline{458V}$$

$$T = \frac{0.159 \times P\phi \cdot I_a \cdot Z}{A}$$

$$= \underline{755.568 \text{ N-m}}$$

7 a) Derive the e.m.f. equation of a transformer & transformation ratio

Let the sinusoidal mutual flux in the core be

$$\phi = \Phi_m \sin \omega t.$$

Induced e.m.f. in a coil of N turns:

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

Peak value $E_{\max} = N\omega\Phi_m = N(2\pi f)\Phi_m$.

For a sinusoid, $E_{\text{rms}} = E_{\max}/\sqrt{2}$:

$$E = 4.44 f N \Phi_m \quad \text{volts}$$

Hence for primary and secondary:

$$E_1 = 4.44 f N_1 \Phi_m, \quad E_2 = 4.44 f N_2 \Phi_m$$

So the **transformation ratio**:

$$k = \frac{E_2}{E_1} = \frac{N_2}{N_1} \approx \frac{V_2}{V_1}$$

($k > 1$ step-up, $k < 1$ step-down).

b) Principle of operation of a 3- ϕ induction motor & why it can't run at synchronous speed

- A balanced 3-phase supply in the stator produces a **rotating magnetic field (RMF)** of constant magnitude rotating at **synchronous speed**

$$N_s = \frac{120f}{P} \text{ r.p.m.}$$

- The RMF cuts the rotor conductors and **induces e.m.f.**; rotor currents interact with the RMF to produce torque (Lorentz force).
- Rotor speed N is always less than N_s . The **slip**

$$s = \frac{N_s - N}{N_s}$$

provides relative motion to induce rotor e.m.f.

Why not at synchronous speed?

If $N = N_s \Rightarrow s = 0$. Then relative speed between rotor and RMF is zero $\rightarrow$ **no induced rotor e.m.f., no rotor current, no torque**. With only losses present, speed drops below N_s until torque is produced again. Hence an induction motor **cannot** run at N_s .

c)

A 600 kVA, 1- ϕ transformer has 92% efficiency at both full load and half-load, unity p.f. Find its efficiency at 75% load, 0.9 pf.

Let core loss P_c (constant) and full-load copper loss $P_{cu,FL}$.

From full load (output = 600 kW, $\eta = 0.92$):

$$0.92 = \frac{600}{600 + P_c + P_{cu,FL}}$$

From half load (output = 300 kW, copper loss = $0.25P_{cu,FL}$):

$$0.92 = \frac{300}{300 + P_c + 0.25P_{cu,FL}}$$

Solving,

$$P_c \approx 17.39 \text{ kW}, \quad P_{cu,FL} \approx 34.78 \text{ kW}$$

At 75% load: output = $0.75 \times 600 \times 0.9 = 405$ kW, copper loss = $0.75^2 P_{cu,FL} = 0.5625 \times 34.78 \approx 19.57$ kW.

Total losses = $P_c + P_{cu} \approx 17.39 + 19.57 = 36.96$ kW.

$$\eta_{75\%,0.9} = \frac{405}{405 + 36.96} \approx 91.6\%$$

8 a) Define slip and derive the expression for frequency of rotor current

Rotor speed and slip:

In induction motor, the rotor field is always less than RMF N_s . $N_r < N_s$

The difference b/w N_s and N_r is called slip and is usually expressed as a percentage of N_s .

$$\text{i.e. } \% S = \frac{N_s - N_r}{N_s} \times 100$$

Scanned with CamScanner

- ∴ ... the rotor is stationary, ... at
- (i) $N_r = 0$, $\text{slip} = \frac{N_s}{N_s} = 1$. standstill condition
 - (ii) $N_r = N_s$, $\text{slip} = 0$, (never happens in IM)

Frequency of the rotor induced emf:

The frequency of induced voltage (current) due to relative speed b/w rotor winding and magnetic field is given by,

$$\text{Frequency} = \frac{p \times \text{relative speed}}{120}$$

where N_r = relative speed b/w magnetic field and the winding.
 p = no. of poles.

For a rotor speed N_r , the relative speed b/w the rotating flux and rotor is $N_s - N_r$.

∴ Let f' be the rotor current frequency.

$$f' = \frac{(N_s - N_r) \times p}{120}$$

$$= \frac{N_s p}{120} \times S$$

$$\therefore f = \frac{N_s p}{120}$$

$$\therefore S = \frac{N_s - N_r}{N_s}$$

$$\boxed{f' = S f}$$

i.e. rotor current frequency
 = slip $\times$ supply frequency.

8 b) Losses in transformer and condition for maximum efficiency

LOSSES IN TRANSFORMER:- (7)

```

graph TD
    A[LOSSES IN TRANSFORMER] --> B[Copper losses]
    A --> C[Core losses]
    
```

Copper loss (variable loss) W_{cu}

→ Cu losses occur in a conductor carrying current. The losses depends on load current drawn by the load. hence it is known as variable loss.

→ These losses occur in both primary and secondary windings

cu loss in 1 $= I_1^2 R_1$
 cu loss in 2 $= I_2^2 R_2$

Total cu loss $= I_1^2 R_1 + I_2^2 R_2$
 $= I_1^2 R_{01}$
 $= I_2^2 R_{02}$

where R_{01} or R_{02} = equivalent resistance referred to 1 and 2 sides respectively.

Core or Iron losses:- W_i

↳ hysteresis + eddy current losses - occur in the core due to the alternating flux.

* These losses depends upon flux (B_m) in the core and supply frequency since ϕ and f are constant in transformer, these losses are also constant. Hence called as constant or core loss.

Eddy current loss:-

* Core is made up of ferro-magnetic material which constitutes single short circuited turns throughout its entire length.

* Therefore the induced emf give rise to current called eddy current which circulates in the core giving rise to heat loss.

$$W_e = k_e B_m^2 f^2 t^2 V$$

t - thickness of lamination.

eddy currents can be minimized by dividing the solid core into thin sheets - laminations.

Hysteresis loss:-

When alternating flux flows thro windings, the core undergoes cycle of magnetisation and demagnetisation. The difference between these two energies is dissipated in the core as heat loss called hysteresis loss.

$$W_h = k_h B_m f V$$

eddy current loss varies as the square of the frequency, whereas hysteresis loss varies directly with the frequency.

Efficiency of a transformer:-

$$\text{Efficiency} = \frac{\text{output power}}{\text{input power}}$$

$$= \frac{\text{output power}}{\text{output power} + \text{losses}}$$

$$\eta = \frac{V_2 I_2 \cos \phi}{V_2 I_2 \cos \phi + W_{cu} + W_i} \quad \text{--- (1)}$$

The fraction of load can be expressed as,

$$x = \frac{I_2}{I_{2fl}} \quad \text{--- (2)}$$

I_2 - secondary or load current
 I_{2fl} - full-load secondary current

$$W_{cu} = \text{total cu loss} \\ = I_2^2 R_{02}$$

R_{02} - equivalent resistance referred to secondary.

$$(W_{cu})_{fl} = \text{total full load cu loss} \\ = I_{2fl}^2 R_{02}$$

$$\frac{W_{cu}}{(W_{cu})_{fl}} = \frac{I_2^2 R_{02}}{I_{2fl}^2 R_{02}} \Rightarrow \left[\frac{I_2}{I_{2fl}} \right]^2 \Rightarrow x^2$$

$$W_{cu} = x^2 (W_{cu})_{fl} \quad \text{--- (3)}$$

② and ③ in eqn ①.

$$\eta = \frac{V_2 \alpha I_{2fl} \cos \phi}{V_2 \alpha I_{2fl} \cos \phi + \alpha^2 (W_{cu})_{fl} + W_i}$$

$$\eta = \frac{\alpha V_2 I_{2fl} \cos \phi}{\alpha V_2 I_{2fl} \cos \phi + \alpha^2 (W_{cu})_{fl} + W_i} \quad \text{--- ④}$$

Condition for maximum efficiency:-

÷ ④ by α ,

$$\eta = \frac{V_2 I_{2fl} \cos \phi}{V_2 I_{2fl} \cos \phi + \alpha (W_{cu})_{fl} + \frac{W_i}{\alpha}}$$

$$\frac{d\eta}{d\alpha} = 0,$$

$$\frac{d}{d\alpha} \left[\alpha (W_{cu})_{fl} + \frac{W_i}{\alpha} \right] = 0.$$

$$(W_{cu})_{fl} - \frac{W_i}{\alpha^2} = 0.$$

$$(W_{cu})_{fl} = \frac{W_i}{\alpha^2}$$

$$\alpha = \sqrt{\frac{W_i}{(W_{cu})_{fl}}}$$

8 c)

(i) Synchronous speed

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

(ii) Slip

$$s = \frac{N_s - N}{N_s} = \frac{1500 - 1470}{1500} = 0.02 = 2\%$$

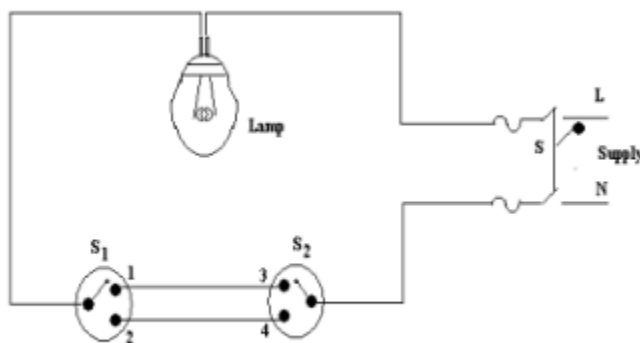
(iii) Rotor induced-emf frequency

$$f_r = s f = 0.02 \times 50 = 1 \text{ Hz}$$

Answer: $N_s = 1500 \text{ rpm}$, $s = 2\%$, $f_r = 1 \text{ Hz}$.

9 a) Two way and three way control of lamp

Two- way and Three- way Control of Lamps: The domestic lighting circuits are quite simple and they are usually controlled from one point. But in certain cases it might be necessary to control a single lamp from more than one point (Two or Three different points). For example: staircases, long corridors, large halls etc. (i)Two-way Control of lamp: Two-way control is usually used for staircase lighting. The lamp can be controlled from two different points: one at the top and the other at the bottom - using two- way switches which strap wires interconnect. They are also used in bedrooms, big halls and large corridors. The circuit is shown in the following figure.



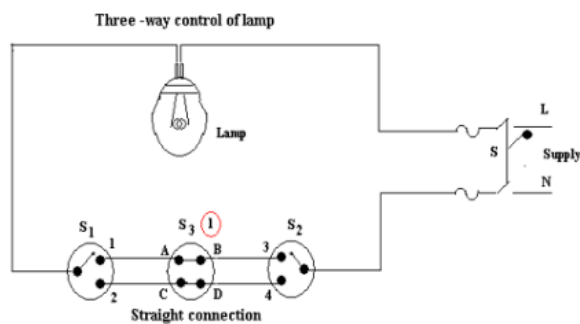
Two -way control of lamp

Switches S1 and S2 are two-way switches with a pair of terminals 1&2, and 3&4 respectively. When the switch S1 is in position 1 and switch S2 is in position 4, the circuit does not form a closed loop and there is no path for the current to flow and hence the lamp will be OFF. When S1 is changed to position 2 the circuit gets completed and hence the lamp glows or is ON. Now if S2 is changed to position 3 with S1 at position 2

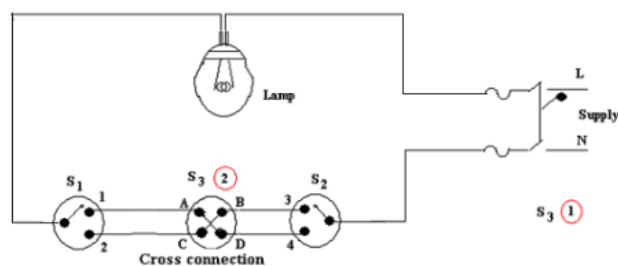
the circuit continuity is broken and the lamp is off. Thus the lamp can be controlled from two different points.

Three- way Control of lamp:

In case of very long corridors it may be necessary to control the lamp from 3 different points. In such cases, the circuit connection requires two; two-way switches S_1 and S_2 and an intermediate switch S_3 . An intermediate switch is a combination of two, two way switches coupled together. It has 4 terminals ABCD. It can be connected in two ways: a) Straight connection b) Cross connection In case of straight connection, the terminals or points AB and CD are connected as shown in figure 1 while in case of cross connection, the terminals AB and CD are connected as shown in figure 2. As explained in two ways, control the lamp is ON if the circuit is complete and is OFF if the circuit does not form a closed loop.



The condition of the lamp depends on the positions of the switches S_1 , S_2 , and S_3 .



9 b) Short notes on fuse and MCB

Fuse

- A fuse is a safety device used to protect electrical circuits from overcurrent or short circuits.
- It consists of a thin wire or strip of low melting point metal (like tin, lead, zinc, or copper alloy).
- When the current exceeds the rated value, the fuse element melts due to heat, thereby breaking the circuit.
- It is simple, inexpensive, and provides fast protection.
- Limitation: Once blown, it must be replaced with a new one.

MCB (Miniature Circuit Breaker)

- An MCB is an electromechanical switch that automatically turns off the circuit during overcurrent or short circuit.
- It uses bimetallic strips (for overload) and an electromagnetic coil (for short circuit) to trip the switch.
- Unlike a fuse, an MCB can be reset manually after tripping; no replacement is needed.
- Provides better sensitivity and reliability than fuses.
- Commonly used in domestic, commercial, and industrial wiring systems.

9 c) Explain the necessity of earthing. Explain pipe earthing with neat diagram

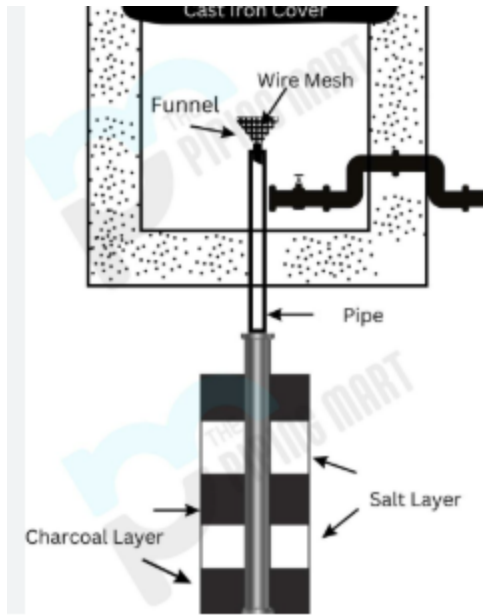
Necessity of Earthing

- Earthing (or grounding) is the process of connecting non-current carrying parts of electrical equipment (metallic body, frames, enclosures) to the earth.
- It is essential because:

1. Safety of human beings – Prevents electric shock if the metal body becomes live due to insulation failure.
2. Safety of equipment – Provides a low-resistance path for fault current, protecting appliances from damage.
3. Protection of building/wiring – Reduces risk of fire hazards from leakage or fault currents.
4. Ensures proper operation of protective devices – Helps fuses and MCBs operate quickly by providing a return path.
5. Maintains potential – Keeps exposed metallic parts at earth potential, avoiding dangerous voltage rise.

Pipe Earthing

- One of the most common and effective methods of earthing.
- A galvanized iron (GI) pipe of 2–3 meters length (40 mm diameter) is buried vertically in a pit filled with alternate layers of charcoal and salt, which improve conductivity.
- The earthing wire (GI or copper) from the equipment is connected to the top of the pipe with a nut–bolt arrangement.
- Water is poured periodically through a pipe to maintain soil moisture and reduce resistance.



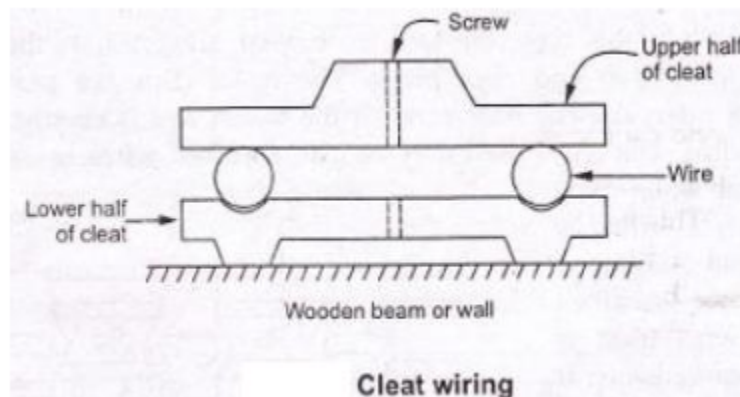
Construction Steps

1. Dig a pit of about 2–3 meters depth.
2. Place a GI pipe vertically in the pit.
3. Surround the pipe with layers of charcoal and salt.
4. Connect the earthing conductor to the GI pipe with a clamp.
5. Provide a funnel with a cover for watering to maintain conductivity.

10 a) Explain different types of wiring system.

Electrical wiring done in residential and commercial buildings to provide power for lights, fans, pumps and other domestic appliances is known as domestic wiring. There are several wiring systems in practice. They can be classified into: Types of wiring: Depending upon the above factors various types of wiring used in practice are: 1. Cleat wiring 2. Casing wiring 3. Surface wiring 4. Conduit wiring i) Cleat wiring: In this type V.I.R or P.V.C wires are clamped between porcelain cleats. The cleats are made up of two halves. One half is grooved through which wire passes while the other fits over the

first. The whole assembly is then mounted on the wall or wooden beam with the help of screws.



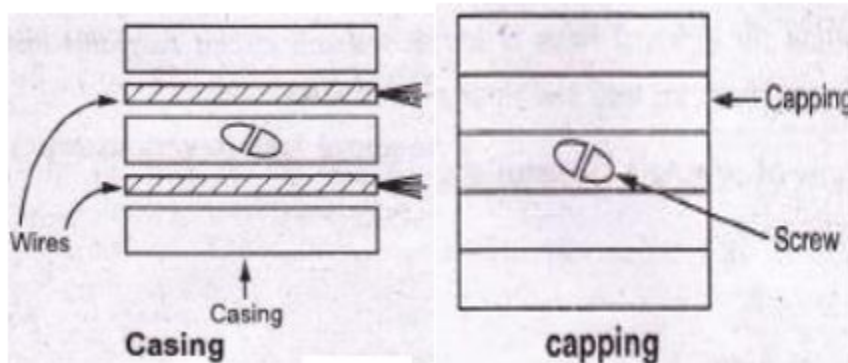
Advantages:

1. This method is one of the cheapest method and most suitable for temporary work.
2. It can be very quickly installed and can be recovered without any damage of material.
3. Inspection and changes can be made very easily.

Disadvantages:

1. This method does not give attractive appearance. After some time due to sagging at some places, it looks shabby.
2. Dust and dirt collects on the cleats.
3. The wires are directly exposed to atmospheric conditions like moisture, chemical fumes etc. maintenance cost is very high. Due to these disadvantages this type is not suitable for permanent jobs.

ii) Casing capping: This is very popularly used for residential buildings. In this method, casing is a rectangular strip made from teak wood or modern days PVC. It has 2 grooves into which the wires are laid. Then the casing is covered with a rectangular strip of wood or P.V.C. of the same width, called capping. The capping is screwed into casing and is fixed to the walls with the help of porcelain discs or cleats.



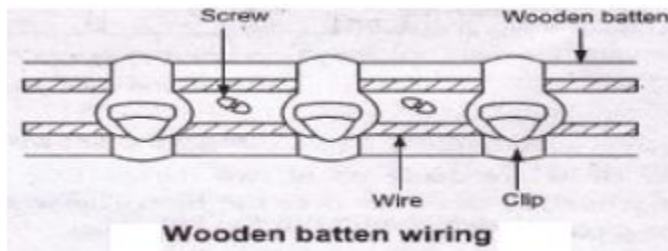
Advantages:

1. neat and clean appearance
2. Good protection to the conductors from dangerous atmospheric conditions

Disadvantages:

1. In case of wooden casing capping, there is a high risk of fire. Requirement of skilled labor.
2. The method is costly.

(iii) Surface wiring: In this type, the wooden battens are fixed on the surface of the wall, by means of screws and rawl plugs. The metal clips are provided with the battens at regular intervals. The wire runs on the batten and is clamped on the batten using the metal clips. The wires used may be lead sheathed wires or can tyre sheathed wires. Depending upon type of wire used surface wiring is also called lead sheathed wiring or can tyre sheathed wiring. If the wire used is though rubber Sheathed then it is called T.R.S. wiring while if the wire used is can tyre Sheathed then it is called C.T.S wiring.



10 b) What is electric shock? What are the precautions to be taken to prevent electric shock?

Electric shock is a jarring, shaking sensation resulting from contact with electric circuits or from the effects of lightning. The victim usually feels that he or she received a sudden blow, if the voltage and resulting current is sufficiently high, the victims may become unconscious. Severe burns may appear on the skin at the place of contact muscular spasm may occur, causing the victim to clasp the apparatus or wire which causes the shock and be unable to turn it loose.

- The amount of current that may pass through the body without danger depends on the individual or current quantity, type, path and length of contact time.

- Body resistance varies from 1000 to 5, 00,000 ohms for unbroken dry skin. Resistance as low as 5milliamperes can be dangerous. If the palm of the hand makes contact with the conductor, a current of about12 milli amperes will tend to cause the hand muscles to contract, freezing the body to the conductor. Such a shock may not cause serious damage, depending on the contact time and your physical condition, particularly the condition of your heart. A current of 25milliamperes has been known to be fatal. Due to the physiological and chemical nature of the human body, five times more direct current than

alternating current is needed to freeze the same body to a conductor. Also 50-hertz (cycles per second) alternating current is about the most dangerous frequency. This is normally used in residential, commercial and industrial power.

Precautions to Prevent Electric Shock

1. Proper Earthing (Grounding):

- Always ensure electrical appliances and wiring are properly earthed to provide a safe path for leakage current.

2. Use of Protective Devices:

- Install fuses, MCBs, RCCBs (Residual Current Circuit Breakers) to disconnect supply in case of faults or leakage.

3. Good Quality Wiring and Insulation:

- Use wires with proper insulation and correct current rating.
- Avoid damaged or frayed wires.

4. Avoid Overloading:

- Do not connect too many appliances on a single socket; overheating may damage insulation.

5. Dry Hands and Feet:

- Never touch electrical equipment or switches with wet hands or while standing on a wet floor.

6. Use Proper Plugs and Sockets:

- Never insert bare wires into sockets.
- Ensure plugs fit tightly.

7. Switch OFF Before Maintenance:

- Always disconnect power before repairing or cleaning electrical appliances.
8. Keep Away from Live Wires:
- Never touch hanging or exposed live conductors.
 - Maintain safe distance from power lines.
9. Use Safety Equipment:
- Wear rubber gloves and shoes while handling electrical systems.
 - Use insulated tools for electrical work.
10. Awareness and Training:
- Educate people about safe handling of electricity.
 - Display warning signs in hazardous areas.

10 c) Define “unit” used for consumption of electrical energy and explain the two part tariff. Mention the advantages and disadvantages

Unit of Electrical Energy

- Electrical energy consumed is measured in kilowatt-hour (kWh).
- 1 unit = 1 kWh = the energy consumed when 1 kilowatt (1000 W) of power is used for 1 hour.
- Example: If a 100 W bulb burns for 10 hours → Energy consumed = $100 \times 10 = 1000 \text{ Wh} = 1 \text{ kWh} = 1 \text{ unit}$.

Two-Part Tariff

- In electricity billing, a two-part tariff is a system where the consumer is charged under two heads:
 1. Fixed Charge (kW or kVA basis):
 - Depends on the maximum demand (connected load or peak demand).
 - Covers capital investment, maintenance, and fixed operating costs.
 2. Running/Variable Charge (per kWh):
 - Depends on actual energy consumed (units used).
 - Covers fuel cost and variable expenses of generation and supply.

So, Total charge = Fixed charge + (Energy consumed $\times$ Rate per unit)

Advantages of Two-Part Tariff

1. Equitable $\rightarrow$ Large consumers pay more due to higher demand.
2. Recovers both fixed costs (infrastructure) and running costs (fuel, supply).
3. Encourages efficient use of electricity since consumers are aware of unit charges.
4. Provides steady income to supply company (through fixed part).

Disadvantages of Two-Part Tariff

1. Small consumers may feel burdened by fixed charges even with low consumption.
2. Calculation of maximum demand requires special meters (expensive).
3. May seem complicated to ordinary consumers compared to a simple per-unit charge.