CBCS SCHEME

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BESCK104B

First Semester B.E./B.Tech. Degree Examination, Dec.2024/Jan.2025

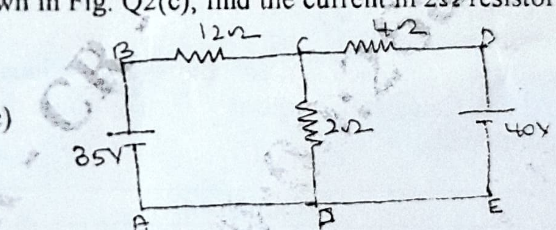
Introduction to Electrical Engineering

Time: 3 hrs. Max. Marks: 100

Note: 1. Answer any FIVE full questions, choosing ONE full question from each module.
2. M : Marks , L: Bloom's level , C: Course outcomes.

		Module – 1	M	L	C
Q.1	a.	With neat single line diagram, explain the various steps of electrical power transmission and distribution system.	8	L2	CO1
	b.	State and explain Kirchoff's current and voltage law.	6	L2	CO1
	c.	A resistance R is connected in series with a parallel circuit comprising of two resistance 12Ω and 8Ω. The total power in the circuit is 70W when the applied voltage is 20V. Calculate R.	6	L3	CO1
		OR			
Q.2	a.	With block diagram, explain Hydel Power generation.	6	L2	CO1
	b.	State and explain Ohm's law with its limitation.	6	L3	CO1
	c.	For the circuit shown in Fig. Q2(c), find the current in 2Ω resistor.	8	L3	CO1

Fig. Q2(c)



		Module – 2	M	L	C
Q.3	a.	Define the following terms applied to alternating current wave : i) RMS value ii) Average value iii) Form factor iv) Peak factor v) Phase vi) Phase difference.	6	L3	CO2
	b.	Show that the current through purely capacitive circuit leads the applied voltage by 90° and average power consumed is zero. Draw the wave shapes of current voltage and power.	8	L3	CO2
	c.	An Inductive coil takes a current of 10A from a supply of 100V, 50Hz and lags the voltage of 30°. Calculate i) Parameters of the circuit ii) Power factor iii) Active reactive and apparent power.	6	L2	CO2
		OR			
Q.4	a.	Explain the generation of three phase A.C. and list the advantage.	6	L2	CO2

	b.	A circuit consists of a resistance of 20Ω and inductance of 0.05H, connected in series. A single phase supply of 230V, 50kg is applied across the circuit. Find i) Impedance ii) Current iii) Power factor iv) Power consumed by the circuit v) Voltage drop across R & L.	8	L3	CO2
	c.	Three coils having resistance of 10Ω and inductance of 0.02H are connected in star across 440V, 50Hz, 3 – ϕ supply. Calculate the line current, p.f and total power consumed.	6	L3	CO2
		Module – 3			
Q.5	a.	Derive E.M.F equation of the DC generator.	6	L3	CO3
	b.	Explain the characteristics of a D.C. shunt motor.	7	L2	CO3
	c.	A 4 pole, 1500 rpm, D.C generator has a lap wound armature having 32 slab and 8 conductor per slot. If the flux per pole is 0.04 wb. Calculate the emf induced in the armature. What would be the emf induced if the winding is wave connected.	7	L3	CO3
		OR			
Q.6	a.	Derive Torque equation of the D.C motor.	6	L3	CO3
	b.	Explain the various methods used to control the speed of DC series motor.	8	L2	CO3
	c.	A 4 – pole D C shunt motor takes 25A from a 250V supply. The armature and field resistances are 0.5Ω and 12Ω respectively. The wave wound armature has 30 slots and each slot containing 10 conductors, if the flux per pole is 0.02 wb. Calculate i) speed ii) torque developed iii) power developed.	6	L3	CO3
		Module – 4			
Q.7	a.	Derive the emf equation of a transformer and hence obtain the voltage and current transformation ratios.	8	L2	CO4
	b.	With neat diagram, explain the types of 3 – ϕ induction motor.	7	L2	CO4
	c.	A transformer is rated at 100KVa. At full load its copper loss is 1200w and its iron loss is 960W. Calculate the following: i) the efficiency at full load, VPF ii) the efficiency at half load, 0.8 pf. iii) the load KVA at which maximum efficiency will occur. iv) maximum efficiency at 0.85 p.f.	5	L3	CO4
		OR			
Q.8	a.	Explain the various losses in transformer, how to minimize them?	8	L2	CO4
	b.	With diagrams, explain the concept of rotating magnetic field.	8	L2	CO4
	c.	A three phase induction motor with 4 pole is supplied from the alternator having 6 poles running at 1000 rpm. Calculate Synchronous speed, rotor speed of the induction motor when slip is 0.04 and frequency of the rotor emf when the speed is 600 rpm.	4	L3	CO4

		Module – 5			
Q.9	**a.**	With neat circuit diagram and switching table explain two way and three way control of load.	**8**	**L2**	**CO5**
	b.	Explain working principle of fuse and miniature circuit breaker.	**7**	**L2**	**CO5**
	c.	What is earthing? With neat diagram, explain any one type of earthing.	**5**	**L2**	**CO5**
		OR			
Q.10	**a.**	What is Electric shock? Give the list of preventive measures against shock.	**6**	**L2**	**CO5**
	b.	What are the desirable characteristics of a tariff and explain two part tariff.	**6**	**L2**	**CO5**
	c.	List out the power rating of home hold appliances including air conditioners , PCs, laptops , printers etc. Find the total power consumed.	**8**	**L3**	**CO5**

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1.a Electrical power transmission and distribution system can be divided into several steps, including:

1. Generation: Electricity is generated at power stations using various sources such as coal, natural gas, nuclear energy, hydroelectricity, wind, or solar energy.
2. Step-up transformers: The voltage of the generated power is stepped up using step-up transformers to reduce energy losses during long-distance transmission.
3. Transmission: High-voltage transmission lines are used to transmit the electricity over long distances from the power station to the substations.
4. Substations: At the substations, the voltage is stepped down using step-down transformers for local distribution.
5. Distribution: Low-voltage distribution lines are used to distribute the electricity to residential, commercial, and industrial consumers.
6. Distribution transformers: At the end of the distribution lines, distribution transformers are used to step down the voltage to the levels suitable for consumer use.
7. Consumption: The electricity is finally consumed by various appliances and devices in homes, businesses, and industries.

Overall, electrical power transmission and distribution system involves the generation, transmission, distribution, and consumption of electricity to meet the needs of the society.

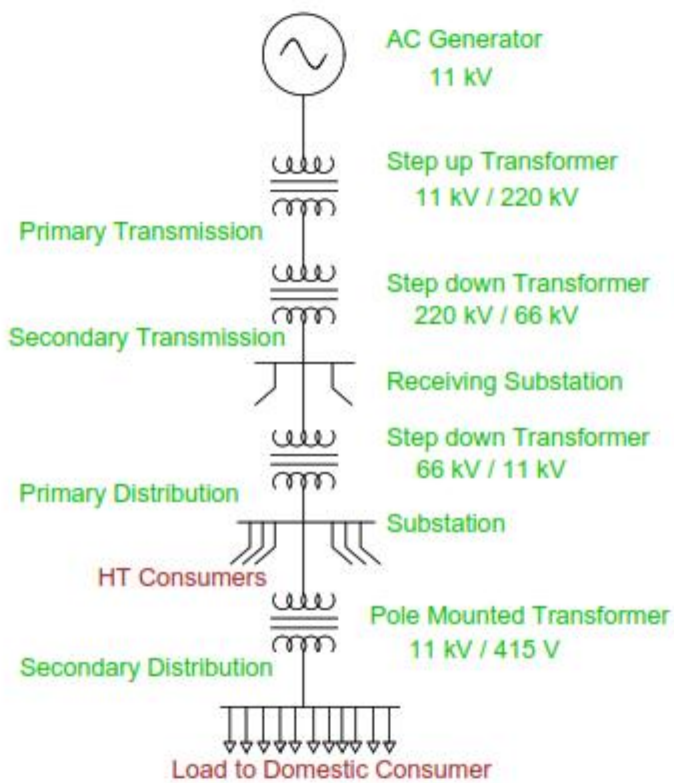

FIG : Single Line Diagram of Power Supply System

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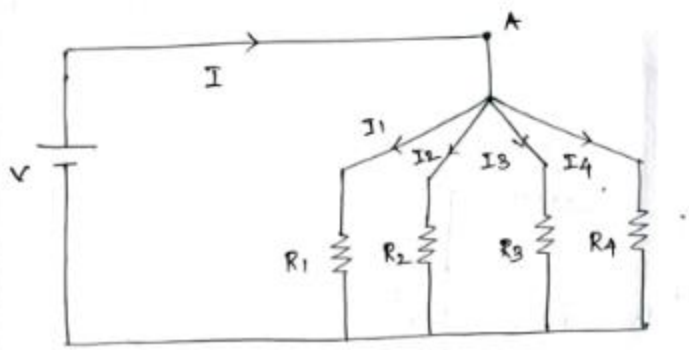
1.b

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 $\Sigma I = 0$.

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

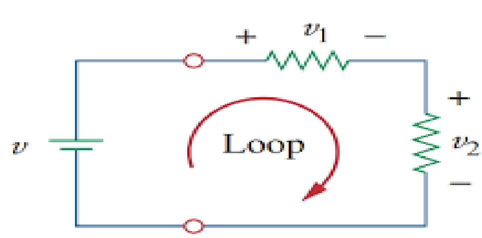


$$I = I_1 + I_2 + I_3 + I_4$$

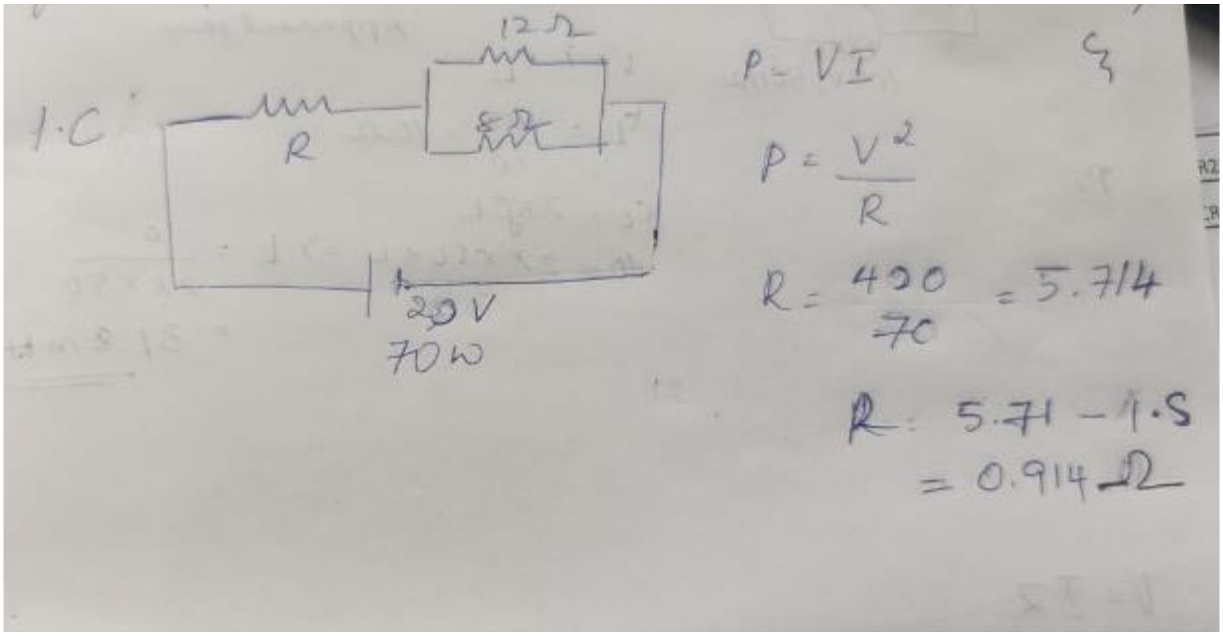
KIRCHHOFF'S VOLTAGE / MESH LAW: [KVL]

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

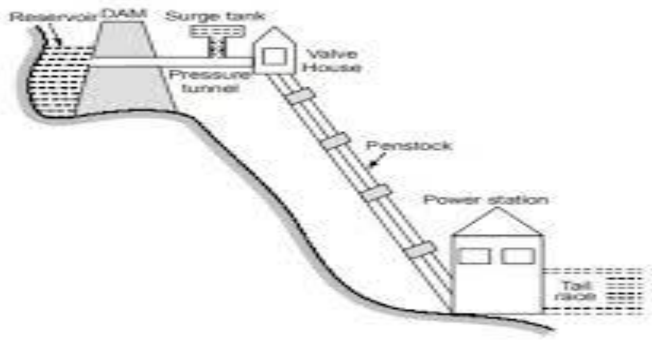
$$\Sigma IR + \Sigma e.m.f = 0.$$



$$KVL: \; -v + v_1 + v_2 = 0$$



2a.
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.

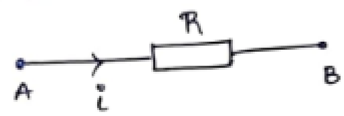


(a)

2B.

OHM'S LAW :- (Dr. George Simon

→ The potential difference between two ends of a conductor is directly proportional to the current flowing through it, provided temperature and other physical parameters remain constant.



$V \propto I$ — (1)

$V = IR$

R – constant of proportionality (resistance of the conductor)

unit ohm Ω

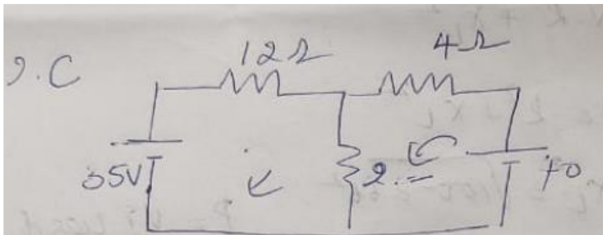
∴ ohm's law,

Limitations - OHM'S LAW

1) It cannot be applied to non-linear devices like diodes, zener diodes, transistors, voltage regulator etc.
2) Ohm's law is applicable as long as temperature and other physical parameters remains constant
3) It cannot be applied to complicated ckts having more no of branches and emf sources.
4) Not suitable for non-metallic conductors like silicon carbide, graphite etc.

2.C

2.C



$$35 = 12I_1 + 2(I_1 + I_2)$$
$$40 = 4I_2 + 2(I_2 + I_1)$$

$$14I_1 + 2I_2 = 35$$
$$2I_1 + 6I_2 = 40$$

$$I_1 = \frac{13}{8} = 1.625A \qquad I_2 = \frac{49}{8} = 6.125A$$

$$I_{2\Omega} = (I_1 + I_2)$$
$$= \underline{\underline{7.5A}}$$

Module – 2

Q.3	a.	Define the following terms applied to alternating current wave : i) RMS value ii) Average value iii) Form factor iv) Peak factor v) Phase vi) Phase difference.	6	L3	CO2

Root - Mean - Square (R.M.S) Value OR Effective Value :

The r.m.s or effective value, of an alternating current is defined as that steady current which when flowing through a given resistance for a given time produces the same amount of heat as produced by the alternating current, when flowing through the same resistance for the same time.

$$\therefore \boxed{I_{r.m.s} = \frac{I_m}{\sqrt{2}} = 0.707 I_m}$$

Similarly $$\boxed{E_{r.m.s} = \frac{E_m}{\sqrt{2}} = 0.707 E_m}$$

R.M.S. value = 70.7% of Maximum value.

Form Factor : It is the ratio of r.m.s value to the average value of the sinusoidal alternating quantity.

$$\text{Form factor } (K_f) = \frac{\text{R.M.S. Value}}{\text{Average Value}}$$

For sinusoidal alternating current,

$$K_f = \frac{0.707 I_m}{0.637 I_m} = 1.11$$

For sinusoidal alternating voltage,

$$K_f = \frac{0.707 E_m}{0.637 E_m} = 1.11$$

Hence, $K_f = 1.11$ for any sinusoidal alternating quantity.

Crest or Peak or Amplitude Factor : (K_a): It is the ratio of maximum value to the r.m.s value of sinusoidal alternating quantity

$$\text{Peak factor}, \ K_a = \frac{\text{Maximum value}}{\text{R.M.S Value}}$$

For any sinusoidal alternating quantity,

$$K_a = \frac{I_m}{0.707 I_m} = 1.414$$

or $$K_a = \frac{E_m}{0.707\, E_m} = 1.414$$

$K_a = 1.414$ for any sinusoidal alternating quantity.

Average Value of an alternating quantity :

→ The arithmetical average of all the values of an alternating quantity over one cycle is called average value.

$$\therefore \text{Average value}, \ E_{av} = \frac{\text{Area of half cycle}}{\text{Base}} = \boxed{\frac{2E_m}{\pi}}$$

$$\boxed{E_{av} = 0.637\, E_m}$$

Similarly,

$$\boxed{I_{av} = \frac{2 I_m}{\pi} = 0.637 I_m}$$

OR, Average value = 63.7% of Maximum Value.

Phase Difference :

- The difference between the phases of the two alternating quantities is called the phase difference.

	b.	Show that the current through purely capacitive circuit leads the applied voltage by 90° and average power consumed is zero. Draw the wave shapes of current voltage and power.	8	L3	CO2

3.

3. PURELY CAPACITIVE CIRCUIT :

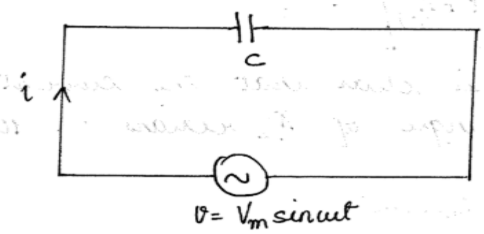


Fig (a): Circuit Diagram

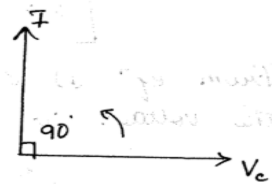


Fig (b): Phasor diagram

Let us consider a pure capacitor circuit connected across a sinusoidal voltage and this voltage is given by,

$$v = V_m \sin \omega t \quad -(1)$$

At any instant let 'q' be the charge on the plates of the capacitor

$$\therefore \quad q = Cv$$

$$\therefore \quad q = Cv$$

$$\Rightarrow \quad q = C(V_m \sin \omega t) \quad -(2)$$

But, $$i = \frac{dq}{dt} \quad -(3)$$

Substitute (2) in (3)

$$i = \frac{d}{dt} CV_m \sin \omega t$$

$$= CV_m \frac{d}{dt} \sin \omega t$$

$$= CV_m (\omega \cos \omega t)$$

$$i = \omega C V_m \cos \omega t$$

$$= \frac{V_m}{1/\omega C} \cos \omega t$$

Or $$i = \frac{V_m}{1/\omega C} \sin(\omega t + \pi/2) \quad -(4)$$

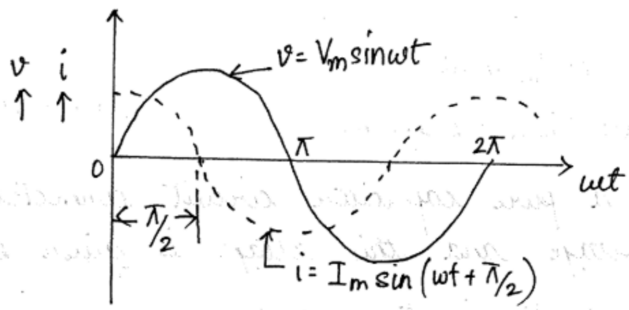
The current $i = I_m$ when $\sin(\omega t + \frac{\pi}{2}) = 1$

$$\therefore \quad I_m = \frac{V_m}{1/\omega C} \quad -(5)$$

substitute eq^n (5) in (4)

$$\boxed{i = I_m \sin\left(\omega t + \frac{\pi}{2}\right)} \quad -(6)$$

From eq^n (1) & (6), it is clear that the current 'i' leads the voltage 'v' by an angle of $\pi/2$ radians or 90°.



Fig(C) : Waveform for 'i' & 'v'.

Capacitive Reactance: $\frac{1}{\omega C}$ in the expression $I_m = \frac{V_m}{1/\omega C}$ is known as capacitive reactance and is denoted as X_c.

i, e $\quad X_c = \frac{1}{\omega C}$

$\therefore \quad I_m = \frac{V_m}{X_c}$

Power: Instantaneous power, $p = v i$

$= V_m \sin\omega t \; I_m \sin\left(\omega t + \frac{\pi}{2}\right)$

$= V_m I_m \sin\omega t \cos\omega t$

$= \frac{V_m I_m}{2} \sin 2\omega t \qquad (\because \sin 2\omega t = 2\sin\omega t \cos\omega t)$

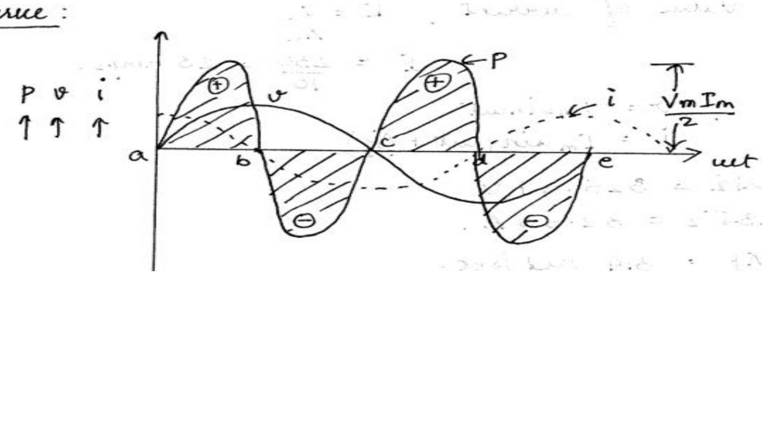
Power for the complete cycle,

$= \frac{1}{2} V_m I_m \int_0^{2\pi} \sin 2\omega t = 0.$

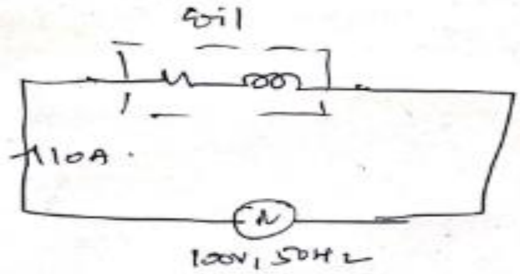
Thus the average power consumed by a pure capacitor is zero.

$\boxed{P = 0}$ W.

Power Curve:



	c.	An Inductive coil takes a current of 10A from a supply of 100V, 50Hz and lags the voltage of 30°. Calculate i) Parameters of the circuit ii) Power factor iii) Active reactive and apparent power.	6	L2	CO2



$\theta = 30^\circ$.

(i) Parameters $R = ?$ $L = ?$

$$Z = \frac{V}{I} = \frac{100}{10} = 10\,\Omega.$$

$Z = 10\,\Omega$, $\cos 30^\circ = 0.866$.

$$\cos\varphi = \frac{R}{Z} \Rightarrow R = Z\cos\varphi = 8.66\,\Omega.$$

$$X_L = \sqrt{Z^2 - R^2} = \sqrt{10^2 - 8.66^2} =$$

$X_L = 5\,\Omega$.

$$X_L = 2\pi f L \Rightarrow L = \frac{X_L}{2\pi f} =$$

$$L = \frac{5}{2\pi \times 50} = 0.015\,H$$

(ii) $\cos\varphi = 0.866$ lag.

(iii) $P = VI\cos\varphi = 100 \times 10 \times 0.866$

$P = 866$ watts.

$$S = VI = 100 \times 10 = 1000\,VA.$$

OR

Q.4	a.	Explain the generation of three phase A.C. and list the advantage.	6	L2	CO2

Necessity and Advantages of 3-ϕ Systems:

1. The output of 3-ϕ machine is always greater than that of a single-phase machine of same size. Hence for a given size and voltage, a 3-ϕ machine occupies less space and has less cost compared to a 1-ϕ machine having same rating.

2. To transmit and distribute a given amount of power a 3-ϕ system requires less copper than a 1-ϕ line.

3. 3-ϕ motors have uniform torque, whereas single-phase motors have pulsating torque.

4. 1-ϕ motors are not self-starting whereas 3-ϕ motors are self-starting.

5. 3-ϕ system give steady output.

6. 1-ϕ supply can be obtained from 3-ϕ but 3-ϕ cannot be obtained from 1-ϕ.

7. Power factor of 1-ϕ motor is poor than 3-ϕ motors of same rating.

Q.5	a.	Derive E.M.F equation of the DC generator.	6	L3	CO3

Emf equation of a dc generator :-

Let E_g - the generated emf in armature

ϕ - useful flux per pole (Wb)

Z - total no of conductors in the armature

P - number of poles

A - number of parallel path

$A = P$ .... lap winding

$A = 2$ .... wave winding

N - speed of armature in r.p.m

cording to Faraday's law,

e average emf induced in the conductor

$$e = \frac{d\phi}{dt} \quad — \quad (1)$$

Total emf generated = emf per parallel path

E_g = emf / conductor × no of conductors per parallel path

$d\phi$ - flux cut by conductor in one revolution

$= P\phi$ webers — (2).

dt - time taken to complete one revolution

$= \frac{60}{N}$ second — ③

② & ③ in ①,

e = emf / conductor — ④

$= \frac{d\phi}{dt} \Rightarrow \frac{p\phi N}{60}$

$$Eg = e \times \frac{Z}{A}$$

$$= \frac{p\phi N Z}{60 A}$$

$$\boxed{Eg = \frac{\phi Z N}{60} \times \frac{P}{A}} \quad \text{— ⑤}$$

emf equation of a dc machine.

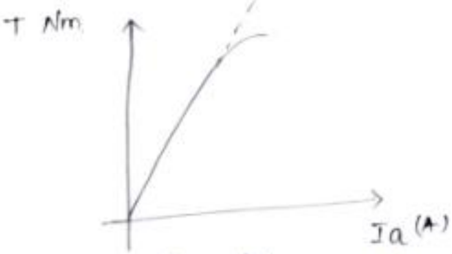
b.	Explain the characteristics of a D.C. shunt motor.	7	L2	CO3

$T \propto \phi I_a$

Thus the torque developed by a dc motor is directly proportional to the product of flux per pole and armature current.

⇒ Shunt motor:-
ϕ is nearly constant

$\therefore \boxed{T \propto I_a}$



in high current region due to saturation of the core, the char loses linearity.

SPEED Vs ARMATURE CURRENT CHARACTERISTIC

(7)

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)

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

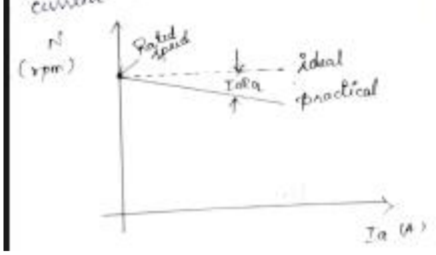
$$N = \frac{V - I_aR_a}{K\phi}$$

$$N \propto \frac{V - I_aR_a}{\phi}$$

$$\boxed{N \propto V - I_aR_a} \quad (\text{flux constant})$$

↳ eqn of straight line with −ve slope.

i.e N decreases linearly with increase in armature current



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

c.	A 4 pole, 1500 rpm , D.C generator has a lap wound armature having 32 slab and 8 conductor per slot. If the flux per pole is 0.04 wb. Calculate the emf induced in the armature. What would be the emf induced if the winding is wave connected.	7	L3	CO3

$P = 4$, $N = 1500$ rpm, Lap $A = P = 4$, $s = 32$, $Z/s = 8$

$Z = 32 \times 8 = 256$, $\phi = 0.04$ Wb

$$E_g = \frac{\phi Z N P}{60 A} = \frac{\phi Z N}{60} = \frac{0.04 \times 256 \times 1500}{60}$$

$$\therefore E_g = 256 \text{ V}$$

If wave, $A = 2$

$$E_g = \frac{\phi Z N P}{60 A} = \frac{\phi Z N P}{120} = \frac{0.04 \times 256 \times 1500 \times 4}{120}$$

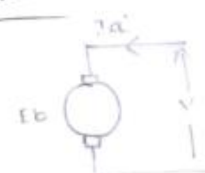
$$\therefore E_g = 512 \text{ V}$$

OR

Q.6	a.	Derive Torque equation of the D.C motor.	6	L3	CO3

Torque Equation of a dc motor :-

Voltage eqn of dc motor



$V = E_b + I_a R_a$ — ①

$V = E_b + I_a R_a$

$\times I_a$, $V I_a = E_b I_a + I_a^2 R_a$ — ②

$V I_a$ → elec i/p to arm

$E_b I_a$ → elec equivalent of gross mech power

$I_a^2 R_a$ → cu loss in arm

i.e input = output + losses

$E_b I_a$ - electrical equivalent of gross mech power — ③

Let T be the average electro-magnetic torque developed by armature in Nm (newton metres)

Mechanical power developed by armature

$$P_m = \omega \times T \quad — ④$$

where $\omega = \frac{2\pi N}{60}$.

i.e $P_m = \frac{2\pi N}{60} \times T$

Using ③ and ④,

$$E_b I_a = \omega T$$

$$\boxed{T = \frac{E_b I_a}{\omega}} \quad — ⑤$$

W.K.T $E_b = \frac{P\phi N Z}{60 A}$

Sub E_b in ⑤, $T = \frac{P\phi Z N}{60 A} \times \frac{I_a}{2\pi N} \times 60$

$$\boxed{T = \frac{1}{2\pi} \frac{P\phi Z}{A} I_a} \quad — ⑥$$

... eqn of dc motor

b.	Explain the various methods used to control the speed of DC series motor.	8	L2	CO3

DC SERIES MOTOR

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

Dc series motor speed can also be controlled by armature and flux control method.

Armature Control Method.

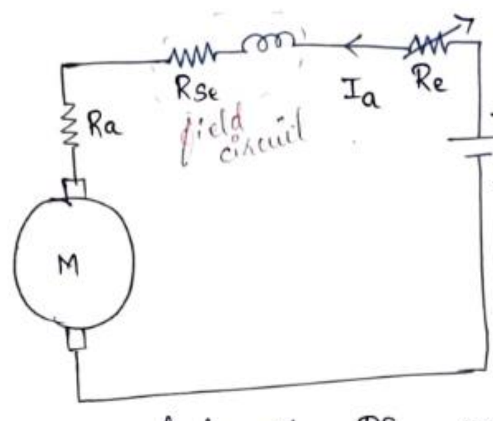
1. Armature voltage control
2. Armature resistance control.

Armature Voltage control

In this method, the speed of the motor is varied by varying the armature voltage using a variable DC power supply. With increasing armature voltage the speed also increases and vice versa.

Armature resistance control

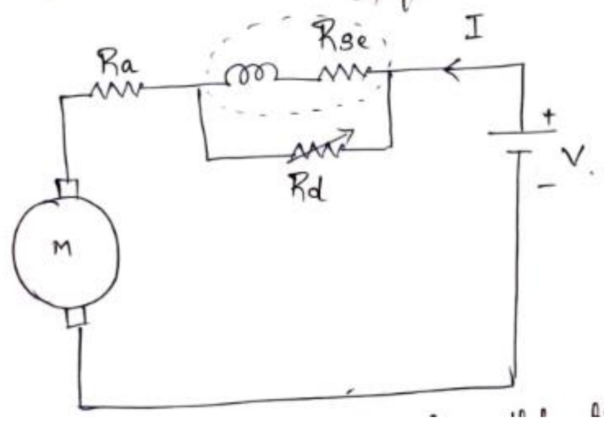
In this method, the speed of the motor is controlled by inserting an external variable resistance in series with armature. With increasing external variable resistance the voltage drop is increased which reduces the armature voltage and as a result speed is also reduced.



Speed control of DC motor using armature resistance control.

Field control method

The field current can be varied by using a diverter or tapped field control. The field diverter speed control method is described below : → field circuit.



field diverter)

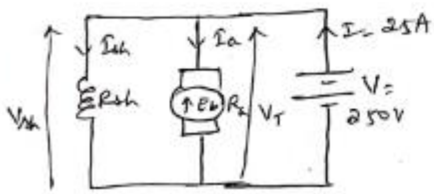
A variable resistance Rd (parallel field diverter) is connected across field resistance. The function of Rd is to reduce current through field winding, which reduces the flux and as a result speed increases.

c.	A 4 – pole D C shunt motor takes 25A from a 250V supply The armature and field resistances are 0.5Ω and 12Ω respectively. The wave wound armature has 30 slots and each slot containing 10 conductors , if the flux per pole is 0.02 wb. Calculate i) speed ii) torque developed iii) power developed.	6	L3	CO3

$P = 4$, $I = 25A$, $V = 250V = V_{sh} = V_T$, $R_a = 0.5\Omega$,

DC Shunt Motor $R_{sh} = 12\Omega$, wave $A = 2$,

$s = 30$, $Z/s = 10$, $Z = 30 \times 10 = 300$



$\phi = 0.02 Wb$

$N = ?$ $T_a = ?$ $P_a = ?$

$E_b - V = -R_a I_a$

$E_b = V - R_a I_a$

$I = I_a + I_{sh}$

$I_{sh} = \frac{V_{sh}}{R_{sh}} = \frac{250}{12} = 20.84 A$

$\therefore I_a = I - I_{sh} = 25 - 20.84$

$= 4.16 A$

Hence $E_b = V - I_a R_a = 250 - (0.5 \times 4.16)$

$= 247.92 V$

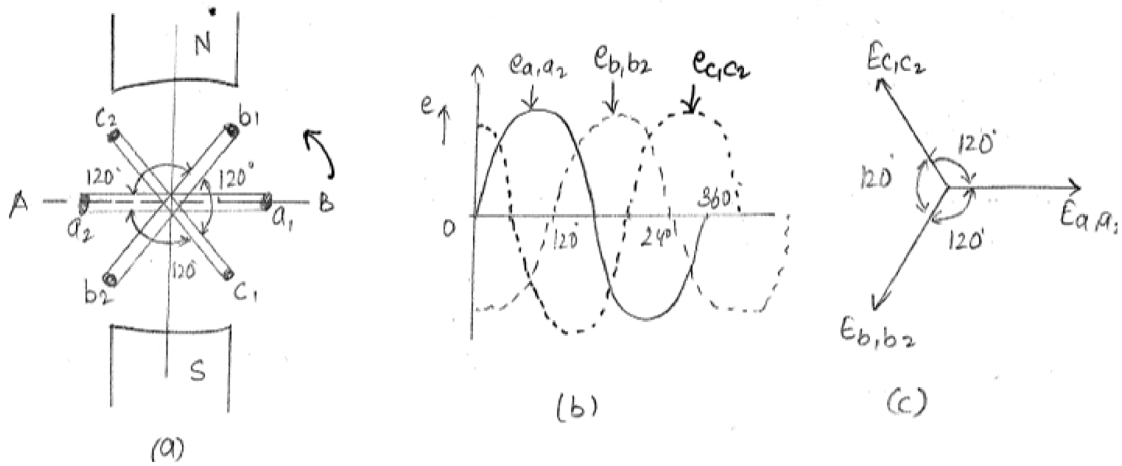
3) $P_a = E_b I_a$ 1) $N = \frac{60 \cdot A \cdot E_b}{\phi Z P} = \frac{60 \times 2 \times 247.92}{0.02 \times 300 \times 4} = 1239.6$ rpm

$= 247.92 \times 4.16$

$= 1031.35 W$

2) $T_a = \frac{0.159 \phi Z P I_a}{A} = \frac{0.159 \times 0.02 \times 300 \times 4 \times 4.16}{2} = 7.936$ N-m

Generation of 3-ϕ Voltages

- In the 3-ϕ system, there are three equal voltages of the same frequency but displaced from one another by $120°$ electrical.
- These voltages are produced by a 3-ϕ generator which has three identical windings or phases displaced $120°$ electrical apart.
- When these windings are rotated in a magnetic field, emf is induced in each winding or phase but displaced by $120°$ electrical.
- 

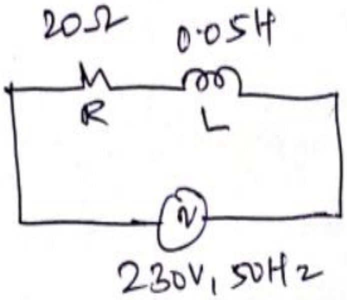
- Thus emf's induced in the three coils are of the same magnitude and frequency but displaced $120°$ electrical from each other.
- The equations for the three voltages are:

$$e_{a_1 a_2} = E_m \sin \omega t$$

$$e_{b_1 b_2} = E_m \sin\left(\omega t - \frac{2\pi}{3}\right) = E_m \sin(\omega t - 120°)$$

$$e_{c_1 c_2} = E_m \sin\left(\omega t - \frac{4\pi}{3}\right) = E_m \sin(\omega t - 240°)$$

	b.	A circuit consists of a resistance of 20Ω and inductance of 0.05H, connected in series. A single phase supply of 230V, 50kg is applied across the circuit. Find i) Impedance ii) Current iii) Power factor iv) Power consumed by the circuit v) Voltage drop across R & L.	8	L3	CO2



$$X_L = 2\pi f L = 2\pi \times 50 \times 0.05 = 15.7\Omega.$$

(i) $Z = \sqrt{R^2 + X_L^2} = 25\Omega$.

(ii) $I = \frac{V}{Z} = 230/25 = 9.2A$.

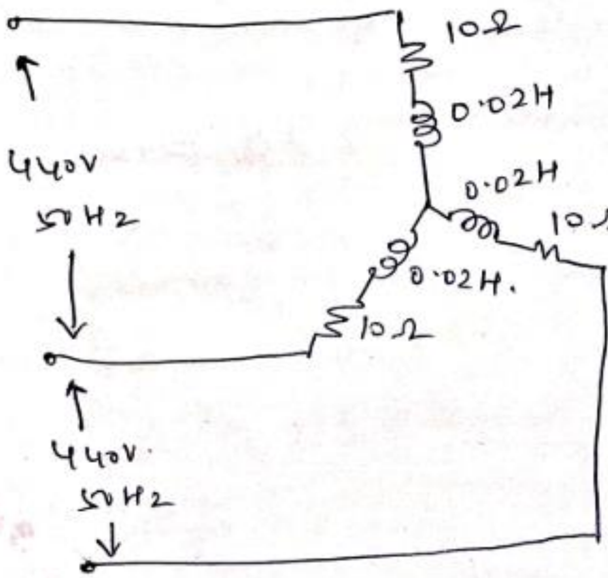
(iii) $\cos\varphi = \frac{R}{Z} = \frac{20}{25} = 0.8$ lag.

(iv) $P = VI\cos\varphi = 230 \times 9.2 \times 0.8 = 1692.8$ watts.

(v) $V_R = IR = 9.2 \times 20 = 184$ volts.

$V_L = IX_L = 9.2 \times 15.7 = 144$ volts.

c.	Three coils having resistance of 10Ω and inductance of 0.02H are connected in star across 440V, 50Hz , 3 – ϕ supply. Calculate the line current , p.f and total power consumed.	6	L3	CO2



$$I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{V_L/\sqrt{3}}{Z_{ph}}$$

$$= \frac{440/\sqrt{3}}{11.8}$$

$Z_{ph} = \sqrt{R^2+X_L^2}$

$= 11.8\Omega$

$X_L = 2\pi f L$

$= 2\pi \times 50 \times 0.02$

$X_L = 6.283\Omega$

$I_{ph} = 19.57A$

i) In star $I_{ph} = I_L = 19.57A$.

(ii) $\cos\varphi = \frac{R}{Z} = \frac{10}{11.8} = 0.84$ lag.

(iii) $P = \sqrt{3}\, V_L I_L \cos\varphi$

$= \sqrt{3} \times 440 \times 19.57 \times 0.84$.

$P = 125.28$ KWatts.

7(a)

1. Transformer EMF Equation Derivation

A transformer works on the principle of electromagnetic induction. It consists of two windings – primary and secondary – wound on a magnetic core. When an alternating current (a.c.) flows through the primary coil, it creates a changing magnetic flux, which induces an e.m.f. (electromotive force) in the secondary coil.

Step-by-Step Derivation:

1. **Magnetic Flux Linkage:** Let the total number of turns in the primary winding be N_1 and the total number of turns in the secondary winding be N_2 .
2. **Magnetic Flux and Faraday's Law of Induction:** According to Faraday's Law of Electromagnetic Induction, the EMF induced in a coil is given by:

$$e(t) = -N\frac{d\Phi}{dt}$$

   where:

   - E is the induced EMF,
   - N is the number of turns in the coil,
   - Φ is the magnetic flux linking the coil,
   - $\frac{d\Phi}{dt}$ is the rate of change of magnetic flux.
3. **Magnetic Flux in the Core:** If $\phi(t)$ is the flux in the core and it varies sinusoidally with time, then:

$$\Phi(t) = \phi_{max}\sin(\omega t)$$

   where $\omega = 2\pi f$ is the angular frequency of the ac supply, and f is the frequency in hertz.

4. **Induced EMF in the Primary Coil:** The induced EMF in the primary winding, E_1, is given by:

$$E_1 = -N_1\frac{d\Phi}{dt}$$

   Since $\Phi(t) = \Phi_{max}sin(\omega t)$, we differentiate this with respect to time:

$$\frac{d\Phi}{dt} = \Phi_{max}\omega cos(\omega t)$$

   Therefore, the induced EMF $e_1(t)$ in the primary winding becomes:

$$|e_1(t)| = N_1\,\Phi_{max}\,\omega cos(\omega t)$$

$$e_{1av} = \frac{2\omega}{\pi} \int_0^{\frac{\pi}{2\omega}} e_1(t)\, dt$$

$$= \frac{2\omega}{\pi} \int_0^{\frac{\pi}{2\omega}} N_1 \Phi_{max}\, \omega cos(\omega t)\, dt$$

$$= \frac{2\omega}{\pi} \int_0^{\frac{\pi}{2\omega}} N_1 \Phi_{max}\, \omega cos(\omega t)\, dt$$

$$= N_1\, \Phi_{max}\, \omega \frac{2\omega}{\pi} \left[\frac{\sin(\omega t)}{\omega} \right]_0^{\frac{\pi}{2\omega}}$$

$= \frac{2}{\pi} N_1 \phi_{max} \omega \Rightarrow e_{1av} = \frac{2}{\pi} N_1 \phi_{max} 2\pi f = 4\phi_{max} N_1 f$

$$E_{rms} = form\, factor * e_{average}$$

form factor for sinusoids is 1.11.

$$E_{1rms} = 1.11 * e_{1average} \Rightarrow E_1 = 1.11 * 4\phi_{max} N_1 f$$

$$E_1 = 4.44\phi_{max} N_1 f$$

5. **Induced EMF in the Secondary Coil:** By the same reasoning, the induced EMF in the secondary winding E2E_2 is given by:

$$E_2 = 4.44\phi_{max} N_2 f$$

Now we can express the relationship between E_1 and E_2 based on the number of turns in the primary and secondary coils.

---

2. Voltage Transformation Ratio

The voltage transformation ratio is derived from the relationship between the induced EMFs in the primary and secondary windings:

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

This means that the voltage in the primary winding is directly proportional to the number of turns in the primary coil and vice versa for the secondary coil.

$$\because E_1 \approx V_1 and\ E_2 \approx V_2$$

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

Which is the voltage transformation equation.

Here,

- V_1 is the voltage applied to the primary coil,
- V_2 is the voltage induced in the secondary coil,
- N_1 is the number of turns in the primary winding,
- N_2 is the number of turns in the secondary winding.

This shows that the voltage in the secondary coil is a scaled version of the primary voltage, depending on the turn ratio.

---

3. Current Transformation Ratio

The current transformation ratio can be derived using the power equilibrium on the two sides of transformer, i.e. power-in must be equal to power-out, assuming an ideal transformer (no losses):

$$P_{primary} = P_{secondary}$$

Since $P = V \times I$ (power is the product of voltage and current), we can write:

$$V_1 I_1 = V_2 I_2$$

Substituting the voltage transformation ratio $\frac{V_1}{V_2} = \frac{N_1}{N_2}$, we get:

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

Thus, the current transformation ratio is:

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

or equivalently,

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

This indicates that the current in the secondary winding is inversely proportional to the number of turns in the winding, relative to the primary current.

Summary of Key Equations:

- **EMF Equation** (for both primary and secondary):

$$E_1 = 4.44 N_1 f \Phi_{max} , E_2 = 4.44 N2 f \Phi_{max}$$

- **Voltage Transformation Ratio**:

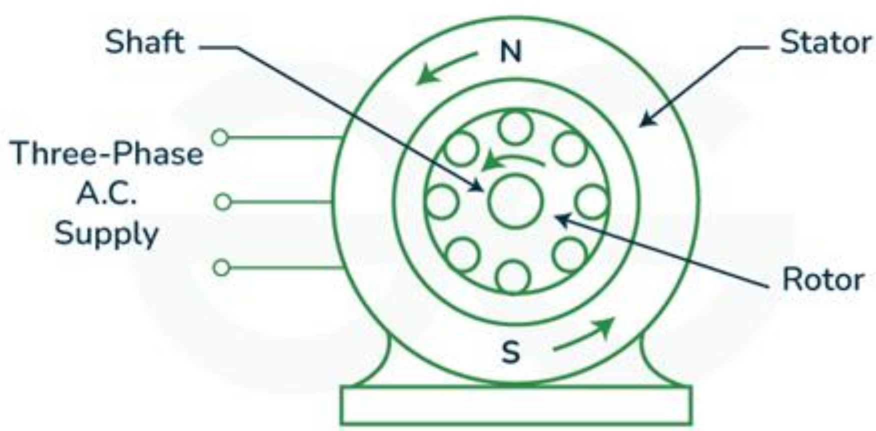
$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

- **Current Transformation Ratio**:

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

7 b.

Construction of 3 Phase Induction Motor
The construction of an induction motor is simple and robust. It consists of two parts.



- Stator
- Rotor

Stator of a 3 Phase Induction Motor
As the name suggests, the stator is a fixed piece of the motor. The stator of the induction motor comprises of three primary parts.

- Stator Casing
- Stator Core

- Stator Winding

Stator Casing
The stator casing is the external cover of the motor. The stator casing offers protection to the stator core and stator windings. It gives mechanical protection to the internal parts of the motor. The casing has projections/ fins on its external surface for heat dissipation and cooling of the motor.

Depending on the machine type, the enclosure is constructed in die-cast or fabricated steel, aluminum/aluminum alloys, or stainless steel.

Stator Core
The stator core's function is to carry the alternating magnetic flux. This alternating flux causes hysteresis and eddy current losses. To limit these losses, the core is fabricated out of high-silicon steel stampings with thickness ranging from 0.3 to 0.6 mm. These stampings are insulated from each other by insulating enamels coating.
The inner surface(cylindrical) of the stator core has conductor slots.

Stator Winding
The stator winding is placed within the slots available on the inner periphery of the stator. The stator is wound for three phases, and a three-phase power supply is applied to it. The motor's pole count is determined by the internal arrangement of the stator windings, and it controls the motor's speed. When the number of poles is higher, the speed is lower, whereas if the number of poles is fewer, the speed is higher. The number of poles is always an even number. The relation between synchronous speed and number poles is,

$$N_s = 120 \times \frac{f}{P}$$

Where,
f = Supply Frequency
P = Total Number of Poles
Ns = Synchronous Speed
The ends of the windings are terminated in the terminal box. Consequently, there are six terminals (two for each phase) in the terminal box. As per the application and sort of starting techniques for motors, the stator winding is connected in star or delta.

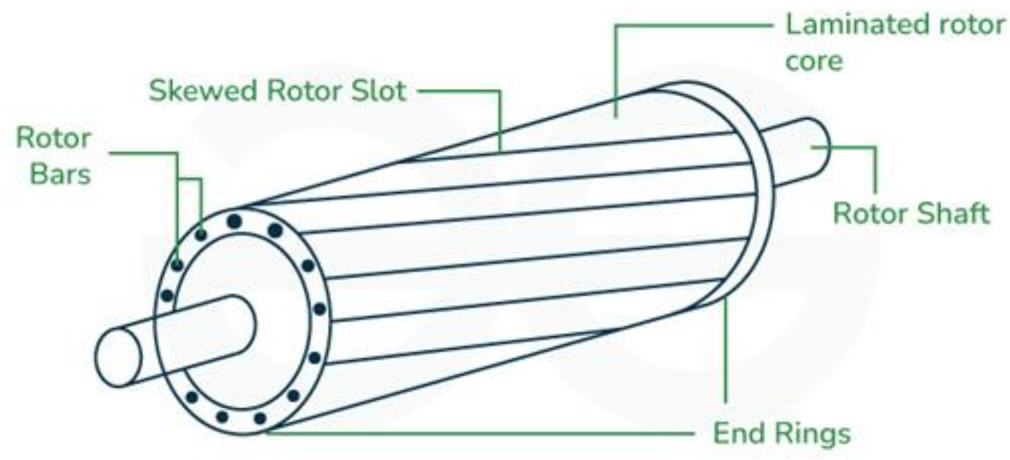
Rotor of 3 Phase Induction Motor
As the name suggests, the rotor is a rotating part of the motor. As indicated by the type of rotor, the induction motor is named.
- Squirrel Cage Induction Motor
- Phase Wound (Wound Rotor) induction motor / Slip-ring induction motor

The structure of the stator is identical in the two kinds of induction motors. We will examine the kinds of rotors deployed in 3-phase induction motors in the types of three phase induction motor.

Types of 3 Phase Induction Motor
Three phase motors are classified mainly in two classes considering the rotor winding.
Squirrel Cage Induction Motor
- Slip-ring or Wound Rotor Induction Motor

Squirrel Cage Induction Motor

The rotor of this type resembles an enclosure of a squirrel. This motor is hence referred to as an induction squirrel cage motor. This kind of rotor is easy to make and is quite robust. More than 80% of the induction motors are squirrel cage type induction motors.



Squirrel Cage induction motor Rotor

The rotor is shaped like a tube, and the peripheral edges have slots. The slots are skewed. It helps to mitigate magnetic locking between the stator and rotor. It achieves smooth rotation and diminishes the mumbling commotion. Since skewing increases the length of the rotor guide, it increases the rotor resistance.

Instead of a rotor winding, the squirrel cage rotor is made up of rotor bars. Aluminum, metal, or copper is used to make rotor bars. End rings permanently the short rotor bars. It effects closure of rotor circuit. Mechanical support is provided by welding or riveting the rotor bars to the end rings. The rotor bars are short-circuited. Along these lines, it is not possible to add external resistance into the rotor circuit. In this sort of rotor, the slip rings and brushes are not used. As a result, the construction of this kind of motor is simpler and robust.

Advantages of Squirrel Cage Induction Motor

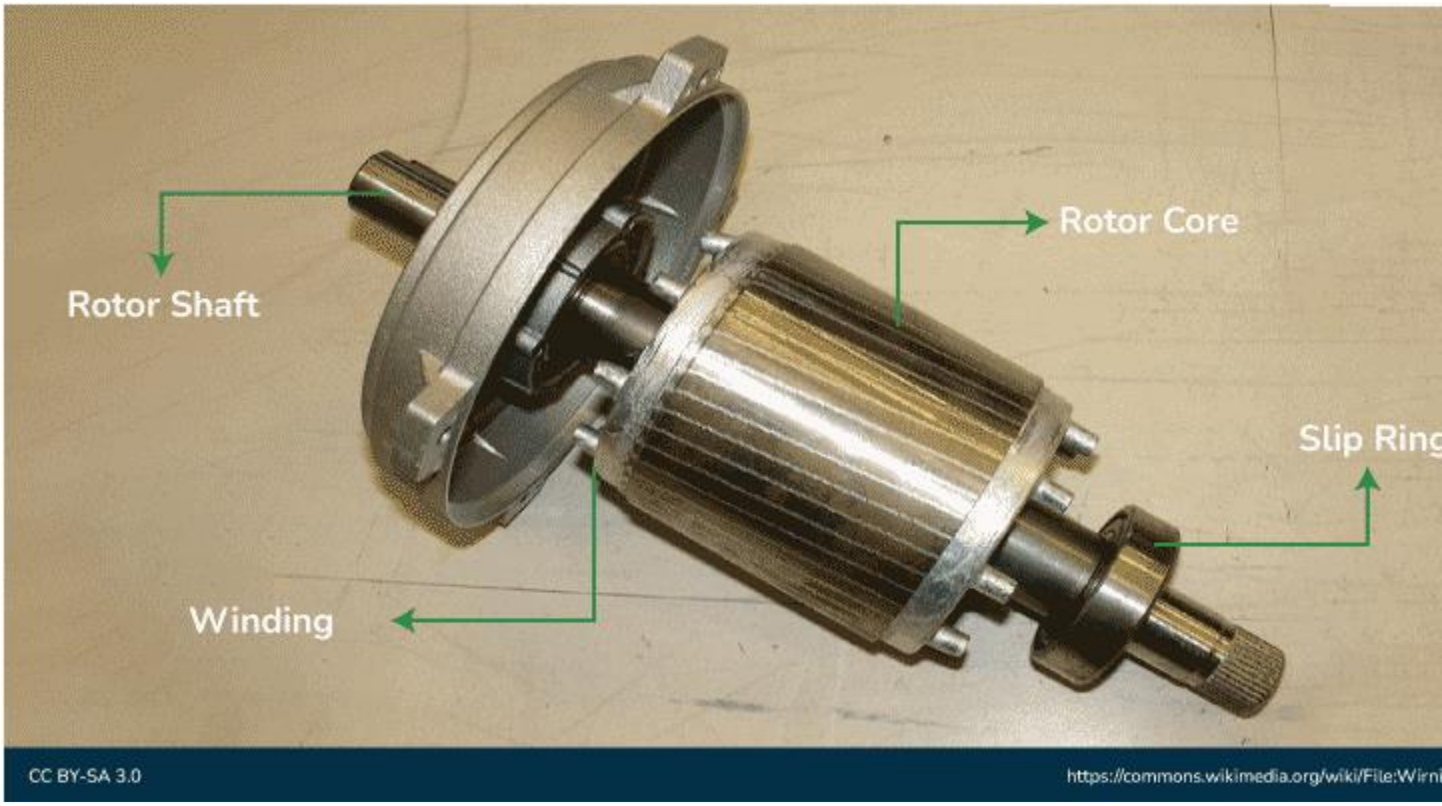
- **Simplicity:** Squirrel cage motors have a simple and robust construction.
- **Low Maintenance:** There are fewer parts that are susceptible to wear and maintenance issues because the rotor is a closed cage with no external connections.
- **High starting torque:** In situations where high starting torque is required, squirrel cage motors frequently exhibit excellent characteristics.
- **Wide Range of applications:** These motors are affordable for numerous applications, such as pumps, fans, compressors, and others.

Disadvantages of squirrel cage induction motor

- **Limited Speed Control:** Speed control options for squirrel cage motors are limited, and their speed is largely determined by the voltage and frequency applied.
- **Limited Starting Control**: While slip-ring motors have greater control over starting torque, squirrel cage motors typically have intermediate starting torque.

Slip-Ring or Wound Rotor Induction Motor

Slip-ring Induction Motor are generally called wound rotor motor. The rotor is made up of a tube-shaped center with slots on its outer edges. The rotor winding is placed inside the slots. In this type of rotor, the winding is arranged in such a way that the number of rotor winding slots matches the number of stator winding poles. The rotor winding can be connected in star or delta. The slip-rings are connected to the end terminals of the rotor windings. Hence, it is named as a slip-ring induction motor. The rotor circuit can connect to external elements/ circuits through the slip-ring and brushes. Likewise, it is useful for controlling the speed of the motor and adjusting the starting torque of the Induction Motor.



The external circuit is used solely for the starting methods. The rotor copper loss increases if it remains connected while the motor has attained the running speed. In the initial condition, a high rotor resistance is advantageous, as it helps motor deliver higher torque. During the initial state, the rotor circuit is connected to external high resistances. The metal collar short-circuits the slip-rings when the motor attains speed close to operational speed. By this arrangement, the brushes and external elements are withdrawn from the rotor circuit. Copper losses from the rotor and brush friction are both reduced because of this. This motor requires more maintenance. This motor can be used in applications requiring high starting torque and variable speed.

Advantages

Variable Speed Control: One of the main advantages of slip-ring motors is the ability to control the speed and torque by varying the external resistances in the rotor circuit. For this, they are suitable for applications that require variable speed.

High Starting Torque Control: Slip-ring motors can deliver higher starting torque, and the external resistances can be changed as per control requirements.

Smooth Acceleration: The ability to control the torque through rotor resistance results in less mechanical vibrations during starting and a smoother speed rise.

Disadvantages

Complex Construction: Slip-ring motors have an improved performance as a result of the external circuits and slip rings, inviting complex construction and higher costs.

Higher Maintenance: The slip rings, external resistances and brushes in the rotor require high maintenance.

7 c.

A transformer is rated at 100 KVA. At full load its-copper loss is 120O W and its iron loss is 960 W. Calculate the following

(i) efficiency at full load, UPF
(ii) efficiency at half load, 0.8 pf.
(iii) the load KVA at which maximum efficiency will occur
(iv) maximum efficiency at 0.85 p.f.

Given Data:

- Transformer rating: 100 KVA
- Full load copper loss(P_{Cu}): 1200W
- Iron loss(P_{Fe}): 960 W
- Power factor: given case to case.

(i) Efficiency at full load (p.f. = 1)

Efficiency (η)

$$\eta = \frac{Output\ power}{Output\ power + Losses}$$

At full load, the output power is $apparent\ power\ output * p.f.$

UPF- unity p.f. -> p.f.=1

$$Power_{out} = 100 * 1$$

$$= 100KW = 100{,}000W$$

$$Losses = P_{Cu} + P_{Fe} = 1200 + 960 = 2160W$$

$$\eta_{\%} = \frac{Power_{out}}{Power_{out} + Losses} * 100$$

$$\eta = \frac{100{,}000}{100{,}000 + 2160} * 100 = 97.89\%$$

(ii) Efficiency at half full load, p.f. =0.8

At sub full load, copper loss varies as square of fraction of load

$$P_{Cu\_Half\_full\_load} = \left(\frac{1}{2}\right)^2 P_{Cu} = \frac{1}{4} * 1200 = 300W$$

Iron Loss remains constant.

$$Total\ losses\ = P_{Fe} + P_{Cu} = 300 + 960 = 1260W$$

Power output for half full load, at 0.8 p.f.

$$P_{out} = ApperentPower * \frac{1}{2} * 0.8 = 40KW$$

$$\eta_{\%} = \frac{40000 * 100}{40000 + 1260}\% = 97\%$$

(iii) Load KVA for maximum efficiency

Condition for maximum efficiency:

Copper Loss=Iron loss

Let Load KVA at max. efficiency be $Load_{\max\_eff}$.

Fraction of Full load,

$$X = \frac{Load_{\max\_eff}}{Apperent\ Power\ Output} \Rightarrow Load_{\max\_eff} = X * Apperent\ Power\ Output$$

$$Copper\ loss\ at\ X\ fraction\ load = X^2 * Full\ load\ Copper\ loss$$

$$X^2 * 1200 = 960 \Rightarrow X = \sqrt{\left(\frac{960}{1200}\right)} = \sqrt{0.8} = 0.894$$

$$Load\ KVA\ for\ max\ efficiency = X * KVA\ rating = 0.894 * 100 = 89.4KVA$$

(iv) Maximum Efficiency at PF = 0.85

At maximum efficiency load (89.4 kVA), output power:

Output Power=89.4×0.85=75.99 kW=75990 W

Total losses at maximum efficiency:

Total Loss = 960 + 960 = 1920 W

Total Loss=960+960=1920 W

$$\eta = (75990 + 1920) * \frac{100}{75990} = 97.53\%$$

Final Answers:

(i) Efficiency at full load, unity PF = 97.89%
(ii) Efficiency at half load, 0.8 PF = 96.95%
(iii) Load kVA at max efficiency = 89.4 kVA
(iv) Maximum efficiency at 0.85 PF = 97.53%

8a. Explain the various losses in a transformer, how to minimize them?

Losses in a Transformer and How to Minimize Them:

A transformer is an electrical device that transfers power between circuits using electromagnetic induction. However, during this process, some energy is lost in various forms. The major losses in a transformer are categorized as core losses, copper losses, stray losses, and dielectric losses.

1. Core Losses (Iron Losses)

These losses occur in the iron core of the transformer due to alternating magnetic fields. Core losses consist of:

a) Hysteresis Loss

Cause: Hysteresis loss occurs due to repeated magnetization and demagnetization of the transformer core.

Formula:

$$P_h = \eta \, B_m^{\chi} \, f \, V$$

where:

B_m - Maximum flux density webers/ m^2

f - Supply frequency Hz

V - Volume of the core m^3

η - Hysteresis constant

χ is typically 1.6 to 2

Minimization:

- Using high-silicon steel (CRGO - Cold Rolled Grain Oriented Steel) for the core, which has low hysteresis loss.

- Using laminated cores to reduce eddy currents.

- Using materials with low hysteresis coefficient.

b) Eddy Current Loss

Cause: Eddy currents are circulating currents induced in the core due to the alternating magnetic field, leading to resistive heating.

Formula:

$$P_e = K \, B_m^2 \, f^2 \, t^2 \, V$$

where:

K - Constant

B_m - Maximum flux density wb/m^2

f - Frequency Hz

t - Thickness of lamination

V - Volume of the core m^3

Minimization:

Laminating the core to increase resistance and reduce circulating currents.

Using thinner laminations to decrease the loop path of eddy currents.

Using high-resistivity core material to reduce eddy currents.

2. Copper Losses (I^2R Losses)

Cause: Copper losses occur due to the resistance (\(R\)) of the transformer windings when the current flows through them.

Formula:

$$P_{cu} = I^2R$$

where:

I - Current

R - Resistance of the winding referred to one side primary or secondary

Minimization:

Using low-resistance materials like copper or aluminum for windings.

Increasing conductor size to reduce resistance.

Improving cooling methods to maintain the efficiency of the transformer.

3. Stray Losses

Cause: These losses occur due to leakage flux that induces eddy currents in nearby metallic parts such as the transformer tank and winding supports.

Minimization:

Proper winding design to reduce leakage flux.

Using magnetic shields to prevent flux leakage in metallic structures.

4. Dielectric Losses

Cause: Occurs in the insulation material of the transformer due to the alternating electric field, leading to energy dissipation as heat.

Minimization:

Using high-quality insulation materials like oil-impregnated paper.

Maintaining the insulation dry and free from moisture.

Regular oil filtration and replacement in oil-filled transformers.

5. Mechanical Losses

Cause: These losses arise due to vibrations and noise in the transformer, especially in the core laminations.

Minimization:

Proper tightening of laminations to reduce vibration.

Use of damping materials to absorb mechanical energy.

Conclusion

To minimize losses and improve transformer efficiency, the following key strategies should be implemented:

✅ Use high-grade core materials (CRGO steel).

✅ Laminated core with thin, high-resistance sheets.

✅ Low-resistance winding materials (copper preferred over aluminum).

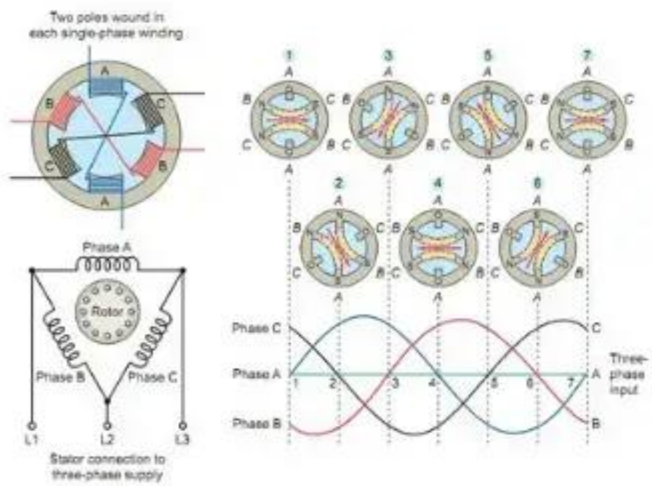
✅ Efficient cooling systems to maintain optimal operating temperature.

✅ Proper insulation and maintenance to prevent dielectric losses.

By optimizing these factors, transformers can achieve higher efficiency, lower operating costs, and longer service life.

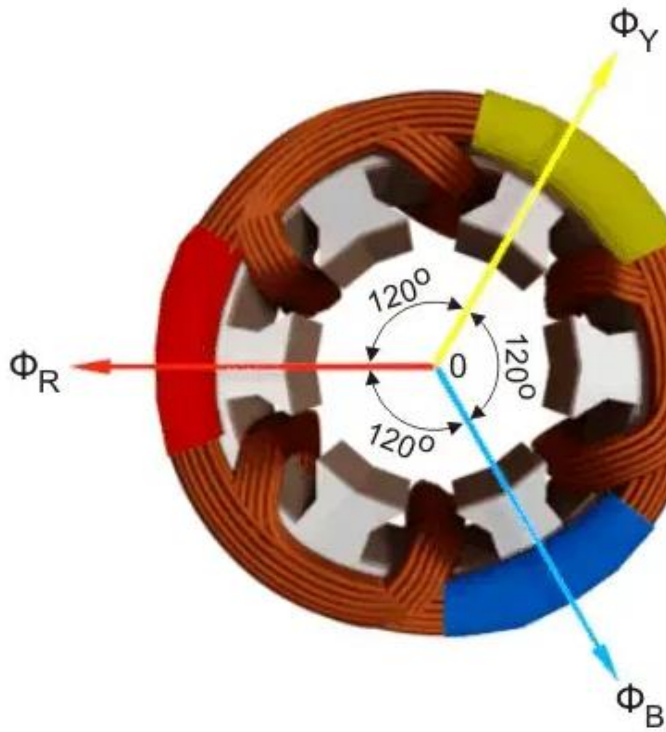
8b. With diagrams, explain the concept of rotating magnetic field.

What is a Rotating Magnetic Field?



- **Rotating Magnetic Field Definition**: A rotating magnetic field is created in space when a three-phase distributed winding in a rotating machine is excited by a balanced three-phase supply. (Three-Phase Supply: This supply involves three currents of equal magnitude, that are 120 electrical degrees apart, creating a balanced system. Magnetic Flux Behavior: The magnetic flux produced in each phase is in phase with the currents and can be represented graphically.)
- **Rotation of Flux Vector**: The resultant flux vector rotates with a constant angular speed.
- **Production of Rotating Magnetic Field**: This rotating field is established due to the balanced supply applied to the stator winding.

When we apply a three-phase supply to a three-phase winding distributed in space, around stator of a rotating machine, a rotating magnetic field is produced which rotates in synchronous speed. We first imagine stator of an electric motor whose three-phase winding is distributed in the stator core in a manner that winding of each phase is separated from each other by 120^{o} mechanical in space.

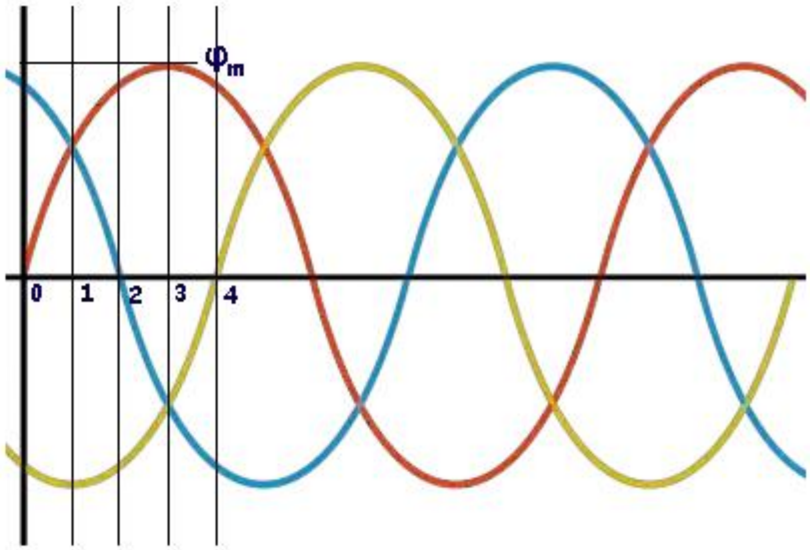


Although the vector sum of three currents in a balanced three-phase system is zero at any moment, the resultant magnetic field produced by these currents is not zero. It has a constant non-zero value that rotates over time.

The magnetic flux produced by the current in each phase can be represented by specific equations. These equations show that the flux is in phase with the current, similar to a three-phase current system.

$$\phi_R = \phi_m \sin(\omega t)$$
$$\phi_Y = \phi_m \sin(\omega t - 120^o)$$
$$\phi_B = \phi_m \sin(\omega t - 240^o)$$

Where φ_R, φ_Y and φ_B are the instantaneous flux of corresponding Red, Yellow and Blue phase winding, φ_m amplitude of the flux wave. The flux wave in space can be represented as shown below.



Now, on the above graphical representation of flux waves, we will first consider the point 0. Here, the value of φ_R is

$$\phi_R = \phi_m \sin(0) = 0$$

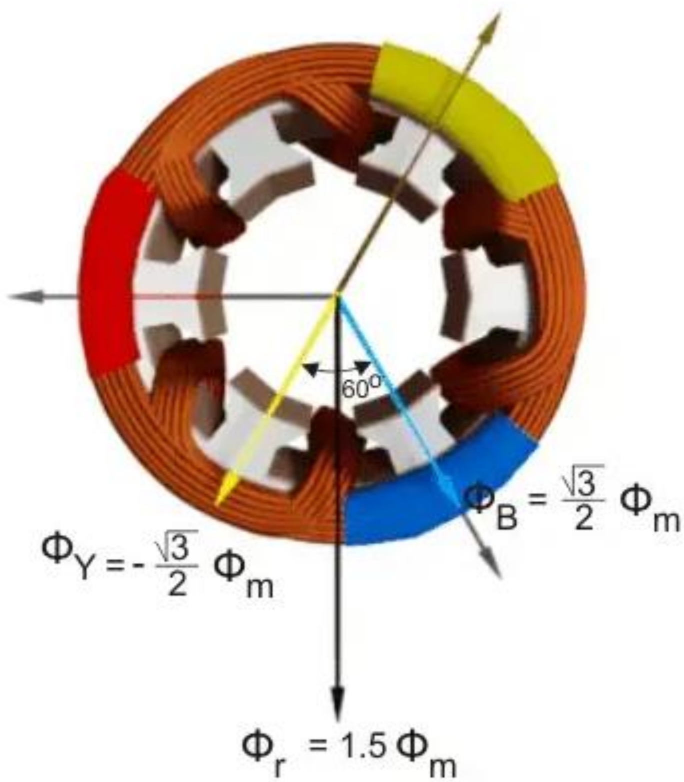
The value of φ_Y is

$$\phi_Y = \phi_m \sin(0 - 120^o) = \phi_m \sin(-120^o) = -\frac{\sqrt{3}}{2}\phi_m$$

The value of φ_B is

$$\phi_B = \phi_m \sin(0 - 240^o) = \phi_m \sin(-240^o) = \frac{\sqrt{3}}{2}\phi_m$$

The resultant of these fluxes at that instant (φ_r) is $1.5\varphi_m$ which is shown in the figure below.



Now, on the above graphical representation of flux waves, we will consider the point 1, where ωt = π / 6 or 30°.
Here, the value of φ_R is

$$\phi_R = \phi_m \sin(30^0) = \frac{1}{2}\phi_m$$

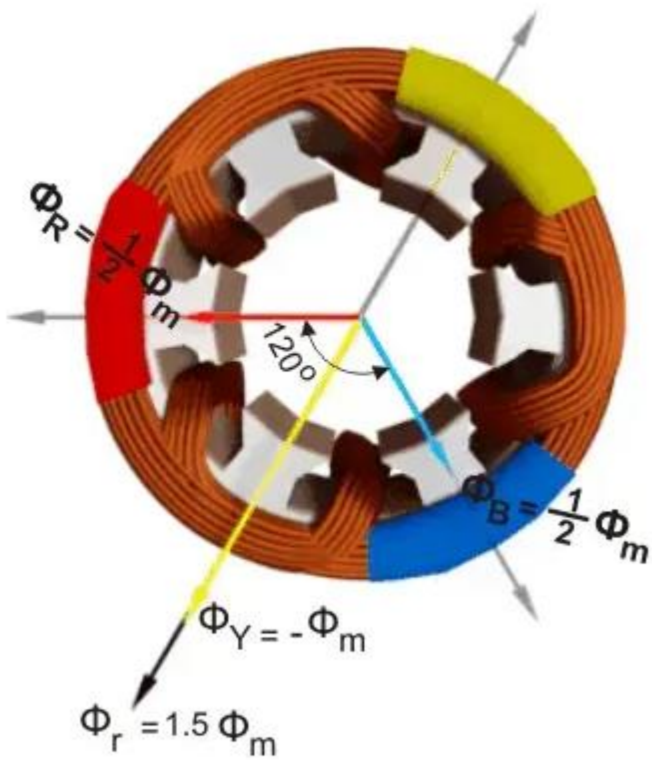
The value of φ_Y is

$$\phi_Y = \phi_m \sin(30^o - 120^o) = \phi_m \sin(-90^o) = -\phi_m$$

The value of φ_B is

$$\phi_B = \phi_m \sin(30^o - 240^o) = \phi_m \sin(-210^o) = \frac{1}{2}\phi_m$$

The resultant of these fluxes at that instant (φ_r) is $1.5\varphi_m$ which is shown in the figure below. here it is clear that the resultant flux vector is rotated 30^o further clockwise without changing its value.



Now, on the graphical representation of flux waves, we will consider the point 2, where $\omega t = \pi / 3$ or 60^o.
Here, the value of φ_R is

$$\phi_R = \phi_m \sin(60^o) = \frac{\sqrt{3}}{2}\phi_m$$

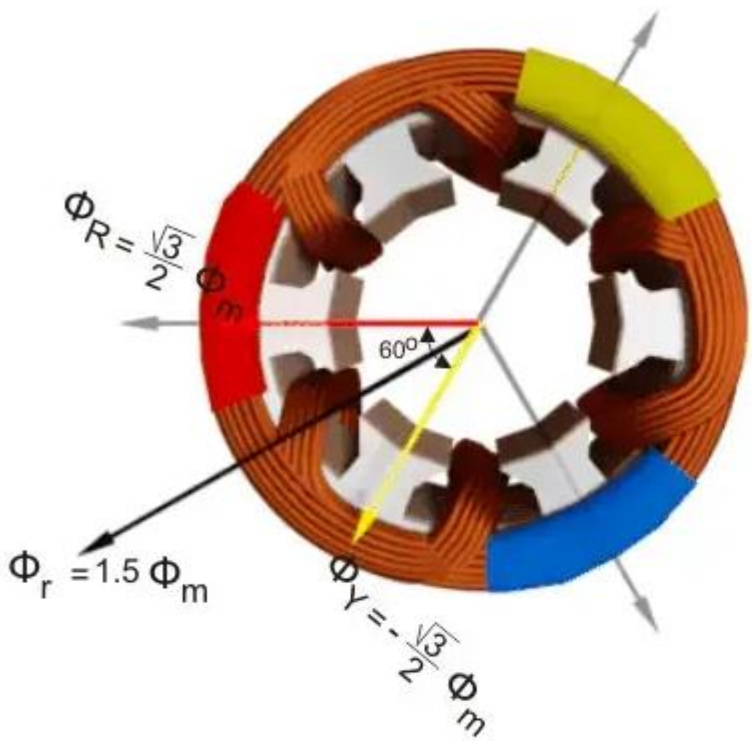
The value of φ_Y is

$$\phi_Y = \phi_m \sin(60^o - 120^0) = \phi_m \sin(-60^o) = -\frac{\sqrt{3}}{2}\phi_m$$

The value of φ_B is

$$\phi_B = \phi_m \sin(60^o - 240^0) = \phi_m \sin(-180) = 0$$

The resultant of these fluxes at that instant (φ_r) is $1.5\varphi_m$ which is shown in the figure below. here it is clear thet the resultant flux vector is rotated 30° further clockwise without changing its value.



Now, on the graphical representation of flux waves, we will consider the point 3, where $\omega t = \pi / 2$ or 90^o.
Here, the value of φ_R is

$$\phi_R = \phi_m \sin(90^o) = \phi_m$$

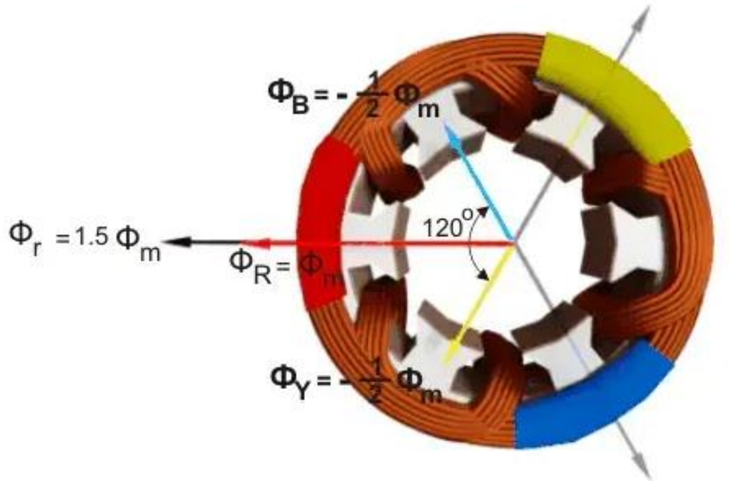
The value of φ_Y is

$$\phi_Y = \phi_m \sin(90^o - 120^o) = \phi_m \sin(-30^o) = -\frac{1}{2}\phi_m$$

The value of φ_B is

$$\phi_B = \phi_m \sin(90^o - 240^o) = \phi_m \sin(-150^o) = -\frac{1}{2}\phi_m$$

The resultant of these fluxes at that instant (φ_r) is $1.5\varphi_m$ which is shown in the figure below. here it is clear that the resultant flux vector is rotated 30^o further clockwise without changing its value.



This demonstrates that a balanced 3 phase supply applied to a three-phase stator winding creates a rotating magnetic field in space.

8c. A three phase induction motor with 4 poles supplied from the alternator having 6 poles running at 1000 rpm. Calculate Synchronous speed, rotor speed of the induction motor when slip 1s 0.04 and frequency of the rotor emf when the speed is 600 rpm.

We will calculate the following step by step:

Given Data:

- Alternator Poles $P_s = 6$

- Alternator Speed $N_s = 1000$ rpm

- Induction Motor Poles $P_r = 4$

- s = 0.04

- Rotor Speed when speed = 600 rpm

Step 1: Calculate Synchronous Speed of the Induction Motor

Synchronous speed is given by:

$$N_s = 120 \times \frac{f}{P}$$

The alternator supplies the induction motor, so the alternator frequency f_s is:

$$f_s = N_s \times \frac{P_s}{120} = 1000 \times \frac{6}{120} = 50\,Hz$$

Now, the synchronous speed of the induction motor:

$$N_{s,r} = 120 \times \frac{f_s}{P_r} = 120 \times 50/4 = 1500\,rpm$$

Thus, the synchronous speed of the induction motor is 1500 rpm.

Step 2: Calculate Rotor Speed N_r when Slip s = 0.04

Rotor speed is given by:

$$N_r = N_s\,(1 - s)$$

$$N_r = 1500\,(1 - 0.04) = 1500 \times 0.96 = 1440\ rpm$$

Thus, the rotor speed of the induction motor is 1440 rpm.

Step 3: Calculate Frequency of Rotor EMF when Speed is 600 rpm

Rotor frequency is given by:

$$f_r = S \times f_s$$

Slip s when rotor speed is 600 rpm:

$$s = (N_s - N_r)/N_s = (1500 - 600)/1500 = 900/1500 = 0.6$$

Now, rotor frequency:

$$f_r = 0.6 * 50 = 30\,Hz$$

Thus, the frequency of the rotor EMF when speed is 600 rpm is 30 Hz.

Final Answers:

1. Synchronous speed of the induction motor = 1500 rpm

2. Rotor speed at slip 0.04 = 1440 rpm

3. Frequency of rotor EMF when speed is 600 rpm = 30 Hz

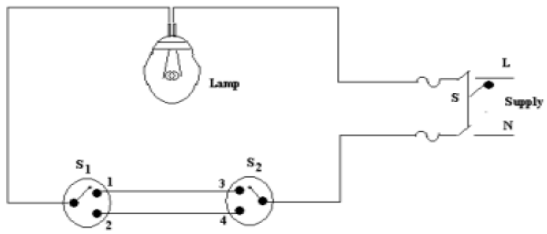
9A)

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 **S_1** and **S_2** are two-way switches with a pair of terminals 1&2, and 3&4 respectively.
- When the switch **S_1** is in position**1** and switch **S_2** 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 **S_1** is changed to position **2** the circuit gets completed and hence the lamp glows or is **ON**. N

- ow if **S_2** is changed to position **3** with **S_1** at position **2** the circuit continuity is broken and the lamp is off.
- Thus the lamp can be controlled from two different points.

Position of S1	Position of S2	Condition of lamp
1	3	ON
1	4	OFF
2	3	OFF
2	4	ON

(ii)Three- way Control of lamp:

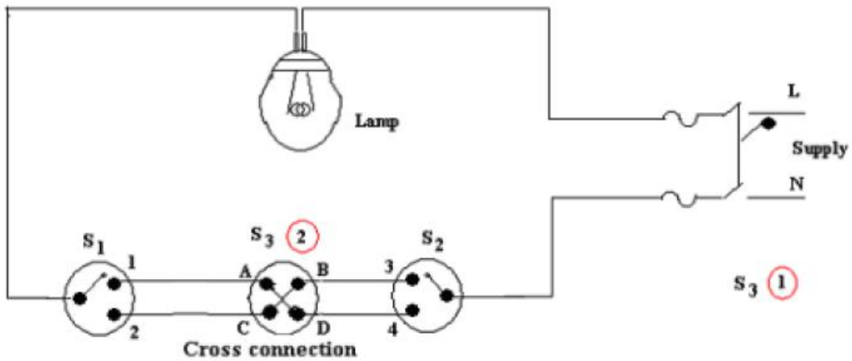
In case of very long corridors it may be necessary to control the lamp from 3 different points. In such cases, the circuit connection requires two; two-way switches **S_1** and **S_2** and an intermediate switch **S_3**. An intermediate switch is a combination of two, two way switches coupled together. It has 4 terminals ABCD. It can be connected in two ways:

a) Straight connection

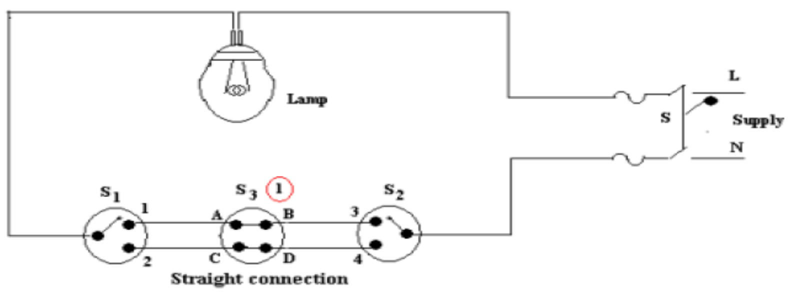
b) Cross connection

In case of straight connection, the terminals or points AB and CD are connected as shown in figure 1(a) while in case of cross connection, the terminals AB and CD is connected as shown in figure 1(b).

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.



Three -way control of lamp

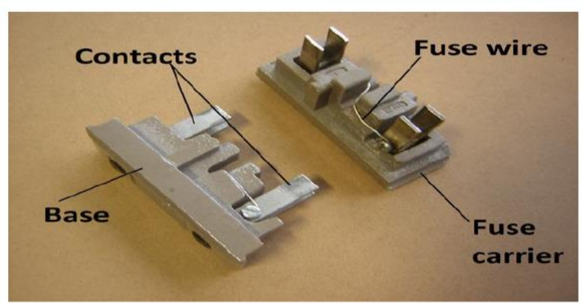


The condition of the lamp depends on the positions of the switches S_1, S_2, and S_3.

9B)

Fuse

- An electrical fuse is a safety device that operates to provide protection against the overflow of current in an electrical circuit. An important component of an electrical fuse is a metal wire or strip that melts when excess current flows through it. It helps to protect the device by stopping or interrupting the current.



Working Principle of Fuse

- To understand the working principle behind an electrical fuse, two critical concepts should be kept in mind Current flows in a loop Heating effect of current. Electric current can flow through a conductor only when the circuit formed is complete. If there is a break in the loop, electric charges cannot flow through. This is also how switches operate. For example, when you put on the light switches at home, the lights come on because you have just completed the circuit allowing charges from the power source to flow through and power your lights. When current passes through a conductor, the different electrical components of the circuit like the devices attached or even the wire itself, offer resistance to the current flow. The work done to overcome this resistance presents itself in the form of heat. This is a simple explanation of the "heating effect" of current.

Principle Of Electrical Fuse

- The primary use of an electric fuse is to protect electrical equipment from excessive current and to prevent short circuits or mismatched loads. Electrical fuses play the role of miniature circuit breakers. Apart from protecting equipment, they are also used as safety measures to prevent any safety hazards to humans.

- The fuse wire in an electrical fuse is selected in such a way that it does not face any damage when the normally stipulated amount of current flows through the circuit. Under normal conditions, the fuse wire is a part of the circuitry, contributing to a complete loop for charges to flow through it. However, when an excessive amount of current flows through the fuse wire, the heating effect of current causes the fuse wire to melt. This is because the fuse wire is chosen such that it has a low melting point. This causes the loop to break thereby stopping the flow of charges in the circuit.

- It is important to select a fuse that is properly specified for the circuit in consideration. For example, if the fuse that is used is underrated, then it will fail even under normal current conditions, unnecessarily breaking the circuit loop. If it is overrated, then it will not break the circuit when required and cause equipment damage and failure and may even present itself as a safety hazard.

Functions of Fuse

In the field of electrical engineering, a fuse is a device that provides overcurrent protection to the functional electrical circuit. Here, we have listed a few major functions of the fuse.

- Acts as a barrier between the electric circuit and the human body
- Prevents device failure due to faulty circuit operation
- Fuse prevents short-circuits
- Prevents overload and blackouts
- Prevents damage that is caused due to mismatched loads
- The markings on the fuse carry information such as the Ampere rating, voltage rating, and interruption rating.

Merits of Fuse

- Fuses are the cheapest form of protection.
- The fuse element change very easily.
- The fuse needs zero maintenance.
- It affords the current limiting effect under short circuit conditions.
- Its operation is completely automatic and requires less time as compared to circuit breakers and no complexity is involved
- Most of the fuses are self-protecting and also they extinguishing the arc.
- When we use the small size of the fuse element impose a current limiting effect under short circuit conditions.
- Its inverse time-current characteristics enable its use for overload protection.
- Fuse has the ability to interrupt enormous short circuits without producing noise, flame or smoke.
- Easy to removable for replacement without any damage to coming into contact with a live part.
- The operation time of fuse can be much smaller than the operation of the circuit breaker. It is the primary protection device, against the short circuits.

De Merits of Fuse

- It is not suitable for overload, at that time fuse blow off replacing of fuse takes time. During this period of lost power the protection of fuse is not reliable, Low breaking capacity.
- Fuse is slow compared to circuit breakers. It is a slow speed.
- Considerable time is required in replacing a fuse after the operations, while the circuit breaker can be used multiple times.
- It can't bear a surge current in the case of motor starting, Fuse has not protected the circuit against under-voltage.
- The fusing elements of the fuse are exposed to air, hence it is oxidized. Therefore the resistance of the element is increased and produced heat when the current passing through it. There is a possibility of renewal by the fuse wire of the wrong size.
- The current time characteristics of a fuse cannot always be correlated with that of the protective device.
- When fuses are connected in series it is difficult to discriminate against the fuse unless the fuse has a significant size difference.
- Fuse does not respond to the high voltage it only cares about current flowing and is not likely to melt and save the house in case of a direct lightning strike. Accurate calibration of fuse wire is impossible, as longer fuse operates earlier than one of shorter length.

Miniature Circuit Breaker (MCB)

- A Miniature Circuit Breaker (MCB) is an automatically operated electrical switch used to protect low voltage electrical circuits from damage caused by excess current from an overload or short circuit. MCBs are typically rated up to a current up to 125 A, do not have adjustable trip characteristics, and can be thermal or thermal-magnetic in operation.

- **Miniature circuit breaker construction** is very simple, robust and maintenance-free. Generally, an MCB is not repaired or maintained, it just replaced by a new one when required. A miniature circuit breaker has normally three main constructional parts. These are:

  1. **Frame of Miniature Circuit Breaker**

- The frame of a miniature circuit breaker is a molded case. This is a rigid, strong, insulated housing in which the other components are mounted.

Con…

2. Operating Mechanism of Miniature Circuit Breaker

- The operating mechanism of a miniature circuit breaker provides the means of manual opening and closing operation of a miniature circuit breaker. It has three-positions "ON," "OFF," and "TRIPPED". The external switching latch can be in the "TRIPPED" position if the MCB is tripped due to over-current.
- When manually switch off the MCB, the switching latch will be in the "OFF" position. In the closed condition of an MCB, the switch is positioned at "ON". By observing the positions of the switching latch one can determine the condition of MCB whether it is closed, tripped or manually switched off.

Con…

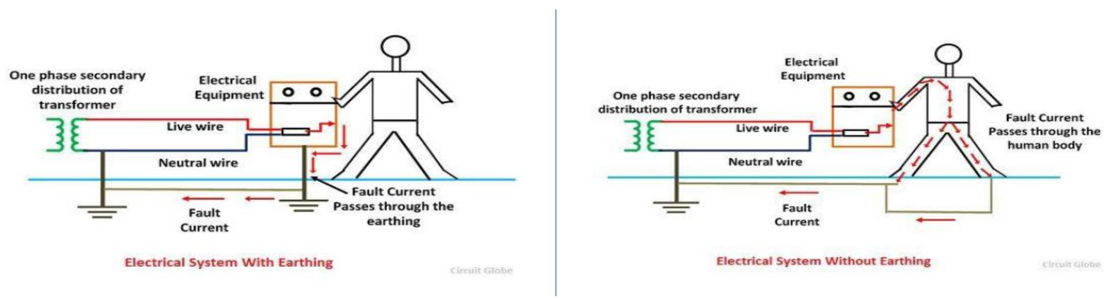
3. Trip Unit of Miniature Circuit Breaker

The trip unit is the main part, responsible for the proper working of the miniature circuit breaker. Two main types of trip mechanisms are provided in MCB. A bimetal provides protection against overload current and an electromagnet provides protection against short-circuit current.

9C)

Earthing and Its Importance

- The process of transferring the immediate discharge of the electrical energy directly to the earth by the help of the low resistance wire is known as the electrical earthing.
- The earthing protects the personnel from the short circuit current.
- The earthing provides the easiest path to the flow of short circuit current even after the failure of the insulation.
- The earthing protects the apparatus and personnel from the high voltage surges and lightning discharge.



How earthing is done?

- To ensure safety, earthing can be done by connecting the electrical appliance to earthing systems or electrodes placed near the soil or below the ground level.
- The electrode or earthing mat equipped with a flat iron riser is installed under the ground level. It helps to connect all the non-current-carrying metallic parts of the equipment.
- When the overload current is passed through the equipment or when the fault occurs in the system due to the current, the fault current from the equipment flows through the earthing system. The earth mat conductors aid in raising the voltage value equal to the resistance of the earth mat multiplied by a ground fault and helps guard the equipment against overload current or fault current.
- In homes, there shall be three types of wires, live, neutral, and earth. Live and [neutral](#)carry electric current from the power station and the earth is connected to the buried metal plate. Electric appliances like refrigerator, iron box, TV are connected to the earth wire while operating. Hence, these devices are protected from the surge or faulty electrical supply. Local earthing is done near the electrical meter of the house.

Advantages :

- Earthing is safe and the best method of offering safety. We know that the earth's potential is zero and is treated as Neutral. Since low equipment is connected to earth using low resistance wire, balancing is achieved.
- Metal can be used in electrical installations without looking for its conductivity, proper earthing ensures that metal does not transfer current.
- A sudden surge in voltage or overload does not harm the device and person if proper earthing measures are done.
- It prevents the risk of fire hazards that could otherwise be caused by the current leakage.

Plate Earthing

What Should Be The Size Of The Earthing Plate?

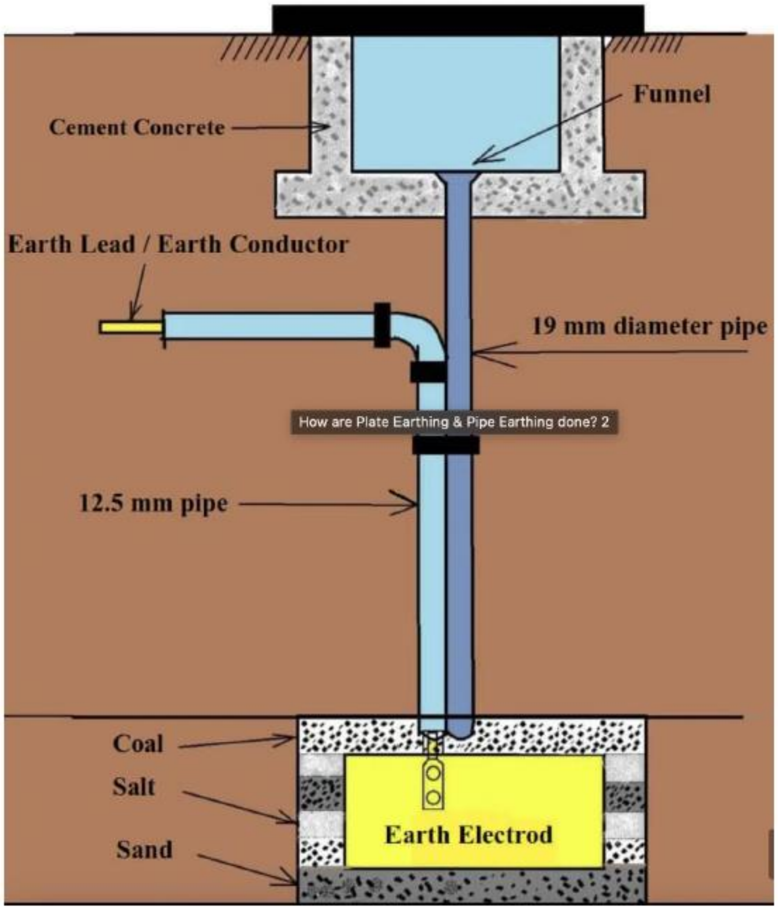
- In that pit, 60 cm long × 60 cm wide and 3.15 mm thick copper Plate or 60 cm long × 60cm wide and 6.3 mm thickness G.I. Plate is used as a main electrode. Two Pipes of diameter 19 mm and 12.7 mm are added to that Plate. A funnel is attached at the top end of the Pipe with a diameter of 19 mm. An open copper / G.I. for connection to the Earth electrode. The wire comes out of the ground via a 12.7 mm diameter Pipe.A layer of sand, salt and coal of 15 cm each is laid around the electrode. Such layer is laid up to 90 cm. After the rest of the pit is filled with black soil, usually after 2.5 meters, the Pipe with earth conductor gets out, where the connection of Earthing is to be done. The Pipe which has a funnel on the top end. A 30cm × 30cm cement concrete tank is built around the ground around the Pipe, and is covered with a lid made of cast iron. In this way Earthing is done by conveying the Plate to the main switch and from there to the earth conductor to the required location. This type of Earthing is done in generating stations and sub stations.

Why Is Salt And Coal Added To Earthing?

- Salt and Coal are poured around the earth electrode. Because salt soaks the ground alkali. And coal makes the ground moisture ashes. Which increases the conductivity of the ground. The conductivity of the land will be high, only then the leakage current will easily go into the ground.

Why Is Water Added To Earthing?

- The ground dries up during the summer season. Due to which the conductivity of the ground is reduced. To increase the moisture in the ground, water is poured through the funnel into the Earthing. A cast iron lid is placed over the Earthing funnel so that the path of pouring water into the earring is not closed.



10A)

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 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 mayor 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.

- The damage from shock is also proportional to the number of vital organs trans versed, especially the percentage of current that reaches the heart Currents especially 100 and 200 mill amperes are lethal. Ventricular fibrillation of the heart occurs when the current through the body approaches 100miliamperes. Ventricle fibrillation is the unco-ordinated actions of the walls of the hearts ventricles. This in turn causes the loss of the pumping action of the heart. This fibrillation will usually continue some force is used to restore the coordination of the hearts actions.
- Severe burns and unconsciousness are also produced by currents of 200 milli amperes or higher. These currents usually do not cause death if the victim is given immediate attention. The victim will usually respond if rendered resuscitation in the form of artificial respiration. This is due to 20 milli amperes of current clamping the heart muscles which prevents the heart from going in to ventricular fibrillation. When a person is rendered unconscious by a current passing through the body. It is impossible to tell you how much current caused the unconsciousness. Artificial respiration is to be applied immediately if breathing has stopped.

Effects of Electric Shock

There may be fatal paralysis of heart.

- There may be sudden stoppage of breathing due to paralysis of muscles used in breathing.
- Heart may continue to beat, while breathing has stopped. In this condition the face appears blue.
- There may be burns, either superficial or deep. They depend on the strength of the electric current causing the injuries.

First Aid for Electric Shock

- Intelligent and prompt action of first aider is required in case of electric shock. If the first aider is not cautious, he may also receive severe electric shock or even die along with the casualty. Therefore every employee or workers in the electrical field or those who are having electric supply should make themselves familiar with the instructions given below:
- Removal from contact: When a person gets back a shock and he is in contact with the supply or conductor, first switch off the switch off the switch or main. If the switch or main is not found, cut the cable with the help of axe or plastic handled knife but don't use scissors. If the cable cutting is also not possible in case of LT supply, the first aider should stand on an insulated material which is dry, if available rubber gloves should be worn, if not dry coat, cap, clothing or folded newspaper should be used while removing the casualty victim. In case of HT supply there is greater danger. The casualty may not be in casual contact
- with the wire as the current can pass through the gap causing an arc. The first aider should keep away from the wires and the casualty should be dragged out by means of walking stick, dry rope, dry bamboo stick etc.
- See the victim's clothes and extinguish the spark if smouldering.

Con…

- Check the victim if he/she breathing but unconscious ring/send for a doctor. If the victim is not breathing, immediately start artificial respiration as detailed below until first aid doctor or first aid arrives.
- In case of fire on electrical installation do not throw water on equipment, because water is a good conductor of electricity. Electrical 290 Technician.
- Use fire extinguishers (CO2) if it is specified for use on electrical appliances.
- Don't energies a line or conductor unless you are sure that it is clear and no one working on it.
- Use proper tools for specific work e.g. don't use plier as a hammer.
- Replace immediately broken switches and plugs etc.
- All metallic parts of electrical equipment should be earthed.
- The conductor used must be of proper size to carry the load current safely.

10B)

- Today's interconnected power systems supply a number of consumers. With such a big organization, management, economy and control come into account automatically. The supply companies (usually in the public sector) have to sell their electricity at such a rate that it covers the costs of generation, transmission, distribution, the salaries of the employees, the interest and depreciation and the profit targeted by the company. This **rate at which electrical energy is sold to the consumers is termed as 'tariff.'**

Types of Tariff

- Flat Demand Rate tariff
- Straight-line Meter rate tariff
- Block meter Rate tariff
- Two-part tariff
- Power factor tariff
- Seasonal rate tariff
- Peak load tariff
- Three-part tariff

Characteristics of a Tariff:

Proper return:

- The total receipts from the consumers must be equal to the cost of producing and supplying electrical energy plus reasonable profit.
- This will enable the electric supply company to ensure continuous and reliable service to the consumers.

Fairness:

- The tariff must be fair so that different types of consumers are satisfied with the rate of charge of electrical energy.
- A big consumer should be charged at a lower rate than a small consumer with fixed charges and thus reducing overall production cost of electrical energy.
- A consumer whose load conditions do not deviate much from the non-variable load should be charged at a lower rate than big consumers with variable load.

(iii) Simplicity:

- The tariff should be simple so that an ordinary consumer can easily understand it.
- A complicated tariff may cause an opposition from the public which is generally distrustful of supply companies.

(iv) Reasonable profit:

- The profit element in the tariff should be reasonable.
- An electric supply company is a public utility company and generally enjoys the benefits of monopoly.
- The investment is relatively safe due to non-competition in the market and the profit is to be restricted to 8% or so per annum.

(v) Attractive:

- The tariff should be attractive so that a large number of consumers are encouraged to use electrical energy.
- Efforts should be made to fix the tariff in such a way so that consumers can pay easily.

- **Definition:** When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed it is called **two-part tariff.**
  - In this tariff scheme, the total costs charged to the consumers consist of two components: fixed charges and running charges. It can be expressed as:

    Total Cost = [A (kW) + B (kWh)] Rs.

    Where, A = charge per kW of max demand (i.e. A is a constant which when multiplied with max demand (kW) gives the total fixed costs.)

    B = charge per kWh of energy consumed (i.e. B is a constant which when multiplied with units consumed (kWh), gives total running charges.)
- The fixed charges will depend upon maximum demand of the consumer and the running charge will depend upon the energy (units) consumed. The fixed charges are due to the interest and depreciation on the capital cost of building and equipment, taxes and a part of operating cost which is independent of energy generated. On the other hand, the running charges are due to the operating cost which varies with variation in generated (or supplied) energy.

Advantages:

- It is easily understood by the consumer.
- It recovers fixed charges which depend upon the maximum demand of the consumer independent of the units consumed.

Disadvantages:

- Consumer has to pay the fixed charges irrespective of the fact whether he has consumed or not the electrical energy.
- There is always error in assessing the maximum demand of the consumer.

10C)

Power Ratings of Household Appliances

Appliance	**Power Rating (Watts)**
Air Conditioner (1.5 Ton)	1500 – 2000
Ceiling Fan	50 – 80

Appliance	Power Rating (Watts)
LED Bulb	5 – 15
CFL Bulb	15 – 25
Refrigerator	100 – 400
Microwave Oven	800 – 1500
Electric Kettle	1000 – 2000
Personal Computer (PC)	200 – 400
Laptop	50 – 100
Printer (Laser)	300 – 500
Printer (Inkjet)	30 – 50
Washing Machine	300 – 800
Television (LED)	50 – 150
Water Heater (Geyser)	1500 – 3000
Iron	800 – 2000

Electricity Bill Calculation

Electricity consumption is calculated using the formula:

$$\text{Energy (kWh)} = \frac{\text{Power (W)} \times \text{Usage Hours per Day} \times \text{Days per Month}}{1000}$$

$$\text{Electricity Bill} = \text{Total kWh} \times \text{Electricity Rate per kWh}$$

Let's assume:

- **Electricity rate** = $0.12 per kWh (this may vary by location)

- **Appliances & Usage:**
  - Air Conditioner (1.5 Ton, 1800W) → **8 hours/day**
  - Ceiling Fan (70W) → **12 hours/day**
  - LED Bulb (10W) → **5 bulbs, 6 hours/day**
  - Refrigerator (300W) → **24 hours/day**
  - Personal Computer (300W) → **5 hours/day**
  - Laptop (70W) → **5 hours/day**
  - Printer (Laser, 400W) → **1 hour/day**
  - Washing Machine (500W) → **1 hour/day**
  - Television (100W) → **4 hours/day**

- Water Heater (2000W) → **1 hour/day**
- Iron (1000W) → **1 hour/day, 15 days/month**

Calculation of the total electricity bill.
Results:

- **Total Energy Consumption** = 851.7 kWh per month
- **Total Electricity Bill** = **$102.20** (at $0.12 per kWh)